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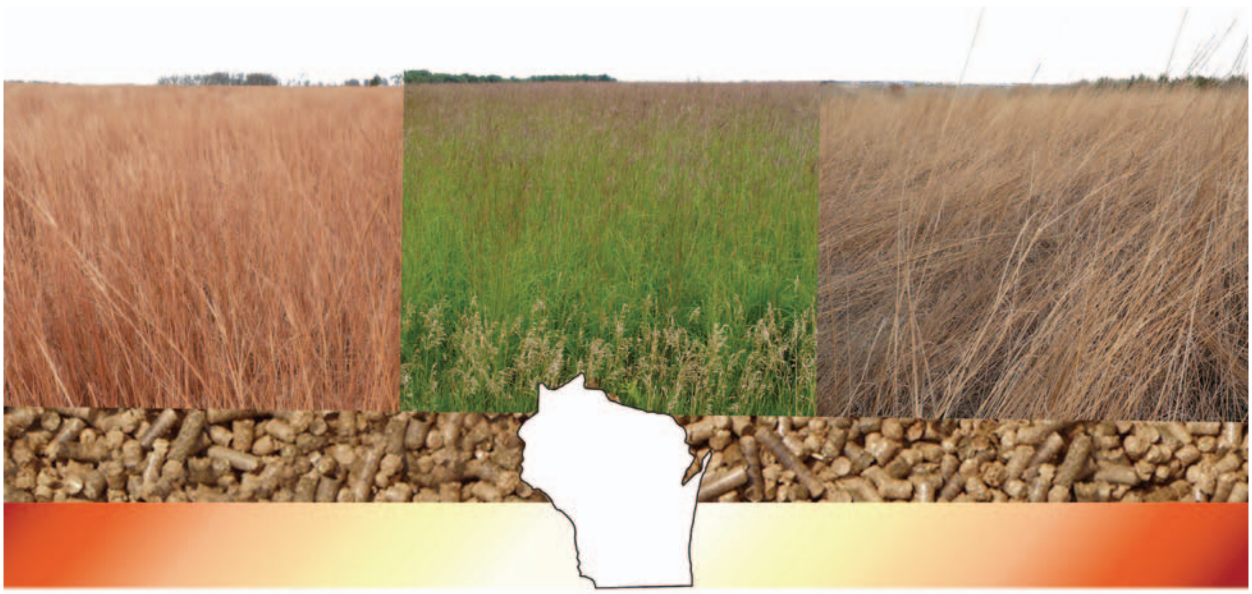
Agricultural Ecological Solutions



Growing Wisconsin Energy

A Native Grass Pellet Bio-Heat Roadmap for Wisconsin

June 2008

A Report By:

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By:

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The power is within you.

Agrecol Corporation

Agrecol Corporation, founded in 1991, combines the best principles of production agriculture with the science of ecology to produce high quality native seed and plants. They are the largest grower of native plants and seed in the Midwest, producing over 200 species of native wildflowers and grasses for conservation, restoration and erosion control.

In 2004, Agrecol converted their heating system from LP, and now heats their entire production facilities with native grass pellets

Agrecol's native plant species are grown from remnant foundation collections gathered primarily in southeastern Wisconsin.

Agrecol's ecological products and services include native seed and plants, design, installation and maintenance, consulting, erosion control and stormwater management.

Agrecol has expanded into biomass energy services and products. In 2004, they installed a new seed cleaning facility at its 1,000-acre seed nursery in Evansville, Wisconsin. They purchased a biomass fueled boiler and pellet mill and heat their entire production facilities with pellets milled from seed waste from their seed cleaning operation (hulls and straw). Today, in addition to plants and seed, Agrecol produces and sells biomass pellets for heat, and is developing native biomass pellet stoves specifically for the residential and commercial heating markets.

The seed cleaning building at Rock Prairie Farm, winter

Agrecol has 1,200 acres of native seed production nurseries in Evansville, Wisconsin

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Each year through a competitive process, the ADD program funds projects that "stimulate Wisconsin's agricultural economy through the development and exploration of new value-added products, new markets, or new technologies in agriculture." The funding has catalyzed important new ideas and strengthened agricultural business development work throughout Wisconsin.

For more information see:

http://datcp.state.wi.us/mktg/business/marketing/val-add/add/index.jsp

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WE ESPECIALLY WANT TO THANK OUR FRIEND AND MENTOR BILL GRAHAM, CHAIRMAN OF AGRECOL CORPORATION.

We dedicate this report to him.

We are in awe of his completely uncommon entrepreneurial vision and his passion for a triple bottom line – product, profit and protection of what we were asked to take care of in the first place: wildlife, water and the land.

William T. Graham
CHAIRMAN OF AGRECOL CORPORATION

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Owner, P Squared Group LLC, Madison, Wisconsin a consulting group specializing in energy, agriculture and natural resource issues. She is a consultant to Agrecol and served as Coordinator and Lead Author for this project. Ms. Porter is an agronomist and has over 20 years of experience in research & public policy, government relations and business development and has managed over 24 grant-funded projects and programs. She received her M.S. degree in Agronomy from the University of Wisconsin, studying the use of Switchgrass (Panicum virgatum L.). From 1992-1994 she served as Product Development Manager for Agrecol Corporation. She is the Midwest Program Director for the Biomass Energy Resource Center (BERC) a national non-profit based in Vermont. She and BERC co-authored Heating with *Biomass: A Feasibility Study of Heating Schools with Wood* funded by Focus on Energy.

JONATHAN BARRY

Farmer, businessman and former public official who earned his B.S. in English at the UW-Madison. Public service includes having served in elected office for 15 years on the Dane County Board, in the Wisconsin State Legislature and as Dane County Executive (1981-1987.) Mr. Barry has chaired two Governor's Commissions, one on state and local mandates and the other on school tax relief. He was a creator, and the organizer and first manager of the Dane County Farmers Market on the Square from 1973-1981. He served as a Regent for the University of Wisconsin from 1990-2003, on the Wisconsin State Technical College System Board from 1988-2003 and on the Wisconsin TEACH Board from 1997-2002. He has operated a family beef and produce farm in Primrose Township since 1970. He has been active in business development serving as: President of Tyrol Basin Ski Resort, past president of W.T. Rogers Company and Gammex RMI Company and as executive vice president and chief operating officer of WTG Corporation a venture capital, holding and development company. He currently serves as consultant to Agrecol. Barry also works part-time as the development director for Operation Fresh Start, a non-profit, working with at risk youth, "building people and houses."

ROGER SAMSON

Samson is the leading expert in North America on the emerging use of residual crop fibers and energy crops for BIOHEAT applications. He has a B.Sc.Agr. from Guelph University (1984) and an M.Sc (Plant Science) from McGill University 1989. He is the Executive Director of Resource Efficient Agricultural Production Canada (REAP), a Canadian non-profit organization research, consulting and international development organization and consults for a wide variety of companies in emerging bioenergy industries. Mr. Samson is a leading expert in the development of switchgrass pellets for commercial heating applications and has been working since 1991 on bioenergy systems. REAP was the first agency in Canada to perform research studies on warm season perennial grasses as energy crops and the first agency in the world to successfully pellet and burn switchgrass as a fuel. Mr. Samson has been involved in biomass energy research and development projects worldwide and has more than 20 biomass energy projects in North America and China, Nigeria, Gambia and the Philippines. He recently authored a comprehensive paper for Critical Reviews in Plant Science titled: "The Potential of C4 Perennial Grasses as a Global Bioheat Source". Mr. Samson has a thorough understanding of biomass resource assessments, energy crop feedstock production, biomass quality requirements for combustion applications, crop densification, supply logistics, and market analysis for agri-fiber pellet feedstocks. As well he provides consulting support to the 7th European framework programs in bioenergy and climate change. He provided technical consultation and oversight to this report.

MARK DOUDLAH

President and General Manager of Agrecol Corporation. Mr. Doudlah shares responsibility for corporate sales and operations. He leads Agrecol's new product research and development team. Doudlah is also a key consultant on pellet mill design for major bioenergy projects. In addition since 1982, he has owned and operated a 1200-acre cash grain operation in Rock County. He manages all farm operations including production methods, personnel, finance, marketing and expansion. Earlier in his career, he worked as a test engineer for JI Case where he was responsible for research, development and testing of agricultural tractors including assessments of performance, quality, reliability, cost improvements and customer acceptance. He has a B.S. in Agricultural Mechanization and Management from UW Madison. He was active in FFA and received a Community Rotary Award for Service in 1984. He is a member of the American Society of Agricultural Engineers.

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The Potential of Biomass

Biomass is an attractive renewable energy fuel and Wisconsin and the upper Midwest are prime candidates for the development of a commercialized grass based pellet bioheat industry. Biomass produces the vast majority of renewable energy (47%) far more than wind (2.3%) or solar (1%). Biomass feedstocks include materials such as switchgrass, corn stover, straw and other agricultural crop residue; wood crops and mill and wood residue.

There is great potential to expand the use of biomass energy in the Midwest because of the abundance of marginal agricultural land not suited for continuous row cropping and the large number of facilities that can be converted from fossil fuel to biomass fuel at relatively low cost.[1] In addition, with concerns about global climate change, energy security and the rising volatility and cost of fossil fuels, grass based biomass can reduce CO_2 and global warming pollution, promote farmer grown energy crops, expand local rural economies and reduce reliance on fossil fuels.

However with increasing interest in and competition for biomass for energy, the question for landowners, business leaders and policy makers is: What is the highest and best use for biomass? Which biomass technology is most efficient in terms of energy produced per acre? Which will provide the greatest climate change benefits? Which is the most cost effective? Which use will be sustainable, bring the greatest number of family supporting jobs and best improve rural farm economies?

Switchgrass: A Model Energy Crop

Switchgrass (Panicum virgatum L.) a perennial grass native to Wisconsin and to the tall grass prairie regions of the U.S is a leading energy crop. It can be used for power, heat, gas and transportation fuel. In 1991 switchgrass was selected as a “model species” by the U.S. Department of Energy sponsored Bioenergy Feedstock Development Program (after screening more than 30 herbaceous and 100 woody crops). It was chosen because of its potential for broad distribution, ease of propagation, perennial growth habit, high yield potential, compatibility with conventional farming practices, and high value in protecting soil conservation and thus water quality (Kszos et al, 2000). Switchgrass was found to provide significant wildlife advantages and excellent nesting habitat for migratory birds (Paine et al., 1996).

Switchgrass is also is a significant carbon sink, sequestering large amounts of carbon in its extensive root system that remains buried after harvesting. (Kucharik, 2008; Casler and Boe, 2003). A full life cycle accounting of cropping systems reported that converting one acre of corn to grass (over 10 years) reduces CO_2 1.32 MT per year, an amount equal to removing 2.4 cars off the road (Robertson, 2008; EPA, 2005). It is estimated that one year of carbon sequestered in 100,000 acres of marginal land is equivalent to removing 24,000 cars off the road for one year. If that stand were planted for 10 years the global warming impact would be equivalent to removing 240,000 cars off the road for one year.

A common misunderstanding is that the majority of energy is produced for electricity. But that isn’t the case. The majority of energy used is for heating. However, in the U.S., efforts to expand biomass as a renewable fuel have focused on electric power generation (co-firing biomass with coal) in part due to new state renewable energy standards mandating utilities supply a specified portion of their electricity with renewable energy.[2] Biomass co-fired in a coal power plant can assist the utility in meeting renewable energy standards and help cut pollution from coal burning. However, power generation is a relatively inefficient process; two thirds of the energy generated is wasted as heat to the environment.[3] A far more efficient application is using biomass for heat (direct combustion) or cogeneration (also called combined heat and power or CHP). Cogeneration or CHP are dramatically more efficient (60-80%) recovering heat that normally is wasted in an electric generator and generating less pollution that electrical generation alone.[4] The Midwest has a large number of facilities that can be converted at relatively low cost to generate electricity along with heat.

Commercial Markets for Pellets

Burning grass for heat has been a well-established practice in Europe for decades and the U.S. is now beginning its own research and development. Cornell University research reported that grass can be easily grown, pelleted and used for fuel in residential stoves or commercial boilers.[5] A study by Kansas State University determined that one acre of switchgrass is capable of producing enough biomass to meet the annual space and water heating needs of an average home (King, 1999). In Pennsylvania Governor Rendell recently awarded $350,000 to the Benton Area School District for a biomass-fired boiler heating system. The flexible-fuel system would replace 37,000 gallons of heating oil a year and use local biomass materials such as switchgrass pellets, wood pellets and corn to provide 80 percent of the district's heating needs.[6] The school estimated it will reduce air pollution by 88%.

Canada is advancing a commercial bioheat pellet industry with pellets made from switchgrass and crop milling residues. Ontario is home to the largest greenhouse industry in North America, an important cluster of economic growth. However, greenhouses are an energy intensive industry and vulnerable to rising fossil fuel costs. Therefore, greenhouse managers across Canada have been exploring grass and agropellets as a more stable and economical bioheat systems. Studies show that biomass pellets are 25-50% cheaper than heating with gas or oil and are the most cost-effective way for government incentives to reduce greenhouse gas emissions outperforming wind, solar power.[7]

A recent white paper by Virginia Tech reports that switchgrass along with woodchips, could provide a quarter of Virginia's gas and heating fuel needs, support 68 small fuel refineries in the state and create 10,500 jobs, including for farmers, truck drivers and refinery workers.[8]

Building biorefineries to pelletize switchgrass into bioheat could have significant economic impacts for Wisconsin and the Midwest. Developing a bioheat market now would enable Wisconsin farmers, co-ops and biomass aggregators to build, test and refine a switchgrass feedstock supply chain. Creating a heat market with more competition within the demand side for biomass (i.e. many small users vs. one large power plant) is likely to create more market opportunities and higher margins for growers. And, developing a secure and reliable feedstock supply chain is essential to a future cellulosic ethanol industry in Wisconsin.

Creating a reliable bioenergy feedstock supply chain requires unique and practical expertise. Wisconsin has a strong agricultural cooperative infrastructure that is uniquely suited to carry on the role of aggregating biomass. Agricultural marketing and farm supply cooperatives generate $514 million in total Wisconsin income (Zeuli, 2002).

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They have ongoing business relationships with farmers and have the equipment, staff and expertise for planting, harvesting, pelleting and storing biomass. Premier Cooperative, based in Mount Horeb is the country's oldest farm supply cooperative and recently received a grant from the Office of Energy Independence to pilot a biomass aggregation project. Landmark Cooperative, a farm supply cooperative serving southeastern Wisconsin, sees a market in providing biomass pellets to their more than 10,000 propane customers.

The most promising region in the U.S. for a grass pellet fuel industry are on marginal lands within the upper Midwest and Northeast - regions with high heating costs due to long winters and high fuel prices. Developing a perennial grass bioenergy market in the Midwest on marginal lands would also provide an incentive to keep these sensitive lands enrolled in the conservation reserve program (CRP) where high grain prices threaten 30 years of conservation, habitat and biodiversity efforts.

This report studied the feasibility of heating four commercial businesses in south central Wisconsin with switchgrass pellets: Agrecol Corporation (Evansville, WI) an agricultural seed company, Oak Hill Correctional Facility (Oregon, WI) a state correctional facility, America's Best Greenhouse (Cottage Grove, WI) a large greenhouse and Pecatonica Elementary (Hollandale, WI) a rural elementary school.

The study found that switchgrass can be grown successfully and cost effectively in Wisconsin. It does not require any new technology and can be grown with existing farm practices and equipment. It is also a strong candidate for pelleting. Pelleting allows switchgrass to overcome many logistics inherent to agricultural biomass: the uniform size allows it to be handled and stored easily, transported more economically and burned more efficiently.

By converting to switchgrass pellets the businesses in this study reduced their fuel costs an average of 42%, with the greatest savings coming from facilities that switched from LP to pellets.

The study found that a 100,000 marginal acres (highly erodible and environmentally sensitive) could realistically produce 500,000 tons of switchgrass while markedly improving water quality, wildlife habitat and reducing global warming pollution. This volume of biomass represents $70 million of farmer grown energy and would replace the estimated $72 - $174 million now exported for natural gas, LP or fuel oil. The money retained in the state would produce farm profits, new business enterprises for harvesting, transportation and processing biomass along with new employment opportunities for workers in the clean energy economy. It is well understood that locally grown and owned projects generate more jobs and more rural economic benefit than those with outside ownership.

In addition the study found that switchgrass, even when grown on marginal sub-prime land in Wisconsin produces more than nine times the energy per acre of land than does the leading biofuels technology of corn (grain) ethanol. This high efficiency in energy production is the result of several factors: switchgrass efficiently captures solar energy, the entire plant is utilized for fuel processing, the bioconversion process retains all the energy captured in the field and the production/conversion process is more energy efficient than corn ethanol.

Biomass heating is a proven and readily adopted technology. In the Midwest, the most efficient method to move bioenergy ahead is through the use of native grasses for heating and combined heat and power (CHP; also known as cogeneration). While fuel prices have skyrocketed, native grass biofuels have the potential to be widely

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available and easily renewable and therefore enjoy greater price stability. Switchgrass pellets can be used to displace fossil fuels thereby reducing expenditures on imported fuels and providing significant direct benefits to local, state and regional economies.

Increasing economic pressure for conversion of CRP lands into row-crop production threatens to negatively impact conservation, habitat and biodiversity functions of CRP. Developing a market for native grass bioenergy will provide counter incentives to keep these environmentally sensitive lands enrolled. Additionally, a future cellulosic ethanol system would benefit from building a native grass supply chain now. Wisconsin should move quickly to develop a new, clean energy native grass bioheat farming system as an alternative to natural gas, propane and fuel oil in public institutions and in commercial heating and CHP applications.

Scope of Study

Agrecol Corporation produced this report under contract by the Department of Agriculture, Trade and Consumer Protection.

The study determined the feasibility of pelleted biomas fuel from switchgrass and native grass mixtures for heat as an alternative to natural gas, propane and fuel oil in commercial applications.

The overall goal of this study is to help advance switchgrass as a viable, biomass heating fuel in particular: (a) Determine the technical feasibility of utilizing native, grass-based, biomass for the production of thermal energy that is competitive with fossil fuel for commercial applications; (b) Assess the land base available for sustainable biomass production; (c) Produce a business scope and regional model for a bioheat enterprise in Wisconsin (d) Conduct public outreach (e) Identify profitable enterprises to keep CRP enrolled.

Author's Note:

Over the past several years, Agrecol Corporation has developed and tested native grass seed mixes with energy yield potential that include a mix of switchgrass with other native grasses, legumes and forbs (ie, Indian Grass, Big Bluestem etc.) This report refers just to switchgrass, but it is the view of the authors that a mixed stand may be more desireable from a production, harvesting and conservation standpoint.

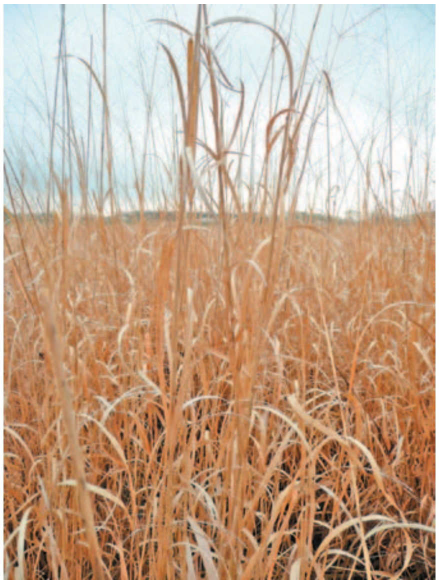
Introduction

The Potential of Biomass in Wisconsin

Wisconsin and the upper Midwest are prime candidates for the development of a commercialized grass-based pellet bioheat industry. Many parts of Wisconsin have relatively low land production costs and high heating costs due to long winters. Wisconsin has nearly 16 million acres of farmland (including approximately 500,000 acres of CRP) – a portion of which could be planted to native grasses and harvested as an energy crop for heat.[9]

Switchgrass has been identified as an important biomass energy crop. Switchgrass is a native grass to Wisconsin and the tall grass plains of the US. It is high yielding, has low inputs, grows long fibrous root systems, is a perennial and is beneficial to water quality and wildlife. It is compatible with conventional farm practices and equipment, and can be sold as fuel or as forage for livestock. Switchgrass is also a significant carbon sink, sequestering carbon in its extensive root system that remains buried after harvest.

Biomass energy crops are renewable, cheaper than fuel oil and L.P and competitive with natural gas. A study by Kansas State University, determined that one acre of Kansas farmland is capable of producing an average annual yield of herbaceous biomass sufficient to meet the annual space and water heating needs of an average home. (King, 1999)



Switchgrass, *Panicum virgatum,* a perennial grass native to Wisconsin

Native Biomass Pellets

A study by Kansas State University determined that one acre of Kansas farmland is capable of producing an average annual yield of herbaceous biomass sufficient to meet the annual space and water heating needs of an average home.

Energy budgets indicate that significant gains in energy return and carbon emissions reduction can be achieved with switchgrass as a biofuel. Past experiments with switchgrass and other biomass feedstocks have shown significant logistical (storage, handling, transportation) challenges.

However an important new strategy for utilizing biomass energy is densifying the material into pellets, briquettes or cubes. Densifying biomass allows the material to be handled and stored more easily, transported more economically and burned more efficiently. The delivery option for the densified biomass will be determined by the distance in the transportation radius.

Another past challenge with combusting grasses has been clinkers (chunks of melted ash) due to high ash content. However, switchgrass – compared to other crops – has one of the lowest K and Cl levels, and a benefit of switchgrass is the ability to adapt delayed harvest strategies (spring harvest) which reduces the K and Cl levels to those comparable to wood pellets. In addition, new technologies such as recent improvements in high efficient (81-87% efficiency) "close coupled" gasifier pellet stoves and furnaces are capable of burning moderately high-ash pelleted fuels.

Switchgrass is a strong candidate for pelleting. The best market for Wisconsin to start with is commercial boilers in rural areas of Wisconsin and then expand to residential markets. Rural businesses often are using LP fuel which is very expensive. Biomass pellets are more economical than LP, oil or electricity and competitive with natural gas.

Prairie plants are unique, with root biomass equal to or even greater than their above ground biomass. Their roots can grow up to ten feet deep.

Creating a Commercial Enterprise

Wisconsin should follow the lead of Europe, which has developed a strong biomass pellet market. Canada, is building a commercial bioheat enterprise for greenhouses. The greenhouse industry in Ontario is a large agri-business industry, representing an important cluster of economic growth and the largest greenhouse industry in North America. Greenhouses are an energy intensive industry (natural gas and fuel oil) and vulnerable to rising fossil fuel costs. Greenhouse managers across Canada have been exploring more stable and economical bioheat systems. Research conducted in four provinces in Canada compared the feasibility of available biomass resources. The results showed that crop milling waste and warm season grasses were promising bioheat sources. In 2006, twenty-five commercial greenhouses in Ontario began using pelletized crop milling residue as fuel. It is estimated that greenhouse producers reduce their annual fuel costs by approximately 33% to 60% by switching from natural gas and heating oil to densified biomass.

Agrecol® Corporation converts to Biomass Heating

In 2004, Agrecol Corporation, the Midwest's largest producer of native plants and seeds, installed a new seed cleaning facility at its 1200-acre seed nursery in Evansville, Wisconsin. Interested in ecological systems and renewable energy, Agrecol decided to experiment with pelletized native grass bioheat by pelletizing their waste from their seed cleaning operation. They installed radiant heat in the cement floors and purchased a Pelco boiler, California pellet mill (1/4"diameter die), Bliss hammer mill, a counter flow dryer and dust filter/collection system. In 2005 they completely eliminated LP, heating their entire production facilities with native grass biomass pellets. Now, in addition to seeds and plants, Agrecol produces and sells switchgrass and native grass pellets for fuel and is developing a pellet stove for residential heating.

Native Grasses

In the Midwest, the easiest way to move bioenergy ahead is through the use of native grasses. While corn and wood pellets prices have sharply increased, native grass biofuels have the potential to be widely available and easily renewable and therefore enjoy greater price stability. Wisconsin should take advantage of the time to develop a new, clean energy native grass bioheat farming system as an alternative to natural gas, propane and fuel oil in commercial applications. Increasing economic pressure for conversion of CRP lands into row-crop production threatens to negatively impact conservation, habitat and bio-diversity functions of CRP. However, developing a native grass bio-energy capability would provide counter incentives to keep these sensitive lands enrolled. Additionally, a future cellulosic ethanol system would benefit from building a native grass supply chain now.

Wisconsin Energy Use: The Majority Used for Heating

Wisconsin's energy use is split roughly into four economic sectors. Twenty five percent of the state's energy is used by transportation with the remaining split by commercial (21%), residential (24%) and industrial (28%) sectors. And surprising to many, the majority of energy used by the non transportation sectors is used for heating not electricity. Within the commercial sector, approximately 58% is devoted to space heating with the remainder used for electricity (42%). The residential sector devotes even more of its energy budget to heating (73.5%) with the remainder used for electricity (26.5%). And in 2006, state-owned buildings reported that 75% of their energy use went for space heating and 25% for electricity (Wisconsin Energy Statistics, 2007). We could use biomass today – to heat many of our buildings, saving money and reducing global warming pollution.

Table 1.1 demonstrates the economic advantages of biomass compared to most fossil fuels. Wood (chips and pellets) are the most widely-used biomass fuel in the northern, forested part of the state. However, southern Wisconsin has potential for grass-based biomass fuel.

Table 1.1:

Comparison of Heating Value of Fuels

Fuel Type	Unit	Cost per Unit	BTU per Unit (dry)	Moisture Content	MMBtu per Unit	Cost per MMBtu Delivered	Average Seasonal Efficiency	Delivered MMBTU per Unit	Cost per MMBtu After Combustion
Wood Chips	ton	$50	16,500,000	40%	9.9	$5.05	65%	6.4	$7.77
Natural Gas	therm	$1.10	100,000	0%	0.100	$11.00	90%	0.090	$12.22
Wood Pellets	ton	$150	16,500,000	5%	15.7	$9.57	75%	11.8	$12.76
Switchgrass Pellets	ton	$140	15,326,000	8%	14.560	$9.62	75%	10.920	$12.82
Corn	bushel	$6.00	392,000	15.5%	0.331	$18.11	80%	0.265	$22.64
LP Gas	gallon	$2.20	92,000	0%	0.092	$23.91	90%	0.083	$26.57
Electricity	kwh	$0.10	3,412	0%	0.003	$29.31	99%	0.003	$29.60
Fuel Oil (No.2)	gallon	$3.30	138,000	0%	0.138	$23.91	80%	0.110	$29.89

Note: Prices change daily. Wood and switchgrass prices are FOB the pellet mill. Chart provided by Biomass Energy Resource Center (BERC).

The Role of Biomass in Wisconsin's Clean Energy Economy

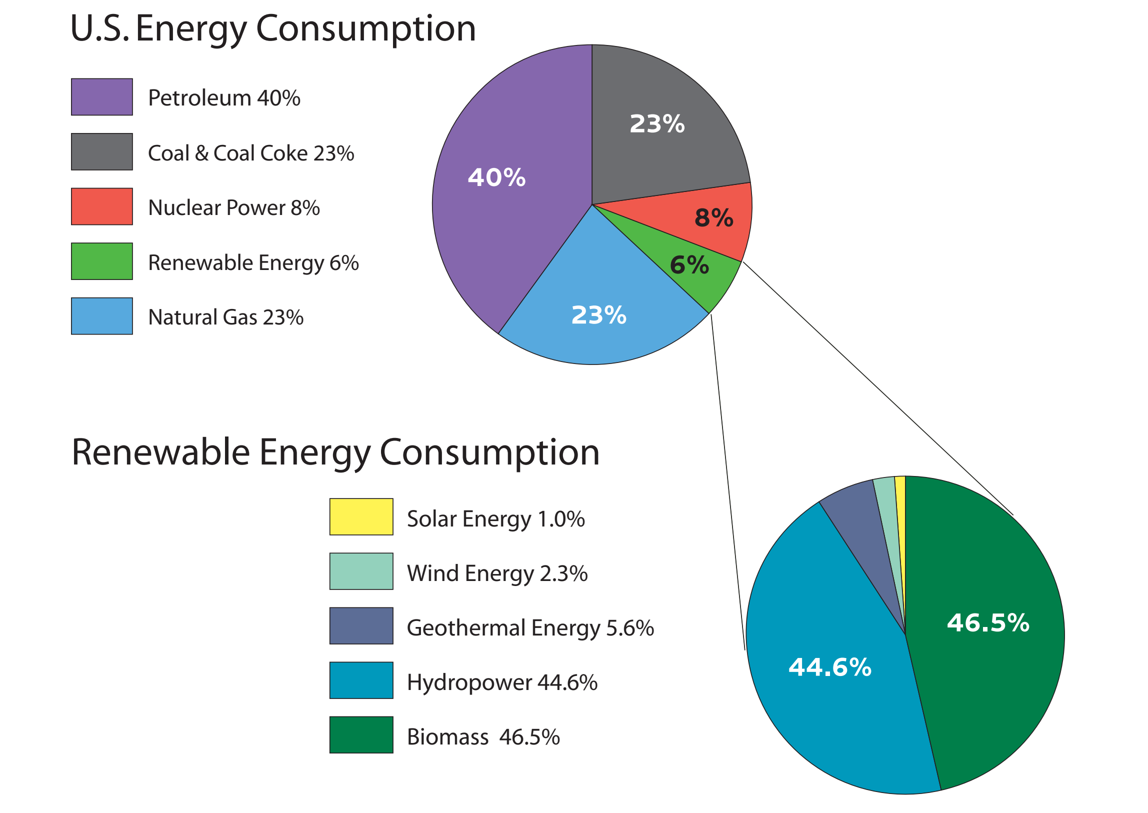
Although the total amount of power or heat generated from biomass is fairly small, biomass makes up the largest percentage (47%) of renewable energy – versus 3.3% for wind and solar combined (Figure 1.2).[10]

Biomass is used as a fuel for cogeneration of steam and electricity in the industrial sector, for power generation in the electricity sector and for space heating in commercial and residential buildings. There are over 200 non-residential systems in Wisconsin using wood or biomass fuels for heat, CHP and power (Wichert, 2007) There is enormous potential to expand the use of biomass energy in the Midwest because of the abundance of agricultural land and the large number of facilities that can be converted at relatively low cost (Repowering the Midwest, 2001) The North-Central Region of the U.S. (12 states) produces 49% of the country's biomass.[11]

In 1978, the U.S Department of Energy (USDOE) Biofuels Feedstock Development Program (BFDP) initiated an energy research and analysis program whose goal was to "develop and demonstrate cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks for use as liquid biofuels, biomass electric power, and/or bioproducts." After screening more than 30 herbaceous and 100 woody crops switchgrass (*Panicum virgatum*) and the genus Populus (primarily hybrid poplar a short rotation tree crop) were selected as model energy crops. Switchgrass was chosen because of its potential for broad distribution, ease of propagation, perennial growth habit, high yield potential, compatibility with conventional farming practices, and its excellent conservation attributes (Kszos et al, 2000). A switchgrass research program (breeding, tissue culture and field studies with breeding programs centered around Georgia, Nebraska and Oklahoma) was begun in 16 states including Wisconsin (McLaughlin et al., 1999).

Figure 1.2

Contribution of Renewable Energy to U.S. Energy Consumption, 2004



Note: US Energy Information Administration

Thermal vs. Electric Generation

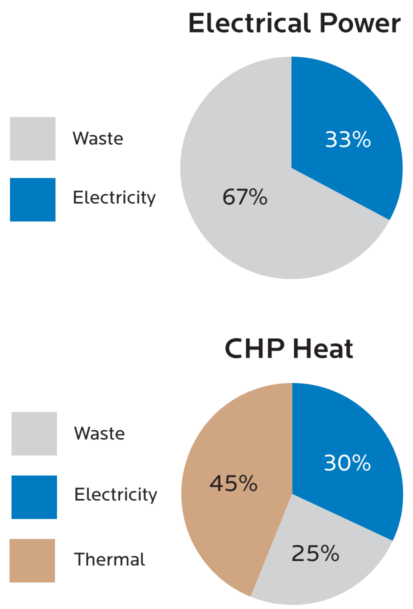
U.S. efforts to expand biomass as a renewable fuel have focused on electric power generation (co-firing biomass with coal) in part due to new state renewable energy standards mandating utilities supply a specified portion of their electricity with renewable energy. Biomass co-fired in a coal power plant can assist the utility in meeting renewable energy standards and help cut pollution from coal burning. However, electricity generation is a relatively inefficient process; two thirds of the energy generated is wasted as heat to the environment.

A far more efficient application is using biomass for heat (direct combustion) or combined heat and power or CHP (cogeneration). CHP or cogeneration are dramatically more efficient (60-80%) recovering heat that normally is wasted in an electric generator and generating less pollution than electrical generation alone.[12]

Table 1.1 and 1.2 show the conversion efficiencies of thermal versus electrical generation.

Table 1.1

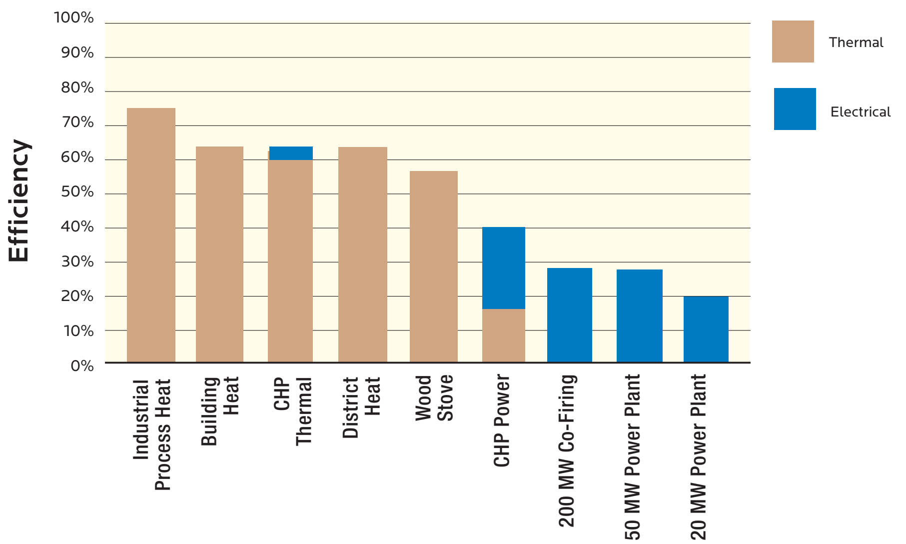
Combined Heat & Power (CHP) vs. Electricity



Note: District Energy St. Paul

Table 1.2

Thermal vs. Electric Conversion Efficiency - Wood to Energy (available technology)



Note: Chart provided by Biomass Energy Resource Center (BERC).

Advancing Renewable Energy Policy

Perhaps long delayed, the U.S. is now beginning to take major steps toward energy security and climate change. Recent changes in climate change policy (cap & trade agreements, low carbon fuel standard, renewable portfolio standards etc) and improvements in production technologies and biomass feedstock aggregation are increasing the demand for biomass fuel.

In 2006, Wisconsin's Governor Doyle launched Wisconsin's "Declaration of Energy Independence" including a state goal of 25% renewable energy by 2025.

In Wisconsin, several nationally significant actions have recently occurred. In 2006, Wisconsin's Governor Doyle launched Wisconsin's "Declaration of Energy Independence" including a state goal of 25% renewable energy by 2025 (If adopted Wisconsin would join Minnesota as the nation's strongest renewable energy standard) In 2007, the USDOE awarded $125 million to The University of Wisconsin to launch the Great Lakes Bioenergy Research Center (GLBRC). The goal of the center. one of three selected nationally, is to conduct basic research to advance cellulosic ethanol and make it "cost-competitive with gasoline by 2012, and assist in reducing America's gasoline consumption by 20 percent in ten years." And last November nine midwest Governor's, co-chaired by Governor Doyle and Minnesota Governor Tim Pawlenty, signed the Midwestern Regional Greenhouse Gas Reduction Accord, a historic agreement establishing greenhouse gas reduction targets and timeframes, developing a market-based cap and trade mechanism and taking other steps to achieve the reduction targets.

Such policies are anticipated to expand the utilization of biomass feedstocks for energy (heat, power and transportation fuels) within a fairly short period of time. The question is, what is the highest and best use for biomass? Which application will bring the greatest number of family supporting jobs, farm profits and provide climate change benefits?

When used in the right application, biomass can reduce CO_2 and global warming gases, promote farmer grown energy crops, expand local rural economies and reduce reliance on fossil fuels. However, as has been seen in the corn ethanol debate, not all biomass feedstocks nor biomass technologies are created equal. In the words of Michigan State University ecologist and scientist in the Great Lakes Bioenergy Research Center Dr. Phil Robertson, "Biofuels is a win win but only if done right and there are lots of opportunities for doing it wrong."[13]

Commercial Biomass Projects in The Midwest

Across the country, many exciting new commercial scale biomass heating or CHP projects are underway. Production of switchgrass, a leading biomass feedstock is likely to be expanded. Below are examples of recently announced commercial scale biomass projects:

Evansville, Wisconsin

Agrecol Corporation

In 2004, Agrecol Corporation, the Midwest's largest producer of native plants and seeds, installed a new 30,000 sq. ft. seed cleaning facility at its 1,200-acre seed nursery in Evansville, Wisconsin.

Agrecol was interested in renewable energy, had waste from their seed cleaning operation and decided to install radiant heat in the cement floors and experiment with pelletized native grass bioheat. They experimented with this system in 2005 and in 2006 purchased a Pelco boiler, California pellet mill, Bliss hammer mill, a counter flow dryer and dust filter/collection system. This past winter they eliminated LP use completely, heating their entire production facilities with native grass biomass pellets.

http://www.agrecol.com/images/news/_HeatedbyWaste.pdf

St Paul, Minnesota

District Energy of St. Paul

A very impressive conversion from fossil fuel to biofuel has recently taken place in St Paul. They have the largest hot water district heating system in North America and began providing district-heating service in 1983.

In 1994, District Energy's Board of Directors decided to pursue renewable energy, conceiving of a combined heat and power (CHP) plant fueled by clean, urban wood waste. The electricity would be sold to the local utility and the "waste" heat would provide 75% of the heating requirements for downtown St. Paul. Operation of the new CHP plant reduced District Energy's reliance on coal by 80 percent, reduced soot emissions by 50 percent and significantly reduced greenhouse gas emissions. The new facility, built in 2002, also helped the community solve a wood waste disposal problem.

Presently District Energy serves 80% of buildings in downtown Saint Paul and adjacent areas, including the State Capitol Complex, all downtown city offices and 300 single-family homes. It supplies 25 MW of power to the grid. President Bush visited District Energy in 2001 and declared it a "model for America."

http://www.districtenergy.com/Publications/download/Energyline_fall05.pdf

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Indiana

Indiana Department of Corrections

- Putnamville Correctional Facility
- Pendleton Correctional Facility
- Westville Correctional Facility
- Indiana State Prison

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Indiana's Lt. Governor Skillman, Indiana Department of Correction (DOC) Commissioner J. David Donahue, and John Murphy, Vice President and General Manager of Johnson Controls Inc., recently announced that four state prisons will be converted to systems that burn biomass for heat.

Indiana will be installing four multi-fueled biomass systems at the Putnamville Correctional facility, Pendleton Correctional facility, Westville Correctional facility and the Indiana State Prison. These four facilities were selected because they were among the state's least energy-efficient, consumed the most electric and gas and were thought to be a natural place to start. If officials see the results predicted, other Indiana facilities will begin transitioning to green energy.

The state will purchase woody biomass as fuel for the boilers. Boilers will be able to use switchgrass and other agri-pellets. The facilities will save taxpayers million dollars per year.

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<td>http://www.biofuelsjournal.com/articles/Indiana_Department_of_Corrections Switches_All_Four_State_Prisions_to_Heating_Systems_that_Burn_Corn____06_13_2006-34757.html</td>
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Iowa City, Iowa University of Iowa • University of Iowa Hospital and Clinics	The University of Iowa's main campus and the University of Iowa Hospital and Clinics complex are served by a large district energy system. District energy involves production of steam, electric power, and chilled water at central utility plants for distribution to buildings through a network of underground pipes and electric cables. The University of Iowa Power Plant is a CHP facility. Fuels burned at the plant include coal, natural gas, tires and oat hulls. The plant co-generates about 30-percent of the total electric power needs and produces all the steam energy used throughout the campus and hospital facilities. A partnership with Quaker Oats Cedar Rapids Plant provides an economical, environmentally friendly source of fuel, oat hulls. The hulls are a by-product of the cereal making process at Quaker and are trucked to the Power Plant and co-fired with coal in the circulating fluidized bed (CFB) boiler. Currently they represent 14% of the fuel source. The end goal for University of Iowa's power plant is to make the University's energy production 100 percent renewable. The University of Iowa is one of only 4 Public Universities that belong to the Chicago Climate Exchange.
	http://energy.uiowa.edu/renewableenergy.htm

Centerview, Missouri • 'Show Me' Energy Cooperative	In December 2007, Evergreen BioFuels USA, a world leader in developing available, sustainable and carbon-negative bioenergy fuels announced an agreement with the 'Show Me' Energy Cooperative, a Missouri Co-op comprised of 400 farm businesses, to engineer, build and manage one of the largest biomass pellet fuel production plants in North America. The $6.5 million plant, anticipated to be completed in early 2008 will produce enough biomass to not only be used in coal utility energy production, as well as the heating needs of about 20,000 homes. In the first phase they will produce pellets from biomass grown in a 100 mile radius of the plant located in Centerview, Mo sold in bags for residential and in bulk to a local electric utility for co-firing.
	http://www.biomassmagazine.com/article.jsp?article_id=1430

Shakopee, Minnesota Koda Energy	The Mdewakanton Sioux and Rahr Malting Company of Shakopee have created a biomass-to-energy project called Koda Energy. The company decided to look at alternative energy came after the company's electric costs doubled and its natural gas costs went up four-fold in recent years. They decided to build a $55 million CHP facility that will burn the malting plant's byproducts, prairie grasses and other crop residue to make steam (heat) and electricity (power). The partnership will generate 16.5 megawatts of baseload electricity which will deliver 125 MMBtu/hour of process heat to the company's production malting operation. The 55 million CHP facility will heat 11,000 homes. Extra electricity generated will be used by the Mdewakanton Sioux and sold to utility companies who are required under Minnesota's renewable energy mandate to increase their alternative energy sources.
	http://www.shakopeedakota.org/smsc/pdf/koda_energy_pamphlet.pdf

Morris, Minnesota University of Minnesota - Morris	In 2005, the University of Minnesota-Morris campus received $6 million in state bonding funds to construct a biomass gasification plant that will heat and cool the schools buildings. The gasifier will convert corn stover and other plant materials into syngas – similar to natural gas – that can be burned to generate heat (and cooling in the future). The biomass gasifier — the first in the state to run on crop residue — is part of UMM's new Renewable Energy Research and Demonstration Center in Morris It serves as a national model for rural schools, factories and communities interested in producing green power from local agricultural resources. The gasification of biomass is an emerging technology that opens the door to using locally available renewable fuel stocks that are greenhouse gas neutral and produce fewer pollutants than the traditional combustion processes for coal, oil or wood. The plant will be permitted to use 15 different types of biomass.
	http://www.morris.umn.edu/ummnews/View.php?itemID=650

Chapter 2

Assessing Land Use for Biomass Production

Converting Marginal Land for Biomass Production

South-central Wisconsin, despite rapid urbanization, is an agricultural powerhouse. According to the latest U.S. census, Dane County agricultural receipts were $287 million, the highest value of any Wisconsin county.[14]

Within 50 miles of Madison, Wisconsin, there are over 2 million acres of traditional agricultural crops. This includes: 989,300 million acres of corn, 438,900 acres of soybeans, 553,900 acres of forage/hay and over 100,000 acres of wheat, oats and barley. In addition, in 2006, within 50 miles there are 8,026 signed contracts and 156,894 acres of land enrolled in the Conservation Reserve Program (CRP).

Highly-Erodible Land (HEL) and CRP

In Wisconsin significant acres of corn and soybean are grown on marginal land - steep, highly erosive land (or HEL) or on land close to lakes or streams (Water Quality Management Areas, or WQMAs). From an environmental standpoint, much of this land should not be farmed continuously in row crops. This marginal land is harder to farm, less productive, less profitable and contributes significantly to soil erosion and decreased water quality.

The CRP program was created to protect environmentally-sensitive lands. CRP land is entrolled by contract for ten years at an accepted bid price ranging from $60–$90 per acre in southern Wisconsin. Since 2006, conservation officials estimate that over 50% of CRP contracts have not been renewed. Sharply higher grain prices are leading to a rapid conversion of CRP land to row cropping, threatening 30 years of conservation progress. This trend is expected to continue as grain prices continue to rise. From the author's point of view, prices being earned by farmers are not the issue. However, we think switchgrass would create a profitable and more sustainable opportunity for farmers on marginal acres.

Although the short term economics of converting CRP land to corn may appear compelling, when compared to $60-90 annual CRP payments, the long term prospects are less so. Corn yields on these marginal croplands are well below statewide averages, typically no more than 120 bu/acre the first year of cropping after coming out of CRP. Out years will likely see yields decline to 100 bu/acre despite increasing fertilizer inputs. Profitability is furthered challenged by rising input costs, particularly from fossil fuel based fertilizer whose costs are escalating.

Growing grass is a proven, viable, low cost and low risk technology that could provide an alternative use for marginal land. A new grass bioenergy market could provide a profit center for landowners while preserving soil and water conservation and wildlife habitat benefits.

Grasses are a remarkable way to protect water quality. They have fewer pesticide and fertilizer needs and because they are perennial, require less tillage. Soil losses for various cropping practices show that soil losses on highly erodible land in grass cover is minimal (0.2 ton/acre/year or less). If an acre of corn grown on highly erodible land were converted to grass, soil losses would be reduced by at least 94%. Levels of phosphorus runoff can be expected to be similarly decreased on highly erodible land converted from tilled corn to grass (Panuska et al., 2007)

Table 2.1 estimates that 148,625 acres of the estimated 287,814 acres of marginal land are potential candidates for a county-wide (Dane County) biomass program and would produce approximately 743,000 tons. This estimate includes 60,323 HEL land now growing corn or soybeans, 38,717 of pastureland (assumes 20% of current pastureland converted to biomass), 43,321 acres of water quality management areas (WQMA is land that is 300' from stream or 1000' from lake) now growing corn or soybeans (assumes 23% of WQMA converted to biomass) and 6,264 CRP acres, (assumes 20% of total acres harvested for biomass).[15, 16]

If 100,000 marginal acres (highly erodible and environmentally sensitive) were converted to switchgrass, the acreage could realistically produce 500,000 tons of switchgrass – while markedly improving soil conservation, water quality, wildlife habitat and reducing global warming pollution. This volume of biomass represents $70 million of farmer grown energy and would replace the estimated $72 - $174 million now exported for natural gas, LP or fuel oil. The money retained in the state would produce farm profits, new business enterprises for harvesting, transportation and processing biomass along with new employment opportunities for workers in the clean energy economy. It is well understood that locally grown and owned projects generate more jobs and more rural economic benefit than those with outside ownership.

The carbon reduction of converting one acre of corn to grass would reduce CO_2 by approximately 1.32 MT – an amount equal to taking 2.4 cars off the road. (see Table 4.1 and 4.2 on pages 36 and 37) This is due to the grasses ability to sequester CO_2 from the air as well as having lower input and tillage needs. It is estimated that one year of carbon sequestered in 100,000 acres of marginal land is equivalent to removing 24,000 cars off the road for one year. If that stand were planted for 10 years the global warming impact would be equivalent to removing 240,000 cars off the road for one year.

Table 2.1

Potential Biomass Yield from Marginal Acres – Dane County

Total Highly-Erodible Land (HEL Land)	287,814 acres	
Total Corn & Soybeans	243,062 acres	
	Corn & Soybeans on HEL	**60,323 acres**
	Percent Corn & Soybeans on HEL: 24.0%	
Total Pasture	193,589 acres	
	Pasture harvested for biomass	**38,717 acres**
	Percent of total pastureland harvested for biomass: 20%	
Total Water-Quality Management Areas (WQMA)	195,326 acres	
	Corn & Soybeans on WQMAs	**43,321 acres**
	Percent WQMA in Corn & Soybeans: 23.0%	
Total Conservation Reserve Program (CRP)	31,321 acres	
	Estimated percent of CRP harvested for Energy: 20%	**6,264 acres**
	Total Marginal Acres*	**148,625 acres**
	Estimated Biomass Yield on Marginal Acres:	**743,125 Tons**

Data provided by Dane County Land Conservation Department

- Biomass yield estimated at 5 tons/acre
- Cropland data (corn, soybeans, alfalfa, pasture) from NASS 2006 data. Pasture etc. includes: pasture, non-ag., range, waste, farmstead
- HEL (highly erodible land) is from soil data and includes both HEL and PHEL (potentially highly erodible) lands.
- WQMAs (Water Quality Management Areas) are defined as areas 300' from stream or 1000' from lake.

Average Switchgrass Yield in Wisconsin

Conservatively, growers can expect typical yields of switchgrass grown in Wisconsin to be in the 4-6 ton/acre range. (Note: Trials from the southern U.S. have shown yields as high as 10-12 tons/acre but these varieties cannot be grown successfully in the upper Midwest). This expectation is backed up by many years of research trials. Below in Table 2.2, University of Wisconsin grass breeder Mike Casler[17] reports an average yield of 6.03 tons/acre among six cultivars with yields ranging from 3.28 – 6.38 tons. (Casler and Boe, 2003). 'Cave in Rock' is the most widely planted switchgrass variety in North America (Samson, 2007).

Table 2.2

Mean yield and ash concentrations for six switchgrass cultivars grown at Arlington, Wisconsin

Cultivar	1998		1999		2000		2001	Mean	
	yield	ash	yield	ash	yield	ash	yield	yield	ash
	t/a	g/kg	t/a	g/kg	t/a	g/kg	t/a	t/a	g/kg
Cave-in-Rock	4.26	24.00	5.94	15.00	7.43	17.00	7.90	6.38	18.67
Dacotah	2.75	28.00	3.09	15.00	3.48	18.00	3.80	3.28	20.33
Forestburg	3.21	25.00	4.46	15.00	4.16	18.00	4.88	4.18	19.33
Shawnee	4.55	27.00	5.33	15.00	7.72	18.00	7.30	6.23	20.00
Sunburst	3.77	27.00	4.80	16.00	5.15	17.00	6.84	5.14	20.00
Trailblazer	4.45	27.00	4.78	17.00	4.98	20.00	5.60	4.95	21.33
Mean	3.83	26.33	4.74	15.50	5.49	18.00	6.05	6.03	23.93

Note: Above cultivars were planted in 1997. Nitrogen was applied at 50/lbs/acre in 1998-2001

Recommended Fertilizer Rates for Switchgrass Grown as Biomass

Switchgrass, when grown for wildlife or conservation purposes, requires very little, if any, fertilizer. However, when grown and harvested as a biomass crop, fertilization is necessary and should be calculated based on anticipated yields harvested (biomass removed). Recommended rates of nitrogen range from 50-100 lbs/acre/year. It is recommended that nitrogen not be applied the first year (establishment year) to reduce competition from cool season grasses. Recommended rates for phosphorus (P) and potassium (K) are 30 and 40 lbs respectively in the first year. After the first year, phosphorus should be applied at 0.83 lbs and potassium at 18.9 lbs per ton of harvested switchgrass. (Duffy and Nanhou, 2002). Table 2.3 shows the average costs of fertilization (as of March 18, 2008) were $71.25/acre. Fertilizer levels may be reduced by delayed harvest, allowing leaching of nutrients from the grass into the soil. However, the yield of spring harvests are lower.

Table 2.3

Costs of Fertilizer for Switchgrass Production[1]

Year	Yield	N	P	K	Lime	Total $ acre
1			30 lbs x 0.81/lb = $24.30	40 lbs x 0.46/lb = $18.40	2 tons @ 11.50/ ton = $23.00	$65.70
2	2.5 tons	50 lbs x .54/lb = $27.00	2.075 lbs x 0.81/ lb = $1.68	47.25 lbs x 0.46/ lb = $21.74	0.5 tons x 11.50/ ton = $5.75	$56.17
3 –10	5 tons	50 lbs x 0.54/ lb = $27.00	4.15 lbs x 0.81/lb = $3.36	94.5 lbs x 0.46/ lb = $43.47		$73.83 (X8 years =$590.64)
					Total Cost for 10 years	**$712.51**
					Avg costs/yr	**$71.25**

Notes and Assumptions regarding fertilizer use[18]:
No N is applied in year one to reduce competition from grassy weeds. After that N is applied at 50 lbs/acre (Reported recommended N rates for biomass range from 50-100 lbs/acre; see Management Guide for Biomass Feedstock Production in the Northern Great Plains; Management Guide for the Production of Switchgrass for Biomass Fuel in Southern Iowa);Phosphorus applied at 0.83 lbs/ton of switchgrass harvested (1.94 P205 per ton); 30 lbs/ acre applied year (Duffy and Nanhou, 2002);Potassium applied at 18.9 lbs/ton of switchgrass harvested (22.8 lbs K20/ton; 40 lbs/acre applied year (Duffy and Nanhou) Fertilizer costs are estimated at 0.54 lb., 0.81/lb and 0.46 lb for N (urea), P (0-46-0) and K (0-0-60) respectively

Switchgrass Production Costs

Published studies of switchgrass production costs are highly variable. The variation reflects the fact that the studies have been done at different points in time, in different regions of the US reflect different assumptions about yield and what costs (land, labor, capital etc) are included. Assumptions about land rents and yields are both critical to determining costs. Land rents in Dane County range from $60-250/acre. For our budget, assuming a future switchgrass biomass energy program would be aimed at marginal acres we used $100/acre for land rents. (Table 2.4)

Assuming 5 tons per acre and using the UW agricultural enterprise budget tool[19] switchgrass production costs (baled FOB the farm) are estimated at $50.06 per ton. This $50.06 is a farmgate production price only and does not include farmer profit, transportation, pelleting, mark-up and storage or other handling costs. Table 3.2 on page 36 estimates the total costs for pelleted switchgrass FOB the pellet plant. Forage chopping and bagging in the field may reduce production costs and should be explored further.

Table 2.4

Production Costs of Switchgrass Baled as Hay

	Price	Quantity	Subtotal
Input Expenses			
Fertilizer	71.25	acre	71.25
Multi-peril crop insurance	13.27	acre	13.27
			$84.52
Energy Expenses			
Gasoline	3.19 per gal	0.67	2.14
Diesel fuel	3.99 per gal	1.4	5.59
Electricity	0.111 per kwh	2	0.22
Engine lubrication	0.81		0.81
			$8.76
Repair & Maintenance Expenses			
Power unit			0.56
Implement			1.26
Durable			2.20
			$4.02
Input Interest Expenses	164.83	0.04	**$6.06**
TOTAL OPERATING EXPENSES			**$103.36**
ALLOCATED OVERHEAD			
Land Rent	$100/acre		**$100.00**
Labor	$20/hr	0.69	**$13.84**
Interest & Insurance Expenses			
Power unit			2.53
Implement			4.25
Durable			9.27
			$16.05
Depreciation Expenses			
Power unit			2.51
Implement			5.54
Durable			9.01
			17.07
Total Allocated Overhead			**$146.96**
Total Operating Costs			**$103.36**
Total Costs per acre			**$250.32**
Total Costs/ton @ 5 tons/acre			**$50.06**

Chapter 3

Pelleting Switchgrass for Biomass Fuel

The Advantages of Pellets

An often mentioned hurdle for biomass utilization are the logistics inherent to an agricultural product; harvesting, moisture, storage, transportation, quality uniformity etc. Typically, biomass is delivered to the biorefinery in bulk via railcars or in trucks as chopped forage or baled hay. One way for switchgrass and other biomass crops to be handled more efficiently is by densifying them into bales, pellets, cubes or briquettes to reduce the bulk volume of the material. Although each method has pro's and con's, pelleting seems to have the greatest number of advantages. Although pelleting adds costs, pelleted switchgrass is flowable and allows the fuel to handled and stored easily and transported more economically. In addition, pelleted biomass decreases the moisture content and allows it to be burned more efficiently. Today there are approximately two million tons of pellets sold in the US and Canada annually.

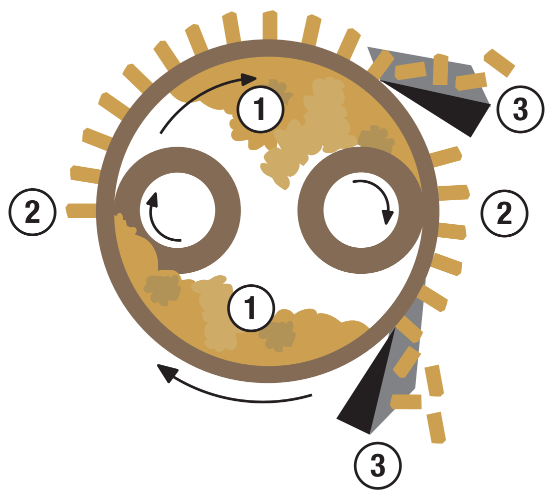
There are many advantages of densified fuel pellets:

- The amount of dust produced is minimized
- The fuel is free flowing, which facilitates material handling and rate of flow control
- The energy density is increased, easing storage and transportation
- The capital cost for storage is reduced
- Higher uniformity and stability permits more efficient combustion control
- There are less particulates produced during the combustion process
- There are considerable reductions in labor for feedstock handling
- Risk of fire is reduced considerably

The process of pellet making is outlined in Figure 3.1. The biomass is chopped and continuously fed into the pelleting cavity, where it is directed equally on either side of the edges, formed by the rollers and the inside face of the die. The rollers turn as the die rotates, forcing the material through the die holes by the extreme pressure caused by the wedging action. As the pellets are extruded, adjustable knives cut them to the desired length. The goal is to produce a pellet with a good hardness and a minimum production of fines (material broken off in the pelleting and handling process).

Figure 3.1

Diagram of Pelleting Process



1. Loose material is fed into pelleting cavity
2. Rotation of die and roller pressure forces material through die, compressing it into pellet.
3. Adjustable knives cut pellets into desired lengths.

A number of properties are commonly known to affect the success of pelleting, including:

- moisture content of the material
- density of the material
- particle size of the material
- fiber strength of the material
- lubricating characteristics of the material
- natural binders

Pelleting productivity is measured by manufacturers in terms of production yield, in units of pounds or kg per Hp. In the case of sawdust residues, this value varies from about 15-35 lbs per Hp, depending on the source of the wood residue; hardwoods are in the low range and softwoods are in the high range (Drisdelle, 1999). In theory, the more pliable the fiber, the easier it is to exude through the roller die. Steam and residency time (cooking or conditioning) create a more pliable fiber and increase pellet yields. The overall goal is to create a more fluid pelleting process, with less friction between the die extrusion surface and the fiber.

A durable pellet is created by the lignin exuded from the feedstock. This process results when fiber passes through the extrusion holes, heats up the die and creates higher temperatures in the fiber (75-85ºC). At this temperature, lignin within the material begins to flow from the fiber cell walls and has the effect of binding with other fibers during extrusion. During the process some moisture is driven off as steam. The resulting product is a uniform-flowing material with a bulk density several times higher than that of the starting raw material. Typically pelleting grasses increases the bulk density of the grind from a bulk density of 200 kg/m3 to 650-700 kg m3 in a pellet form.

The main factors that have been studied to improve the pelleting process are die geometry, steam conditioning temperature, pressure, moisture optimization, length of the grind, and binding agents. A review of these factors and the basics of the binding process are described below.

Diameter of The Die

In North America, most wood and alfalfa pellets are 6.3 mm (1/4-inch) diameter. In northern Europe, the most common sizes are, in decreasing order, 7-8mm, 9-10 mm and 6-7mm (Vinterback et al. 1998). Dies need to be selected based on the feedstock to be processed. A balance needs to be found between pellet durability and throughput when choosing dies. The longer the fiber stays in the die the more durable the pellet. However long fiber retention times in dies can result in reduced throughput and operational problems such as plugging. Production experience in commercial plants with pelletizing highly fibrous herbaceous biomass like oat hulls and warm season grasses has found that a L/D (length over diameter) of the die should be approximately 8.5-9:1. This range is intermediate to that generally used for wood pellets (4-5:1) and the alfalfa dehy industry (10:1) (Michel Viau, personal communication). The diameter of the die also affects production. Hill and Pulkinen (1988) found that smaller diameter size dies, when combined with fibers that are relatively difficult to pelletize, require slower RPM. In a laboratory pellet study, higher speeds (501-565 rpm) were found to plug 6.1 mm dies, but low quality alfalfa was successfully pelleted at rotation speeds of 250-316 rpm (2.8 and 2.6 m/s respectively). Rapid die rotation tends to overload the pellet motor due to the high fiber content of the forage.

To date, there has been no assessment of the relative merits of using larger dies with slower RPM to pelletize switchgrass. This likely could further optimize warm season grass pellet production. Modest increases in pellet size could likely be tolerated on most pellet stoves without changing grate sizing. Thus, the potential for increasing pellet size in North America may warrant investigation if suitable L/D dies can be used in conjunction with the bigger size pellet produced. This may reduce costs by reducing grinding size requirements. Michel Viau of Vifam Services in Montreal has successfully produced 5/16” (8mm) pellets made from overwintered switchgrass and burned the material in a 9 kw gasifier pellet stove.

Binding Agents

Reviews of the binding process and characteristics of plant tissues to form pellets have been completed in recent years (Tabil et al, 1997; Sokhansanj et al, 1999, Samson et al 2005). The binding is made possible by natural cohesion between particles and the mechanical load that forces inter-particle contact. Some binding agents that can improve binding and pellet durability include the use of corn stalks and wheat bran (Don Nott, personal communication). Production of switchgass pellets without binders is being successfully achieved but requires several basic process conditions to achieve high density and high durability pellets.

Impact of Chop Size on Pellet Process

A number of studies have examined the impact of the length of chop on the pellet process. Overall it has been realized that fine grinding produces denser pellets and increases the throughput capacity of machines as the material passes through the machine more easily (Dobie, 1959). Fine chopped material provides a greater surface area for moisture addition during steam treatment. Most commercial alfalfa pellet mills are using hammermills with a 7/64" (2.8 mm) screen to produce a suitable length of chop. It is recommended that the chop size be approximately one-half the diameter of the pellet being produced. In commercial production trials producing switchgrass pellets in Quebec, a grind of 7/64" has been used (Jannasch et al, 2003). Agrecol Corporation in Wisconsin used a 3/32" (2.4 mm) screen for grinding warm season grasses. The number of hammers, the screen hole design, and hammer tip speed also affect the fineness and uniformity of the grind when used in commercial installations (Michel Viau, personal communication).

Lab studies with switchgrass and other herbaceous feedstocks suggest grinds finer than 2.4 mm hammer mill screens may increase pellet density and durability (Mani et al, 2002; Shaw and Tabil, 2006). Shaw and Tabil (2006) found that when producing pellets under 139 MPa pressure, hammermill screens of 0.8 and 1.6 mm increased pellet density by 10% and 3% respectively compared to the 3.2 mm screen. Mill operators will need to assess the relative merits of increasing the fineness of grind versus pressure as a means to increase pellet density and durability.

An important consideration on whether to finely grind the material is the energy consumption used. Mani et al (2004) compared the energy requirement for hammermilling switchgrass at 1/8" + 1/16" (3.2mm) screen size. The 1/8" consumed approximately 25-30 kwh/tonne while the 1/16" (1.6 mm) increased energy consumption to 55-60kwh/tonne. This increased costs by approximately $3/tonne assuming power rates of 10 cents/kwh.

Steam and Temperature

The livestock feed industry routinely adds steam in its pelleting operations to improve pellet durability. Added steam provides heat and moisture and it also helps to reduce energy consumption during pelleting. Steam also activates natural binders and lubricants in the biomass. Tabil and Sokhansanj (1996) found that alfalfa pellet durability increased linearly as conditioning temperature was raised from 65 to 95C. Hill and Pulikinen (1988) found that pellet durability improved 30-35% (while the pellet power consumption increased from to 30%) when the conditioning temperature increased from 55 to 85C.

In recent years, a more advanced understanding of the role of the temperature on feedstock quality has been better understood. The state of "glass transition temperature" is defined as the temperature at which the material softens due to coordinated molecular motion and is critical to densification (Roos, 1995). In switchgrass, this occurs at 75-100 degrees C (Kaliyan and Morey, 2006). At these temperatures, the lignin and hemi-cellulose components of plants become flexible. (Back and Salmen, 1982). Working to produce 6.3 mm pellets using 3 herbaceous feedstocks, Shaw and Tabil (2007) also found 100 degrees C temperatures were superior to 80 degrees C temperatures in improving pellet durability.

Moisture Content

Feedstock moisture also appears to have an important effect on improving pellet density and durability. As water softens lignin, moisture can improve durability if densification temperatures are low.

To produce durable pellets, several precautions are required:

- The grass material should be 6-13% moisture
- The material should be finely ground using a screen of at least 7/64" (2.8 mm) and ideally 3/32" (2.4 mm) or less
- The pellet die should have a L/D (length/diameter) of 8.5-9:1
- Steam should be used to condition and heat the pellet. Recommend temperatures of at least 90 degrees Celsius (194 degrees F)

It is essential that further optimization of switchgrass pelleting be completed on commercial pelleting systems. Parameters such as time of switchgrass harvest, the residence time of high temperature saturated steam, impact of various L/D dies, and the impact of increasing pellet diameter on pellet bulk density and durability require further assessment to more fully optimize switchgrass pellet production and pellet quality.

The scientific reports reviewed tend to report more difficulty producing high-durability briquettes than pellets. Unfortunately no direct comparisons were made between pelleting and briquetting equipment in any studies.

Costs of Pelleting

Pelleting costs (including profit to the pellet plant) for an average pellet mill in Wisconsin producing approximately 25,000 tons annually, are reported to range from $40-60/ton (Morice, 2008). Table 3.2 shows a larger plant producing 150,000 tons annually would have lower costs in the $33-36/ton range. Adding in profit for the grower, expected costs FOB the pellet plant range from $107 – 154/ton.

Table 3.2.

Estimated cost for pelleted switchgrass, including production, transportation (up to 30 miles) and pelleting

Production Costs[1]	$50.06		
Average FOB Farm price/ton[2]	$70.06-90.06		
Trucking costs per loaded mile[3]	$3.75		
Trucking Distance	30 miles		
Total trucking costs/ton	$4.68		
Delivered Price FOB Pellet Plant	$74.74 – 94.74		
		Cost FOB Pellet Plant Capacity 25,000 tons/year[4]	Cost FOB Pellet Plant Capacity 150,000 tons/year[5]
		$40 – 60	$33 – 36
		Total costs pelleted switchgrass FOB Pellet Plant	
		$114.74 – 154.74	$107.74 –130.74

1 Switchgrass costs of $50.06/ton estimated by enterprise budgeting @ $100/land rent and yield @ 5 ton/acre.
2 Assumes farmer profit range from $20-40/ton or $100-200/acre assuming 5 tons/acre yield
3 Pricing for trucking assumes semi-truck trailer carrying 24 tons/load
4 Price per estimates, T.J. Morice, Marth Wood Products
5 Price per Pelletex® Corporation

Table 3.2 shows production costs of $50/ton, including a land rent of $100 per acre. This indicates that, before adding a profit, the landowner's income would exceed most, if not all, CRP payment levels in the region (approximately $60-$90 per acre in southern Wisconsin).

At a five ton/acre yield, a $30/ton markup for the landowner would provide an additional $150 profit which, with the land rental included, provides a $250 annual net income per acre to the landowner. These numbers indicate that even without producer subsidy, the net income potential from marginal and CRP lands may be sufficient for landowners to choose to grow switchgrass for energy if there were an assured, long term market.

A more recent report estimates that 25% of the costs of pelleting is from electricity. Table 3.3 below shows the electrical costs broken out by function: material handling, grinding, pelleting, cooling and miscellaneous. For a 150,000 ton plant, you can expect to use approximately 85 KWH per ton of material pelleted. At .10/kwH this would cost $8.50 per ton, approximately 25% of costs. A very thorough report on biomass pelleting was recently done by Ken Campbell for the Minnesota Agricultural Utilization Research Institute, "A Feasibility Study Guide for an Agricultural Biomass Pellet Company." Campbell estimates that the total capital budget for a 14/ton/hr pellet plant is estimated at $9.13 million dollars.

Table 3.3

Electrical Use (by function) in a pellet mill[1]

kWh per ton	
Transportation	5
Grinding	15
Pelleting	60
Cooling	2.5
Miscellaneous	2.5
Total KWh	85
Cost, electricity	$8.50

1 Assumes pellet mill production of 150,000 tons/year and electric rates @ .10/kwH

Capital Cost of Pellet Mills

Currently there are eight active wood pellet mills in Wisconsin with three more coming on line. (There are also dozens of agricultural pellet mills used for pelleting livestock feed.) The majority of these plants are pelleting wood and average 20,000 tons per year.[20] Recently a $6 million wood pellet mill was approved for Hayward and is expected to produce 36,000 tons of residential and industrial grade pellets.[21,22]

Table 3.4 shows the estimated costs of a large (150,000 ton per year) switchgrass pellet mill ($8.64 million) and a wood pellet mill ($28.7 million).[23] A wood pellet mill requires more capital costs to chip, separate and dry the green wood.

Table 3.4

Estimated Capital Costs of Switchgrass vs. Wood Pellet Mill[1]

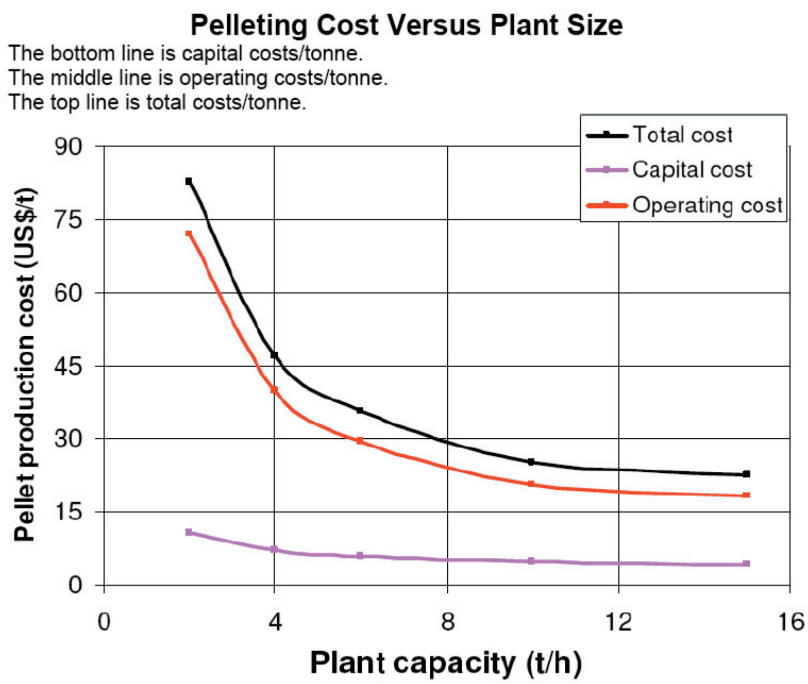
	Equipment	Switchgrass Pellet Mill	Wood Pellet Mill[2]
Raw Material Receiving	weighbridge, moisture measuring, truck dumper		$997,300
Chipping Line	50' line		$4,620,000
Foreign Material Separation	drum screens, separators		$822,960
Wet Milling Package	hammer mills and conveyers for 150,000 ton system		$4,760,000
Belt Dryer Package	belt dryers		$2,400,750
Sand Separation System	separates sand and soil out of the bark before chipping		$110,880
Conveyers		$1,242,434	$1,242,434
Dry Material Storage System	Concrete silo, vented at top	$928,125	$928,125
Pellet Manufacturing Equipment Line	Bins, augers, conveyers, hammer mills, 4 California Pellet mills	$4,147,427	$4,147,427
Pellet Storage System (18 days)	Galvanized grain bin	$2,105,400	$2,105,400
Dust Collection System	Air cleaning system – for worker health & safety	$226,958	$226,958
Boiler System	20 MW system, provides heat to dry wood chips		$6,398,130
Total (Equipment and Installation only; no building)		**$8,650,344**	**$28,760,364**

1 Wood comes in @ aprox. 50% moisture vs. air dried (sun) switchgrass and requires additional equipment for chipping, separating and drying
2 Pellet mill costs and investment costs per ton provided by Pellet-Ex Corporation http://www.pelletex.com/

Like any capital investment costs per ton decrease with greater capacity. The economies of scale for a pellet mill are shown in Figure 3.2. The data shows that these pellet mills maximize efficiency when they produce more than 10 tons of pellets per hour.

Figure 3.2

Pelleting Cost V. Plant Size



Graph presented by Sudhagar Mani, Ph.D., University of British Columbia, in a presentation titled "Simulation of Biomass Pelleting Operation" at the Bioenergy Conference & Exhibition 2006, Prince George, May 31, 2006.

Improving Biomass Quality for Combustion

There are considerable differences in combustion-quality characteristics between biomass fuels. Agri-fibers are generally more difficult to burn then wood residues. They are lower in BTU (switchgrass is approximately 5% lower in BTU/lb than wood) and higher in chlorine, alkali and ash. Improving biomass quality of agri-fibers depends upon minimizing their nutrient, ash, moisture content and the emissions of particulate matter during combustion.

High nutrient contents, particularly chlorine and potassium, can cause clinker formation (chunks of melted ash) and corrosion inside of combustion units (Elbersen et al., 2002). Maximum target values of 0.2% K and 0.1% Cl have been recommended for efficient use of biofuels for power generation in Denmark (Sander 1997). The Pellet Fuels Institute recommends that chlorine levels be below 300 pp (0.03%). (Campbell, 2007).

Using fuel that is low in K, Cl, Na and S is of particular importance for achieving high-quality biomass fuels and lowering particulate emissions during biomass combustion. The major factors affecting the level of these compounds are fertilization practices, choice of species, stem thickness, time of crop harvest, relative maturity of the cultivar, and the level of precipitation in a region (Samson et al., 2005; Samson et al., 2007c). Biomass-fueled boilers have traditionally been developed for wood, which is lower in ash and chlorine levels. However, new multi-fuel boilers have been developed that can burn agricultural and wood biomass effectively (Appendices 3 and 4). One way to improve fuel quality is to delay harvest in the fall for several weeks after cutting – or overwinter and harvest in the spring.

Nutrient Management: Spring Harvesting Improves Fuel Quality

Potassium and chlorine are both water-soluble and can be effectively leached out of thin-stemmed grasses in humid climates. As potassium is water soluble, the potassium content in plants can decrease appreciably following senescence of materials during the end of growing season, particularly if significant rainfall occurs during this period. Prairie ecology studies have shown that potassium in unharvested material is efficiently recycled into the soil over the late fall and winter (Koelling and Kucera, 1965). Kucera and Ehrenreich (1962) in Missouri found potassium content of native prairie plants to decline from 1.34% K2O in mid-June, to 0.63% by mid-September, and to 0.05% by the end of November.

In Quebec, 'Cave-in-Rock' switchgrass harvested in early October was found to contain 0.95% potassium, while over-wintered switchgrass harvested in mid-May was found to contain just 0.06% potassium (Goel et al., 2000). The chlorine content of perennial grass feedstocks is reduced if a late-season or overwintering harvest management regime is practiced. Burvall (1997) found an 86% reduction in chlorine content of reed canarygrass when it was over-wintered in Sweden.

Managing Silica and Ash Levels in Grasses

Silica is a common chemical found in grasses, deposited in the leaves, leaf stems and inflorescences of plants (Lanning and Eleuterius, 1989). Lanning and Eleuterius (1987) working in Kansas prairie stands, found switchgrass silica contents to be lowest in stems and higher in leaf sheaths, inflorescences and leaf blades. Silica levels are suggested to have evolved to be high in inflorescence structures to prevent the grazing of seed heads. Although silica is not a problem for commercial combustion boilers, it can present problems for smaller, residential pellet stoves. Producing swithgrass with lower silica levels increases energy contents, reduces abrasion on metal stove pans and reduces ash.

The difference in ash content between leaf and stem was reported by Samson et al (2007) who reported switchgrass stems averaged 1.03% ash and leaves had 6.94% ash. The impact of ash content on the energy content of the feedstock is also important as leaves contain approximately 6% less energy than stems. Switchgrass stems on average contained higher energy levels than leaves, 19.55 GJ/tonne is 98% of the average energy content of that reported for high quality wood pellets of 20 GJ/tonne (Obernberger and Thek, 2004).

Fractionation

In the search for low silica herbaceous feedstocks for the pulp and paper industry, Scandinavia has conducted considerable research and development on fractionation technologies (separation of stem from leaf) to separate the low silica containing stems from leaves. (Pahkala and Pihala, 2000; Finell et al., 2002; Finell, 2003). Several approaches to dry fractionation have been developed and integrated into commercial straw pulping facilities in Denmark (Finell et al., 2002). The basic process of disc mill fractionation developed by UMS A/S in Denmark is overviewed by Finell (2003) and includes bale shredding with a debaler, hammer milling, disc milling, pre-separation (separating leaf meal and internode chips) and then a final sifting to further refine the accepted fraction of internode chips for pulping. In the case of reed canary grass, typically 40-60% of the plant could be recovered for pulping applications with the residual material used as a commercial pellet fuel (Finell, 2003).

This technology can be applied to warm season grass fuels for use in the residential and commercial pellet markets.

Chapter 4

Biomass and Climate Change

Global Climate Change

Global climate change is the pressing environmental issue of our time. Understanding emissions for both fossil and biomass fuels is important for developing sound policy.

The major cause of climate change is CO_2 emissions from burning fossil fuels (coal, oil, natural gas and gasoline). Fossil fuel combustion takes carbon that was locked away underground (as crude oil, gas, or coal) and transfers that carbon to the atmosphere as new CO_2. On the other hand, when biomass is burned it recycles carbon that was already in the natural carbon cycle, which is recaptured through sustainable plant growth. Consequently, biomass energy systems are considered carbon-neutral – no new CO_2 is added to the atmosphere as long as the biomass is sustainably managed. When fossil fuel based heating systems are converted to biomass, net CO_2 emissions are reduced by 75-90%, depending on how much of the fossil fuel was replaced. (BERC, 2008)

Photosynthesis and Climate Change

When plants grow they harness water and the energy of the sunlight via photosynthesis, converting carbon dioxide (CO_2) from the air into carbohydrates (CH_2O) the cell walls of plants and releasing oxygen (O_2) back into the air.

$$Co_2 + H_20 + \text{sunlight} \Rightarrow CH_20 + O_2$$

In combustion, an opposite equation takes place:

$$CH_20 + O_2 + \text{energy} \Rightarrow Co_2 + H_20 + \text{light} + \text{energy}$$

(Olsen, 2001)

Carbon Footprint of Low-Input Cropping Systems

The extent to which cropping systems reduce climate change depends on the energy life cycle of each particular cropping system.

Dr. Phil Robertson (Michigan State University) and Dr. Chris Kucharik (University of Wisconsin) are two scientific leaders studying the global warming impact of Midwestern cropping systems. Robertson is the lead researcher for the Great Lakes Bioenergy Research Center, a partnership between Michigan State University and the University of Wisconsin.

Robertson evaluated the global warming impacts of annual grain crops (corn, chisel plowed; corn no till; corn organic) perennial biomass crops (alfalfa and poplar trees) and unmanaged perennial grass based systems. Biomass produced from perennial grasses (require lower fertilizer, less tillage etc) have better net energy ratios and reduce global warming more than biomass produced for row crops. Among the cropping systems studied, corn based systems (with higher fertilizer, more tillage, drying etc.) increases global warming the most (Robertson, 2008). Table 4.1 shows the perennial grass systems reduce global warming by the largest percentage, reducing CO_2 by –211 (CO_2 eq/m^2/y) while corn grown with conventional tillage increases CO_2 by 114 (CO_2 eq/m^2/y) (Robertson, 2008).

The simple act of planting grass is a surprisingly effective tool for reducing global warming emissions. Converting one acre of corn to perennial grasses reduces CO_2 by 1.32 MT/year (Table 4.2). A field converted from high input corn to low input perennial grass and kept in grass for 10 years would decrease emissions by 13.2 MT. (1.32 x 10 years = 13.2 MT) an amount equal to removing 2.4 cars off the road. Using these figures, a 100,000 acre switchgrass biomass project would be equal to removing 240,000 cars from the road. (Note: Kucharik's Dane County data showed lower carbon impacts, 0.83 CO_2 eq mitigated per acre.)

Table 4.1

Global Warming Potential of Field Crop Activities

g CO_2 eq/m2/y							
	Soil Carbon	N-Fertilizer	Lime	Fuel	N_20	CH_4	Net
Anual Grain Crops							
Corn, conventional tillage	0	27	23	16	52	-4	114
No-Till	-110	27	34	12	56	-5	-14
Organic with Cover	-29	0	0	19	56	-5	-41
Perennial Biomass Crops							
Alfalfa	-161	0	80	8	59	-6	-20
Poplar Trees	-117	5	0	2	10	-5	-105
Successional Communities							
Early Successional	-220	0	0	0	15	-6	-211

Table 4.2.

The impact of converting corn to grass in terms of taking cars off the road

	Total CO_2 eq mitigated (MT) per acre by CRP[1]	No. of acres converted from corn to grass	Total CO_2 eq mitigated MT per year	Total CO_2eq mitigated MT over 10 yrs	Avg Co_2 eq of emissions MT/vehicle/yr[2]	Translate the equivalence: Number of cars taken off the road by converting corn acres to grass
Scenario	1.32	1	1.32	13.15	5.48	2.40 (13.15/5.48)

1 Robertson, Phil. 2008. Full Cost Accounting: Global Warming Potential of Field Crop Activities. Presentation: The Biogeochemical Challenge. March 7, 2008. GLBRC, UW Madison.

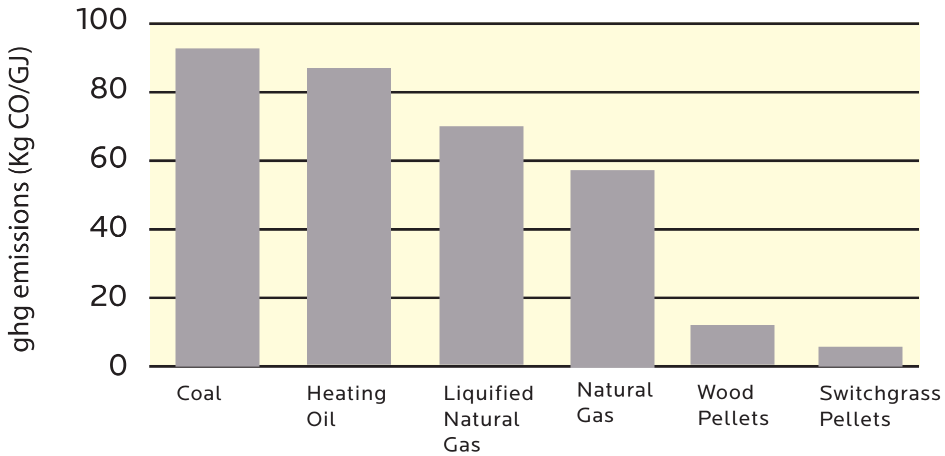
2 Greehouse Gas Emissions from a Typical Passenger Vehicle. EPA Publication 420-F-05--004. http://www.epa.gov/oms/climate/420f05004.htm

Comparing Emissions from Fossil Fuels

The greenhouse gas emissions associated with the major fossil fuels used in North America by sector are identified in Figure 4.3. Data for conventional natural gas, heating oil and coal energy use for the Great Lakes region (Samson et al 2008) was derived from the Natural Resources Canada Lifecycle Emissions Model (GHGenius). GHGenius is a program with a systematic approach to modeling both energy technologies and fuel use. Commercial and residential heating with natural gas were identified to have the lowest emissions at 57.6 kgCO_2e/GJ. Imported liquified natural gas (LNG) which was estimated from published reports to be 73.7 kgCO_2e/GJ (Samson et al. 2008), has a significantly higher GHG footprint than North American produced natural gas. The petroleum mix in the US is now changing as a result of increasing reliance on imported petroleum products from Canada's oilsands industry.

Figure 4.3

Life-cycle greenhouse gas emissions of fossil fuels and pellets



*heating oil value represents typical oil mix sourced from Canada (where 48% is domestic production and 52% international sources)
** LNG estimate based on studies of Russian gas imports into Europe (Uherek, 2005) and Australian LNG imports into the US (Heede, 2006; Jaramillo et al., 2007).

Emissions from heavy oil

The heating sector encompasses commercial, industrial and residential uses. A main trend in GHG emissions in Wisconsin may be increasing emissions from petroleum-based fuels with increasing reliance on imported heating oil from heavy oil production. As can be seen from Figure 4.3, new-generation heating-oil production in Canada now has GHG emissions approaching coal in terms of its GHG footprint. Switchgrass and wood pellets have been estimated to have life-cycle emissions of 13.46 average 8.17 kg CO_2eq/ks respectively. Heavy oil has higher emissions because a) natural gas is used in the tarsands extraction process; or b) oilsands materials located on site are gasified to provide the processing energy for heavy oil production.

There has been little discussion within Wisconsin about the coming change in supply to LNG imports in the next decade and the resulting impact on GHG emissions.

Another important new energy source for North America is liquefied natural gas (LNG). A recent Canadian National Energy Board study indicates exports to the US will decline rapidly over the next 10 years as a result of increased Canadian demand for natural gas for oilsands extraction and declining Canadian production. There has been little discussion within Wisconsin about the coming change in supply to LNG imports in the next decade and the resulting impact on GHG emissions. A key supplier may be Russia. The major sources of Russian gas pipeline imports into Germany have been recently studied by a joint Russian/German team and identified to be 73.8 Kg CO_2e/GJ (Uherek, 2005) or 18% below the reference value for oil. LNG imports will significantly increase the carbon footprint of natural gas use in Wisconsin due to increased emissions associated with longer distance gas transport in pipelines, LNG liquification, ocean transport and heating during re-gasification. An average value of 73.7 kg CO_2e/GJ can be used in North America which is 28% greater than the emissions of North American produced natural gas which is similar to other estimates (Heede, 2006; Jaramillo et al., 2007; and Uherek, 2005).

Switchgrass vs. Corn Ethanol

Biomass used for heat produces nine times more energy per acre than corn ethanol.

Recent studies have compared the costs and benefits of biomass used for transportation fuel versus heating fuel and the results were striking (Grahn et al, 2007; Samson et al, 2008). Switchgrass, even when grown on marginal CRP land, produces 9.2 times the net energy per acre of corn ethanol. (Table 4.3)

The gross energy yield in the field for switchgrass, when grown on marginal agricultural land is 2X greater than the gross energy yield for corn ethanol grown on higher quality Wisconsin farmland.

Table 4.3

Switchgrass vs. Corn Ethanol

Crop	Yield	Energy	Total Energy Yield after Conversion	Energy Output to Input ratio	Energy used in production and conversion	Net Energy yield/acre
			MMBtu/acre		MMBtu	
Switchgrass Pellets	5 tons/acre	14.5 MMBtu/ton	72.5	13.0:1	5.58	66.92
Corn Ethanol	138.8 bu/acre or 372.6 gal/acre	75,000 Btu/gal	27.9	1.28:1	21.79	6.11

One ton of pelleted switchgrass grown on marginal land provides 14.5 million BTU (MMBtu) per ton, or 72.5 MMBtu/acre (5 tons/acre x 14.5 MMBtu).

Corn ethanol, produced at Wisconsin's five-year average for corn yield of 138.2 bu/acre, provides a production yield of up to 372.6 gal/acre of ethanol (2.7 gallons ethanol per bushel). Ethanol, contains 75,700 btu/gal is 27.90 MMBtu/acre. (372 gal x 75,000 BTU/)

The energy requirements for the production and conversion of switchgrass are relatively low. Established switchgrass stands, do not require tillage, pesticides or herbicides and maintain productivity with modest fertilizer inputs. Field studies with production and pelleting of switchgrass in Ontario by REAP-Canada and by Agrecol Corporation document an energy output to input ratio for switchgrass grown at a yield of five tons/acre of 13.0 to 1. Therefore, the energy inputs (at the five ton/acre yield), to produce 72.5 MMBtu/acre amount to 5.58 MMBtu.

The corn ethanol industry documents an output to input energy ratio of 1.28 to 1. At Wisconsin's average five-year corn yield, the output of 27.9 MMBtu/acre, using the industry energy yield ratio of 1.28 : 1, requires 22.02 MMBtu of energy inputs for production and processing.

The net energy yield for switchgrass, when grown on CRP or marginal farmland, at a 13 to 1 ratio may be calculated as being 72.2 MMBtu less 5.58 MMBtu or 66.92 MMBtu per acre.

The net energy yield for corn ethanol, when grown on high quality farmland, may be calculated as being 27.9 MMBtu less 21.79 MMBtu or 6.11 MMBtu per acre.

Thus, switchgrass pellets on marginal land in Wisconsin produces 9.2 times more net energy than the leading 1st generation biofuel technology in the state.

A case can certainly be made that the energy provided by switchgrass pellets cannot be directly put into a car and used as fuel. However, policies today are based on the volume of renewable energy with little emphasis on the net energy produced per acre or the ability of that renewable technology to reduce greenhouse gas pollution. A more effective approach would be to focus policies on bioenergy systems that produce the greatest net energy in use of land and the highest CO_2 reductions.

Further, it may be argued that corn ethanol production is a transitional technology that is anticipated to improve in energy yield efficiency while perhaps also leading to a new technology of cellulosic ethanol. It is however, beyond the scope of this report to attempt an evaluation of other potential biofuel technologies in production or in the research stage.

The United States currently uses approximately 6% of its petroleum for heating oil and is also importing increasing amounts of natural gas. Switchgrass pellets can be used to displace these fuels and increase available fuel for the transportation sector. Growing switchgrass for heat does not require any new technology, can be accomplished with existing farm practices and equipment. It is efficient in terms of actual net energy produced per acre of land and can be produced on marginal, non-food-crop land. These facts would appear to make this a compelling option for the State of Wisconsin to pursue.

Air Emissions and Biomass Pellets[1]

All combustion processes, whether the fuel is coal, oil, gas or biomass emit exhaust components having different environmental and health impacts. In terms of health impacts from biomass combustion, particulate matter (PM) is the air pollutant of greatest concern. Particulates are pieces of solid matter or very fine droplets, ranging in size from visible to invisible. Relatively small PM, 10 micrometers or less in diameter, is called PM10. Small PM is of greater concern for human health than larger PM. Increasingly concern about very fine particulates (2.5 microns and smaller) is receiving attention by health and environmental officials. Work investigating wood and pellet boiler emissions of very fine particulates is ongoing.

All but the very best wood burning systems, whether in buildings or power plants, have higher PM emissions than do corresponding gas and oil systems. For this reason, it is necessary to use a stack with a height that will effectively disperse emissions into the air and reduce ground-level concentrations of PM to acceptable levels.

It should be noted that a conventional residential biomass wood stove has PM emissions 500 times greater than a wood-fired power plant with sophisticated emissions control equipment, for the same amount of wood fuel input. Similarly, commercial biomass systems have highly efficient combustion and their chimneys emit virtually no visible smoke (the white plume of vapor on cold days is condensed water).

Stack height is determined based on worst-case weather conditions and what is necessary to ensure air quality at the ground meets health-based standards. Currently, there is much greater risk from PM in the exhaust of idling school buses than from wood-heating plant emissions. (Biomass Energy Resource Center, 2008) To continue to build public acceptance of biomass, we must pay close attention to air quality issues and incorporate pollution-control options as needed.

There are potentially 4 factors which can contribute to minimizing particulate emissions:

* an improved boiler design
* use of a densified form of the biomass
* use of additives incorporated into the fuel
* use of a cyclone or other apparatus to trap dust

Boiler Design

Major progress has been made in improving boiler design. The main factors that have recently been identified to contribute to reducing particulate load are the use of an oxygen-controlled boiler and the use of a condensing boiler. In small scale Austrian boilers burning wood pellets emissions have been reduced from an average of 15 mg/MJ in 1996-1998 to 10 mg/mj in 2005. Flue condensing boilers were found to reduce emissions by 50%. Haslinger et al 2005 reported small scale condensing pellet boilers of 8 and 16 kW to have particulate emissions of 3 and 4 mg/MJ respectively. Johansson et al (2004) tested 18 and 21 kW oil

[1]Information on air emissions of biomass provided by the Biomass Energy Research Center (BERC)

boilers and found particulate emissions of 6 and 12 mg/MJ. Thus advanced pellet boilers burning wood pellets will have no detrimental impacts in ambient air quality where heating oil is replaced. Important gains in ambient air quality can be realized where pellets replace common solid wood burning appliances. Houeck and Broderick (2005) compared PM 2.5 emission factors (adjusted for efficiency) of conventional woodstoves, catalytic certified woodstoves and certified pellet stoves emissions and found them emit 66.8, 15.1 and 2.5 lb/ton for each of the respective appliances.

Pelleting Improves Fuel Quality

In terms of PM loading potential of fuels, pelleted fuels can significantly improving combustion qualities and decrease particulate loading when compared to bulk fuels due to the increased uniformity of the fuel, less fines and better control over the combustion process. Wood pellets are also lower in PM than wood chips (Obernberger et al, 2007) which contain more bark material. Wood pellets are also lower than most agricultural biomass fuels. An overall ranking that appears to be emerging is that wood pellets< delayed harvest grass pellets<crop milling residues pellets and grains< straw and stalk. Compared with emissions from wood pellets (17 mg/Nm3), particulate matter emissions from crop milling residues and feed grains ranged from 80-200 mg/Nm3 (Hartmann et al., 2007). Cereal straw pellet samples tested in the 125-275 mg PM /Nm3 emission range. Table 4.6 illustrates the particulate emissions found for the various feed-stocks.

Additives

Biomass combustion appliance manufacturers often recommend the addition of lime (C_aO) to reduce clinker formation and slagging. Hartmann et al (2007) found that this practice, reduced particulate loading by approximately 15%. Ronback et al (2007) found 2% fine limestone mixed with oat grain fuel reduced total particulate loading by 15% and reduced total dust formation by 28%. Limestone creates a chemical compound such as $CaS0_4$ which has a higher melting temperature, thus these species stay in the bottom ash. The authors felt this additive would be most valuable in larger combustion systems where the increased ash content of the fuel would have minimal negative impacts on combustion efficiency. The limestone also has the added benefit of reducing HCl formation.

Emission Reduction Apparatus

Finally it is well known that emission reduction apparatus can be installed to effectively reduce particulate loads. Biedermann and Obernberger (2005) suggests using a two-stage process, first removing coarse fly ash with a cyclone fly ash unit (mainly coarse fly ash particles) and then removing fine fly ash with a highly efficient fine fly ash precipitator. Other techniques such as the use of underground flue gas pipe can also trap particulates in a cost effective manner. Ronnback et al (2007) found the use of an underground channel to reduce chlorine total dust and sulfur emissions by 40%, 42% and 67% respectively.

Pollutant Emissions

NO_x compounds play an important role in the production of particulate matter and atmospheric haze, smog, acid rain and eutrophication from nitrogen deposition in aquatic areas. Hartmann et al., (2007) found that in flue gas emissions, NO_x emissions are clearly a function of the element (in this case nitrogen) content in the fuel when compared with other pollutants such as carbon dioxide (CO2), carbon monoxide (CO) and volatile hydrocarbons (TOC). Lower N containing fuels such as wood chips, wood pellets and miscanthus fuels had NO_x emissions below 200 mg/Nm3, while grain fuels had emissions from 400-600 mg NO_x/Nm3.

Hartmann et al., (2007) determined that NO_x emissions from biomass combustion in a small scale Guntamatic Powercorn 30 kW Lambda-controlled boiler were equivalent to 353.9 times the N content (%) to the power of 0.35 using a regression analysis. Using this relationship, NO_x emissions were estimated from the nitrogen content for common agri-fuel feedstocks, the results of which are presented in Table 4.4.

Low nitrogen-containing fuels having an N content less than 0.5% were identified to have the lowest overall estimates for NO_x emissions, with the overwintered switchgrass feedstock approaching the low levels achieved by the wood pellets. Some milling byproducts, specifically oat hulls and corn cobs also had low NO_x estimates and appear to be promising feedstocks for combustion based on their N content. Straw fibers also possessed moderately low nitrogen contents. However, all of the grain fuels and the processed wheat residues were estimated to produce high levels of NO_x, between 400-500 mg/Nm3. Using mixtures of these fuels may provide some benefit in terms of making pellets, and increasing combustion efficiency and will keep NO_x emissions at acceptable levels. Overall there appears to be major environmental advantages from an NO_x standpoint of developing warm season grasses as bioheat feedstocks relative to other agricultural biomass options.

Table 4.4

Estimated NOx emissions associated with nitrogen content of switchgrass and other feedstocks suitable for Wisconsin

Residue	Nitrogen Content[1] (%)	Estimated NO_x Emissions (mg/Nm^3)
Wood Pellets	0.3[2]	232
Energy Crop Pellets		
Fall harvested switchgrass	0.46[3]	270
Spring harvested switchgrass	0.37[3]	250
Straw Residues		
Wheat	0.48	274
Oat	0.64	303
Barley	0.64	303
Corn	0.8	327
Grains		
Wheat	2.24	469
Oat	2.08	457
Barley	1.92	445
Corn	1.44	402
Milling Residues		
Wheat bran	2.72	502
Wheat middlings	3.04	522
Oat hulls	0.64	303
Pin Oats	1.28	386
Corn Cobs	0.48	274

1 Preston (2006)
2 Obernberger and Thek (2004)
3 Average of Goel et al., (2000); and Adler et al., (2006)

Pelleting Switchgrass: A "How-To-Guide"

Agrecol's Steps to Pelleting Switchgrass

Grow the Grass

↓

Harvest the Grass

↓

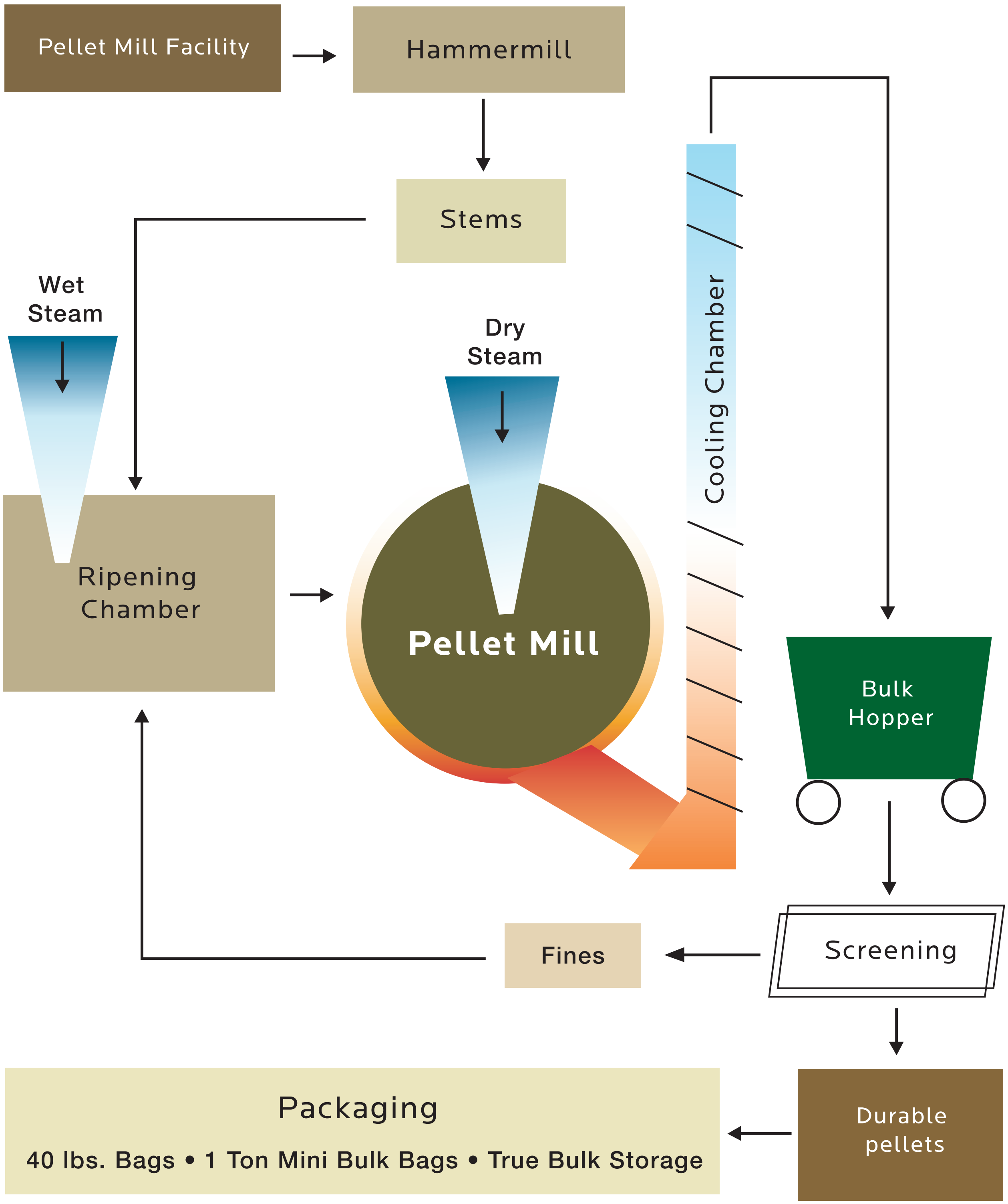
Mow → Bale or Chop → Temporary Storage

Temporary Storage
- Tarp
- Storage Tube
- Bunker

↓

Move to Pellet Mill Facility

Agrecol's Steps to Pelleting Switchgrass



Options for Densifying Biomass:

There are several options for densifying biomass from the field level to an energy-dense pellet.

Typically densification options range from: chopped hay, bales, cubes, briquettes and pellets. The end use and transportation will determine which densification option to select.

Chopped Hay

Bales

Cubes

Briquettes

Pellets

1. Chopped Hay

When you harvest the material, we recommend putting multiple windrows together to use the chopper efficiently in the field.

If you set the forage chopper cut length small enough (length of cut) you will produce a fairly fine and more desirable product for the pellet plant. You might be able to eliminate the wet hammer mill redundant process in the plant.

Current choppers are capable of chopping 30 to 100 dry tons/hour at a length as short as 1/4".

The forage is chopped by a self propelled chopper and blown into a separate truck or wagon. The chopped forage is then field stored in a simple bunker or large plastic tube in the corner of a field that is accessible by road for later transportation to the plant.

2. Bales

Can provide a range in density from 8 to 11 lbs/cu3. From a logistics standpoint, it makes the most sense to make bales 8 feet wide (the width of a semi truck.). This makes transportation, stacking and handling convenient with the use of a material handling loader

Bales are bound with either twine or wire and big enough to require mechanical/hydraulic loaders. They weigh 700-1200 lbs. Most are 3 x 3 x 8 or 4 x 4 x 8. Although round bales may be cheaper to produce per ton, with biomass fuel typically it is more efficient and safer (don't roll) to produce large square bales for transportation and storage logistics.

Typically balers are capable of baling 10 to 20 tons/hour.

Options for Densifying Biomass

3. Cubes

Cubes were created for a specialty market, to make the transportation of western hay possible. To make cubes, hay is dehydrated and molded into low density cubes. Typically cubes are approximately 1.5 inches in size. Typically, cubes are not very durable.

4. Briquettes

Briquettes range in size from 2 – 4$^{3}/_{4}$” and throughput capacities from 1-3 ton per hour. Briquettes are typically stored in bulk handling buildings and loaded with end loaders and unloaded with a screw reclaimer and conveyer system. Many systems that handle chunk coal will handle briquettes.

Briquettes are 2-4$^{2}/_{3}$” in diameter

5. Pellets

Fuel pellets are typically $^{1}/_{4}$ – $^{5}/_{16}$” in diameter and between $^{3}/_{4}$” to $^{1}/_{2}$” long. The advantage of pellets over briquettes is that they are readily flowable. Its easier to store pellets because the equipment needed is available and has been developed by agricultural and the feed industry.

Grain bins, hopper bottom trailers, railroad hopper cars (grain) are all examples that can be used to store and transport pellets.

Pellets are typically 1/4” in diameter

Compared to pellets, briquettes are often as durable and cheaper to make per ton. The densification equipment itself is nearly the same cost but much less material condition equipment is needed in the briquette plant.

Traditional pellets and briquettes both need to be stored indoors or they will disintegrate in the presence of moisture. The densities for both are relatively the same, 40lbs/ft3.

The larger the die, the larger the material can be that is fed into the pellet mill or briquette line. The smaller the die the finer you have to grind the biomass feedstock, the more horsepower it takes per ton. The larger the die diameter the more forgiving the process is (moisture, particulate size) in densifying the biomass.

Producing Pellets

1. Hammer milling

A mechanical process where rotating blades impact the material at high speed breaking it into smaller pieces. The screen surrounding the blades help determine particle size.

To mill down native grasses, a large throat area and a large surface area of screen area to horsepower is required to achieve throughput production tonnages.

Hammermill

Biomass after Hammermilling

2. Fractionation

Fractionation is a process of physical separation of leaf tissue from the stem tissue. Leaves have a higher percentage of ash and contain many nutrients harmful to boiler steel. Ash can decrease BTU value of fuel, clinker up boilers and require higher volume ash removal.

Normally, switchgrass ranges between 4-8% ash. Separating out the leaves from the stem produces a fuel that is lower in ash content, has less clinker formation, longer boiler life and less ash to remove after burning. See results below:

Fractionation Cyclone

Agrecol Preliminary Switchgrass Test Results

	Whole Switchgrass	Switchgrass - Stem Only
Ash % content	5.34	2.87
BTU content	7,914	7,967

The fractionated leaf material is itself a potential value-added product for use as a soil amendment due to it's nutrient content.

Producing Pellets

3. Ripening Chamber

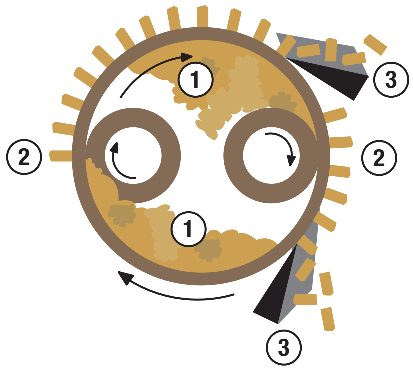
We recommend that switchgrass pellet mills should have adequate ripening chambers where wet steam is added to increase the moisture content of the material and that dry steam be used to elevate the temperature of the material prior to pelleting.

Proper moisture creates steam that maximizes throughput and pellet durability. Steam, from the added moisture along with pressure together extrudes a durable pellet.

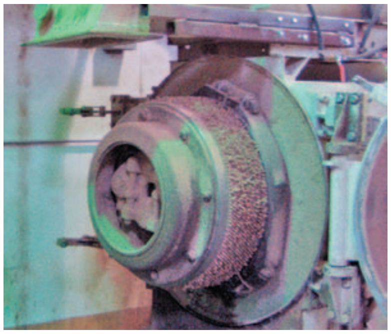
Our pellet mill did not have steam, so we added a spray injection system to the mixing chamber. This chamber was located above the pellet mill to pre-wet the material prior to pelleting.

The time to allow the water to penetrate the switchgrass stems is 5 times longer than wood. It is critical to size the ripening chambers proportionately to allow adequate time for the material to re-wet into the product – not just the surface.

When the feedstock is warmer and slightly moist, it is more pliable and then when compressed by the roller into the die, the resulting pellet is a firm, glassy pellet of high density and quality. This pellet however is NOT durable until cooled.



Pellet Mill – diagram of die and rollers


Pellet Mill with cover open

4. Pelletizing

A pellet mill extrudes material under high pressure through a die using a configuration of rollers.

Through experimenting, we found that moisture content of the material fed into the pellet mill is very important. Initially when we fed dry feedstock material into the pellet mill it would either plug the die or would make non-durable, unacceptable pellets. Initially the pellets were very low in density, looked like shredded wheat, without the sheen typically seen in a high quality pellet. We realized after talking to industry experts that we needed steam.


Extrusion of pellets from die

Temperature of pellets as they are extruded from the die. 180 degrees F is the minimum temperature required to produce durable pellets

Producing Pellets

5. Cooling chamber

A cooling chamber is place where the `pellets can be rapidly cooled. Agrecol uses a counter-flow air cooling system to cool the pellets.

The chamber has mechanically louvered floor grates that allows the first incoming pellets to be louvered out into a bulk hopper to be screened.

Cooling Chamber

6. Screening

Pellets are rolled over a screen to remove fines from the durable pellets. The fines are sent back through the system to be re-pelleted.

Hopper

7. Bagging

After screening, durable pellets are: bagged into: 40 lb retail bags, mini bulk (1 ton) bags for commercial use or “true bulked” into a bin or hopper (like corn or soybeans).

Durability is critical, especially for residential use. It has been shown that pellet bags are handled 9 times on average, before entering the homeowner pellet stove. In addition these stoves require a high quality pellet (free of fines) to operate efficiently and decrease fly ash.

Finished switchgrass pellets
– Stored in 1-ton mini-bulk bags

Producing Pellets

8. Combustion

Compared to wood, biomass pellets are higher in ash content. Stoves and furnaces that utilize biomass fuel should be equipped with mechanical agitators and automated ash removal systems.

To increase the performance of residential stoves, Europe has tightened its pellet standards; restricting its chemical composition, ash and other fines allowable. The end result is a higher quality fuel, better performance and in the end, happier customers.

There are several manufacturers who claim to use biomass pellets for fuels.

Agrecol purchased a 2.5 MMBTU input boiler in 2004 (Pelco). The boiler was advertised as multi-fuel boiler, able to burn coal, cherry pits, corn and wood pellets. The Pelco unit is built with 2 air fans that are adjustable – one for pressurized intake and the other creates a vacuum for exhaust.

To optimize the combustion for grass pellets, we purchased a barometric gage (that measures pressure), and adjusted both the intake and the exhaust to create a vacuum (slight negative pressure) in the fire box to optimize burn performance.

Pelco boiler and fuel hopper

Firebox

Radiant floor heat system

Producing Pellets

9. Ashing

The final step in combustion is removing ash from the boiler or furnace. In commercial or industrial systems, ash removal is completely automated. The simplest and most ecological approach is spreading the ash back onto the land. Ash can serve as a soil amendment, it is rich in nutrients and a convenient means of recycling.


Ash from the burner

Pellet mills in the U.S. make two grades of pellets - premium and standard. The difference between the two is largely ash content. Ash is the inorganic material that remains after combustion. Standard grade fuel allows up to 3% ash content, while premium grade is less than 1 percent in the US. This difference in ash is a result of the material pelleted. Standard pellets are derived from materials that produce more residual ash, such as tree bark or agricultural residues. Premium pellets are usually produced from hardwood or softwood sawdust containing no tree bark. Premium pellets make up 95 percent of current pellet production and can be burned in all appliances. Standard pellets should only be burned in appliances designed to burn the higher ash content pellets. (Appendices 3 and 4)


Ash in commercial boilers is automatically removed. It can be reapplied to the soil as a soil amendment.

Agrecol Corporation

Evansville, Wisconsin

Agrecol® Corporation, in business since 1991 and located near Evansville Wisconsin, has grown to become the Midwest's largest producer of native plants and seeds, including bio-energy seed mixes.

Native Grass production fields at Rock Prairie Farm

(Part of) Agrecol's Staff: Paul Collins, Mary de la Rosa and Mark Doudlah

One of Agrecol's Switchgrass production fields on the World Dairy Center. (150 acres)

In 2005, Agrecol constructed a new 30,000 square foot seed cleaning facility with radiant heat floors at its 1200 acre seed farm and nursery. The company produces seed from over 200 native grass and forbs species on their fully irrigated farm in Evansville and has several hundred acres in seed production at other locations in Rock and Dane counties.

"When we produce prairie seed, we have a lot of material we call 'MOG', or material other than grain," says Mark Doudlah, President of Agrecol. Since this MOG comes from many species of native plants, and still contains some seed from these diverse natives not fully separated in the cleaning process, it cannot be land spread over their nursery plantings as to do so, would cause these 'pure stands' to soon become a mixture of native species and thus compromise seed production.

"We decided that this material doesn't belong in a landfill," said Doudlah, "and we found composting to be too labor intensive and not a sure means to eliminate the invasive seed problems....so we decided to pelletize the MOG and heat our whole facility with our 'waste' product."

The seed cleaning building at Agrecol's Rock Prairie Farm, Evansville, Wisconsin. This building is heated with their own native grass biomass pellets.

Agrecol's Pelco® Boiler

Agrecol first experimented with turning this residue from their seed cleaning operations into fuel pellets and, in 2006, purchased a Pelco boiler, and bought older equipment from a Janesville feed pelleting plant. The used equipment included a California pellet mill (1/4" diameter die), Bliss hammer mill, a counter flow dryer and dust filter/collection system. Over the 2006-07 winter, Agrecol eliminated propane use entirely, heating their entire production facilities with native grass biomass pellets

"We estimate that we'll have a payback in three years (on the investment)," Doudlah said. "If we were heating with propane, which is our only alternative here on the farm, it would cost over $25,000 a year." "We are burning about 80 tons of pelleted MOG biomass per heating season and are now beginning to sell pellets in the market. It is a new profit-generating enterprise for our company."

Agrecol currently has pelleting capacity over 15,000 tons/year of biomass pellets. They have planted 186 acres of switchgrass on rented land adjacent to the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) headquarters in Madison and have an additional 600 acres of various types of grasses on the Evansville farm. The company now has another added-value product from their seed production: they harvest the seed and turn the waste into biomass pellets for fuel.

Doudlah acknowledges that the pelletizing capacity of the Agrecol facility is quite small when compared to the new high capacity (100,000 ton or more) biomass plants that are now being designed/constructed across North America. "We're still experimenting with biomass heating and have the advantage of producing both seed and pellets on our own land and so it works for us now," Doudlah said "but the future is going to bring larger and much more efficient pellet plants on line and we intend to be part of that too."

DATCP Secretary Rod Nilsestuen agrees. He praised Chairman Bill Graham and the company for being a learning center for future biofuel use, saying it is dealing with "a lot of the on-the-ground issues that a lot of people are going to face" in converting agricultural products into energy. "This has almost been a pri-

DATCP Secretary Rod Nilsestuen awarding the ADD grant to Agrecol

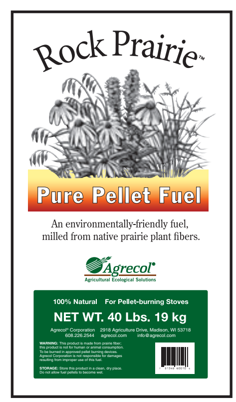
vate experimental farm," Nilsestuen said. "They're a discovery place as well as a commercial business."

Among the 200 varieties of prairie grasses grown by Agrecol is switchgrass, which is of course at the top of the list for bio fuels because of its high-yield and high-energy potential even when grown on more marginally productive soils. But Doudlah stresses that the goal should not be to just focus on switchgrass alone. "Agrecol doesn't want to think just in terms of another monoculture crop like corn or beans or what have you," he said. Agrecol has developed and is continually testing energy yields of seed mixtures that include switchgrass but also bluestem and Indian grass varietals, legumes as well as some flowering forbs, They believe that their seed 'energy mixes', which may be adapted for particular geographic regions, improve harvest 'standability', add to diversity, aesthetic and wildlife value and provide superior energy yield in varying seasonal conditions.

John Imes, Executive Director of the Wisconsin Environmental Initiative, sees broader implications in Agrecol's model for alternative fuel production in part because of their demonstrated ability to harvest energy from lower yielding or so-called marginal soils, including highly erodible land. "...if we could find a way to get energy from these lands in a way that upholds the native and natural habitat components, then we could focus our agriculture on the food and fiber, high production (land). And there wouldn't be this potential conflict between food or fuel. That to me is very exciting."

Agrecol's Biomass Energy Products Include:

Agrecol produces and sells native biomass pellets and is developing pellet stoves for residential and commercial markets



Pure Prairie Fuel – 40 lb Bag

Energy Seed Mix

Analysis

Agrecol's fuel options like many rural businesses, was limited to LP. When they compared the costs of LP to pellets they estimated they could save thousands of dollars each year. The table below compares the cost for a range of fuels. Wood chips are the most economical. Natural gas was the next most economical fuel followed by wood and switchgrass pellets. In southern Wisconsin, pelleting an agricultural crop like Switchgrass may be more feasible than wood chips or pellets because of supply. Switchgrass pellets were 52% less expensive than LP.

Table 1.1:

Comparison of Heating Value of Fuels

Fuel Type	Unit	Cost per Unit	BTU per Unit (dry)	Moisture Content	MMBtu per Unit	Cost per MMBtu Delivered	Average Seasonal Efficiency	Delivered MMBTU per Unit	Cost per MMBtu After Combustion
Wood Chips	ton	$50	16,500,000	40%	9.9	$5.05	65%	6.4	$7.77
Natural Gas	therm	$1.10	100,000	0%	0.100	$11.00	90%	0.090	$12.22
Wood Pellets	ton	$150	16,500,000	5%	15.7	$9.57	75%	11.8	$12.76
Switchgrass Pellets	ton	$140	15,326,000	8%	14.560	$9.62	75%	10.920	$12.82
Corn	bushel	$6.00	392,000	15.5%	0.331	$18.11	80%	0.265	$22.64
LP Gas	gallon	$2.20	92,000	0%	0.092	$23.91	90%	0.083	$26.57
Electricity	kwh	$0.10	3,412	0%	0.003	$29.31	99%	0.003	$29.60
Fuel Oil (No.2)	gallon	$3.30	138,000	0%	0.138	$23.91	80%	0.110	$29.89

Note: Prices change daily. Wood and switchgrass prices are FOB the pellet mill. Chart provided by Biomass Energy Resource Center (BERC).

America’s Best Flowers

Cottage Grove, Wisconsin

Ed and Carol Knapton began their current business in 1987 with a self-built wooden greenhouse. Located now in Cottage Grove, Wisconsin, they own and operate nineteen greenhouses totaling 83,000 square feet and market their flowers, perennials and shrubs through direct retailing at their nursery location and to wholesale customers.

During the prior fifteen years, the couple raised produce and berries, selling both at the Dane County Farmers Market and with a pick-your-own operation. At peak, they had 35 acres of pick-your-own vegetables, 5 acres of raspberries, 2 acres of asparagus and 23 acres of strawberries. Following a major fire in 1983, and after an interlude of off-farm full-time employment, they began their business in Cottage Grove. Ed is currently the President of The Commercial Flower Growers of Wisconsin and a Senator representing Wisconsin members of the American Nursery and Landscape Association.

In 2005-06, the cost of their primary fuel, propane, increased to the

The Knapton's believe that their business could become a "showplace for energy efficiency and biomass-fueled technology."

point where it became uneconomic for them to continue growing winter crops such as poinsettias. Due to the higher fuel costs, they were forced to reduce operations to a seasonal schedule and discontinue heating during the colder winter months which required laying-off staff and ceasing to supply some long-time wholesale customers.

While America's Best does have access to natural gas, the supply is limited to the point where they cannot meet heating needs during the winter with natural gas alone. Adding pipeline capacity to increase natural gas availability would be expensive and cannot be justified. Additionally, natural gas prices have sharply fluctuated and tended to increase overall in recent years, so Mr. Knapton is actively seeking a less expensive and more stable alternative to both propane and natural gas.

Issues

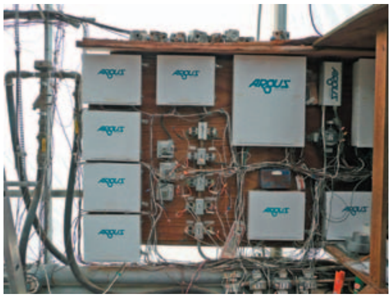
America's Best Flowers has modern facilities with radiant in-floor hot water heating and hung Modine™ heaters. Conversion to heating with bio-mass fueled boilers would be straightforward and involve only that technology that is already commercially available.

The Knapton's believe that their business could become a "showplace for energy efficiency and bio-mass fueled technology." To that end, they are currently pricing agro-pellet boiler systems sized to their specific operation as well as modifications such as better insulated curtain sidewalls to the greenhouses themselves that would reduce energy use and further improve their costs of operation. Their goal is to become one of the most cost-competitive greenhouse operations in America while at the same time moving back into year-round production on a consistently profitable basis without being subject to rising and volatile fossil fuel prices.

Year-round heating with agro-pellets alone would require approximately 550 tons of biomass pellets. Assuming an average yield of 5 tons/acre, approximately 110 acres of switch grass would be needed to produce enough fuel for the business. For the seasonal requirements, the tonnage would be about 300 tons with a land area in switch grass of about 60 acres.

Mr. Knapton is planning to plant 25 acres adjacent to his greenhouses into a switchgrass mix during the 2008 season.

Modine Heater



Zone control panel

Analysis:

America's Best Flowers requires approximately 7.336 million BTU for a full year's heating requirements or 4,629 million BTU for seasonal operations. At estimated prices for propane of $2.28/gallon, the cost year-round would be $175,181.

Switching from LP to switchgrass pellets would save America's Best $108,171 in fuel costs or 62% less than their current LP heating system.

Table 6.2

America's Best Greenhouse: Propane vs. Pellets

Propane	
BTU/gallon	95,475
Appliance Fuel Efficiency	80%
07-08 Price per gallon	$2.28
Total Fuel MMBTU per Season	7,336
Total MMBTU of Heat Delivered	5,869
Cost/Therm of Heat Delivered	$2.99
Total Fuel Cost for Heating Season	$175,181
Pellets	
BTU per pound	7,663
Percent Ash	5%
Appliance Fuel Efficiency	80%
Delivered Price per Ton	$140.00
Total Tons Pellets Required	479
Total Fuel MMBTU per Season	7,336
Total MMBTU of Heat Delivered	5,869
Total Tons Ash Produced	23
Total Fuel Cost for Heating Season	$67,010
Total Annual Net Savings	$108,171
Cost/Therm of Heat Delivered	$1.14
Percent Reduction in Cost of Heat	62%

Oakhill Correction Facility

Oregon, Wisconsin

The Wisconsin Department of Corrections facility South of Madison near Oregon, encompasses 24 heated buildings totaling 327,380 square feet. Thermal heat is provided to this complex from a central plant that utilizes four boilers. The fuel source is natural gas with an alternative capability of fuel oil.

During the 2006 heating season the facility reported natural gas use of over 36,000 MMBTU at a total cost for natural gas of about $393,000 or about $10.50 per MMBTU. Fuel oil use during this period was minimal and appears to have been limited to testing purposes only. Operating costs, in addition to natural gas, of labor, maintenance and demand charges are $121,214 for the period yielding a total loaded cost of about $515,000.

Use of these boilers is rotated both in response to demand and to spread the hours of use among them. The boilers are quite old and, according to Wisconsin's Division of State Facilities Secretary and Chief Power Plant Engineer, at least two of them have been slated for replacement within the next two to three years. The boiler size is in the range of 200 to 210 hp or approximately 7 MBtu. These boilers were utilized during all or part of nine months of the year and they were off-line entirely for three months.

The current operating method limits these boilers' efficiency. Overall reported energy efficiency ranged from a high of 82.8% during February 2006, to a low of approximately 73% during the months of April, May, September and October of 2006. With today's available boiler technology, burning biomass pellets of switchgrass, wood or shelled corn achieves efficiency ratings of 80% or better when operated at near capacity.

Analysis:

Table 6.3

Oakhill Correctional Facility: Natural Gas Vs. Pellets

BTU/MCF	1,000,000
Nat. Gas Boiler Efficiency	74%
07-08 Price per MMBTU	$ 10.00
Total MMBTU of Fuel Required per Season	34,967
Pellet BTU per pound	7,663
Percent Ash	5%
Pellet Boiler Fuel Efficiency	80%
Delivered Price per Ton	$ 140.00
Size of Pellet Boiler (Mlbs/hr)	8.00
% of Pellet Boiler Op Hrs/Mo to Consider as Baseload	80%
Pellets	
Percent of Steam Produced by Pellets	61%
Total Tons Pellets Required	1,393
Total Tons Ash Produced	69
Total Pellet Fuel Cost for Heating Season	$195,373
Natural Gas	
MMBTU of Nat. Gas Used	13,625
Total Natural Gas Cost for Heating Season	$136,245
Totals	
Cost per Therm of Heat Delivered	$1.22
Total Heating Season Fuel Cost (pellets and gas)	$331,618
Total, 2006 Heating Costs	$393,000
Percent Reduction in Cost of Heat	15.6%

Pecatonica Elementary School

Hollandale, Wisconsin

The Pecatonica elementary school is located in a rural area about six miles from the Village of Blanchardville, Wisconsin. Current attendance is 213 students.

Of the total 37,000 square feet, 22,300 sq. ft. date from the 1950's and 14,600 sq. ft. were added in 1992. The newer portion of the school is heated by forced air from a steam/air heat exchanger and the older sections are heated by radiators.

The building is heated by three, older, Burnham Corp., oil-fired low pressure steam boilers, each of about 35 boiler H.P. and each rated at 10.2 G.P.H. of light fuel oil with an output of 1134 MBH.

For reasons of energy efficiency and maintenance reliability, The Pecatonica School District is considering, within the next three-five years, both replacing these boilers and upgrading the older sections of the building to a steam/air exchange forced air system. The capital cost for this project—replacing the three boilers and changing to forced air in the older sections is estimated to likely exceed $350,000—however detailed engineering and estimates have not yet been done. Of this cost, replacing the boilers with new Burnham Commercial boilers of equivalent size have been quoted to the author at $18-22,000 each, plus delivery and setup/installation.

Fuel oil costs at Pecatonica Elementary are significant for the school district. Also, as a rural school district with some declines in enrollment recently, all expenditures are being closely scrutinized. The price trend for fuel oil has been one of steady increase with a sharper uptrend in just the past two years as the price paid by Pecatonica has risen from $1.76/gal in January of 2007 to this January of 2008 where the price was now $2.60/gal. Further increases are expected.

Pecatonica Elementary uses approximately 14-16,000 gallons of fuel oil yearly, which, at current prices, may be expected to cost about $40,000 per year.

David McSherry, the grades 7-12 principal, (who is also in charge of all public works) is interested in exploring bio mass as an alternative for several reasons:

"It will be 3-4 years before we are ready to replace our heating system so the timing may be right. With all the money problems facing public schools right now, we have to take a look at everything. Plus, I agree we need to look at this as a country and world wide issue."

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Analysis:

Biomass pellets could clearly reduce the heating fuel costs for Pecatonica School. A simplified analysis of its current method compared with an alternative that used biomass pellets for 80 percent of the heating needs showed that Pecatonica School could reduce its heating costs at current prices by over $15,000 – or about 39% percent. A biomass pellet system would slightly increase the need for labor for ash removal and routine boiler maintenance. These tasks could be handled by existing staff at the school.

Title 6.4

Pecatonica Elementary:Fuel oil Vs. Pellets

Fuel Oil	
BTU/gallon	140,000
Average Price per Gallon	$2.60
Boiler Fuel Efficiency	80%
Est. Total Fuel Use per Season (Gal)	15,000
Total Fuel MMBTU per Season	2,100
Total MMBTU of Heat Delivered	1,680
Cost/Therm of HEat Delivered	$2.32
Total Fuel Cost for Heating Season	**$39,000**

Pellets	
BTU per pound	7,663
Percent Ash	5%
Appliance Fuel Efficiency	80%
Delivered Price per Ton	$ 140.00
Percent of Fuel Displaced by Pellets	80%
Total Tons Pellets Required	110
Total Gallons of #2 Fuel Required	3,000
Total Tons Ash Produced	3
Total Cost of Pellets for Heating Season	$ 15,895
Total Cost of #2 Fuel for Heating Season	$ 7,800
Total Fuel Cost for Heating Season (pellets and fuel oil)	$ 23,695
Total Annual Net Savings	$ 15,305
Cost/Therm of Heat Delivered	$ 1.41
Percent Reduction in Cost of Heat	39%

Conclusions

In Wisconsin the majority of energy used by residential, commercial and industrial sectors goes for heating

- Within the commercial sector, approximately 58% is devoted to space heating with the remainder used for electricity (42%). The residential sector devotes even more of its energy budget to heating (73.5%) with the remainder used for electricity (26.5%). In 2006, state owned buildings reported that 75% of their energy use went for space heating and 25% for electricity.

Biomass is a clean energy fuel for Wisconsin and the Midwest

- Biomass heating is a proven, viable, low cost and low risk technology.
- There are large amounts of agricultural land available (the north central region of the U.S. produces 49% of the country's biomass) and there are a number of industrial and institutional facilities that could be easily converted from fossil fuels to biomass at relatively low cost.
- Biomass makes up the vast majority of our renewable energy (47%) – far more than wind (2.3%) or solar (1.0%)

The most economical and efficient use for biomass is heating and CHP

- Biomass for heat (direct combustion) or combined heat and power (CHP, also called co-generation) is far more efficient than co-firing for electricity. CHP recovers heat that normally is wasted in an electricity generator and generates less pollution that electrical generation alone.
- Supporting a diverse market (many community scale facilities heating with biomass) will create more competition on the demand side for biomass. More demand will likely create more options and higher margins for growers than focusing biomass on electrical generation alone.

Switchgrass is a model energy crop

- Switchgrass is perennial plant native to Wisconsin. It is deeply rooted, and helps conserve soil and protect water quality. It sequesters large amounts of carbon in its extensive root system that remains buried after harvest. It has been shown to offer many wildlife advantages and provides excellent nesting cover for migratory birds.
- Switchgrass has been identified as a model energy crop and Wisconsin and the upper Midwest are prime candidates for the development of a commercialized grass based pellet bioheat industry.

- It can be grown in mixtures with other grasses, legumes and forbs. It can be grown with conventional farming practices and equipment. It is less risky than other energy crops as it can be used as biomass for fuel or as forage for livestock.

Switchgrass grown for energy on marginal land could prove profitable

- Sharply higher grain prices are leading to rapid conversion of CRP and environmentally-sensitive land.
- Although the short-term economics of converting CRP land to corn appear compelling (compared to $60-$90 CRP payments) the long-term prospects are not.
- Growing switchgrass for energy on marginal land can provide a sustainable profit equal to or exceeding the profit of corn grown on similar land.
- Grasses grown for energy on marginal land reduce soil loss by 94%. Phosphorus runoff is similarly reduced.

Feasibility study shows promising results

- For the four businesses studied, switchgrass reduced heating costs by an average of 42%.
- Switchgrass was produced in Wisconsin for $50.06/ton baled assuming $100/acre land rent and 5 ton/acre production. Switchgrass pellets can be produced for $107-154/ton depending on the output of the pellet plant.
- Costs for a large (150,000 ton per year) switchgrass pellet mill ($8.65 million) were reported to be less than half that of that for a wood pellet mill ($28.7 million). A wood pellet mill requires more capital costs to chip, separate and dry the green wood. Efficiency is maximized when pellet plants produce more than 10 tons of pellets per hour.
- A full life cycle accounting of cropping systems shows the global warming benefit of converting marginal acres to switchgrass. Converting one acre of corn to switchgrass reduces CO_2 by 1.32 MT/year, an amount equal to removing 2.4 cars off the road.
- The study found that 100,000 marginal acres (highly erodible and environmentally sensitive) could realistically be converted to native grasses and provide 500,000 tons of pellets. The global warming benefit of converting these 100,000 acres to switchgrass (because of sequestration and lower inputs) would be equivalent to removing 240,000 cars from the road for one year.
- This volume of biomass represents $70 million of farmer grown energy and would replace an estimated $72 –174 million dollars now exported for oil, natural gas and LP.
- The money retained in the state would produce new jobs, new farm profits and new clean energy business enterprises.

Recommendations

Biomass heating is a proven and readily adopted technology. But farmers aren't likely to grow biomass crops without a known market (the proverbial chicken and egg dilemma) and commercial businesses aren't likely to choose biomass as a fuel source if it isn't cost effective and reliable. Action by the state, in the short term, could bridge this divide and help grow the biomass market.

Although biomass is renewable, technologies differ as to how green they are. In our view the wisest course is to promote biomass crops that are native, perennial and sustainable and fit into our existing farming practices and equipment. We also urge prioritizing biomass technologies that offer the highest efficiency (net energy per acre) and maximize global warming mitigation potential.

We recommend the following steps be taken to create a sustainable biomass market for Wisconsin and the upper Midwest.

Biomass Energy Reserve Program (Supply)

Create an energy crop reserve program that can develop a feedstock supply chain. Incentivize growing perennial grasses for energy to help reduce risk for farmers. Provide a 50:50 match to federal dollars via the federal Biomass Energy Program and use new Farm Bill incentives.

Provide grants and loans for equipment needed to improve the efficiency of harvesting, processing and storing biomass.

Leverage state investments by seeking federal matching funds for numerous projects. Contract with regional development agencies to provide grant and project planning and preparation assistance for multiple projects.

Explore new incentives in the 2008 Farm Bill that can help build a Biomass Energy Reserve Program. The Rural Energy for America Program can help establish new boilers and new pellet manufacture plants. The Biomass Crop Assistance Program can help establish new switchgrass crops and delivery infrastructure. The Rural Repowering program will aid conversion of larger scale fossil fuel boilers.

Biomass Heating Program (Demand)

The state could save money and build demand for biomass by converting existing state-owned boilers to biomass. This would expand current biomass fuel supply companies and spur additional investment. Focus on University facilities, state and municipal office buildings and interested rural businesses and industries. Such a program could assist Act 141, which calls for state agencies to purchase renewable energy. Biomass heating would assist the Governor's Doyle's plans for: 25% renewable energy by 2025, creation of energy independent communities, and his call for four Universities (River Falls, Oshkosh, Stevens Point and Green Bay) to get off the grid.

The state could also assist interested corn ethanol plants in converting fossil fuel boilers to biomass.

The one value of biomass heating is that it can be done now – it doesn't have to wait for new research or technology. When cellulosic ethanol (or more advanced fuel technology) becomes viable, Wisconsin will be farther ahead having already taken steps to develop, improve and overcome logistics associated with developing a feedstock supply chain and nurturing a biomass heating market

Develop a Wisconsin Fuels for Schools Program

Fuels for Schools programs help reduce energy costs for schools and strengthen locally grown energy. Currently there are seven states with such programs in place and Wisconsin has 11 schools that are leading the way, heating with wood chips, wood pellets or corn. We recommend a goal of converting 50 additional schools to biomass in five years.

A recent report showed that as many as 25% of Wisconsin schools could save money from switching from natural gas or oil to wood. The study also found that biomass systems reduced energy costs by 29 percent to 57 percent compared to natural gas, saving each school between $30,000 and $80,000 annually, depending on current fuel prices. Savings over the life of the system (30 years) were shown between $525,000 to $1.5 million compared to natural gas systems.

Additional Applied Research

Conduct additional applied research to improve the efficiency and reduce costs of feedstock delivery. Measure the environmental performance of biomass feedstock and evaluate the impacts of biomass on global warming pollution and on soil, air, water quality and wildlife habitat. Recommend measures to improve feasibility and sustainability.

To continue to build public acceptance any state promotion of biomass must pay close attention to air quality issues and incorporate pollution control options as needed.

Conduct a statewide assessment of the amount of biomass that can be harvested sustainably. Compare the economic impacts of current biomass technologies.

Create a Biomass Task Force

Create a task force to establish biomass performance standards, monitor industry progress and to identify policies to support development of a sustainable feedstock supply chain and the expansion of a biomass heating industry.

Establish biomass energy performance standards based on the amount of net energy produced, global warming mitigation potential (CO_2 eq) and other public policy conservation goals.

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End Notes

1 Repowering the Midwest: The Clean Energy Plan for the Heartland. See Chapter 5.3 Biomass Energy

2 Wisconsin along with 26 other states have adopted renewable portfolio standards, mandating electricity supply companies to produce a specified fraction of their electricity from renewable energy sources.

3 http://uspowerpartners.org/Topics/SECTION1Topic-Cogen_CHP.htm

4 http://uspowerpartners.org/Topics/SECTION1Topic-Cogen_CHP.htm

5 http://www.grassbioenergy.org/

6 http://www.depweb.state.pa.us/news/cwp/view.asp?Q=513236&A=3

7 http://www.fcpp.org/images/publications/070ConversationfromtheFrontierRogerSamsonformatted.pdf

8 unpublished white paper by VA Tech's Vic Fisher; http://www.washingtonpost.com/wp-dyn/content/article/2007/09/05/AR2007090502327_2.html

9 Note: CRP data from FSA http://content.fsa.usda.gov/crpstorpt/rmepeii_r1/WI.HTM

It is generally anticipated that Wisconsin will see fairly radical reductions in CRP as farmers respond to the high grain prices. An April 9, 2008 NY Times report, "As Prices Rise, Farmers Spurn Conservation Program" noted that farmers across the nationa are plowing up CRP to plant grain crops. "Environmental and hunting groups are warning that years of progress could soon be lost, particularly with the native prairie in the Upper Midwest. Conservation groups are concerned about the three-quarters of a million acres of grassland that were removed from the program last year in the so-called duck factory in the Upper Midwest. "We foresee a dramatic reduction," said Mr. Ringelman, a conservation director for Ducks Unlimited."

10 Hag, Zia. "Biomass for Electricity Generation," Energy Information Administration.

11 Perennial Bioenergy Feedstock Report to House Agriculture Committee, Great Plains Institute, April 2007

12 http://uspowerpartners.org/Topics/SECTION1Topic-Cogen_CHP.htm

13 On March 7, 2008, Professor Phil Robertson, MSU, a key researcher in the newly created Great Lakes Bioenergy Research Center gave a lecture titled "Biofuels Sustainability: A Biogeochemical Challenge." In his talk he warned that "biomass is a win win but only if done right and there are lots of opportunities for doing it wrong… It is imperative that we be aware of the pitfalls."

14 USDA Censnus of Agriculture, 2002

15 Data produced by the Dane County Land Conservation Department

16 Estimate of marginal lands assumes enrolled CRP acres are marginal land

17 Dr. Mike Casler is a grass breeder (USDA-ARS, U.S. Dairy Forage Research Center, Madison). It is suggested he be contacted regarding suggestions on cultivars or varieties best adapted to Wisconsin that will likely provide the best fuel quality (ash, alkali content etc.)

18 For Fertilizer levels see: Costs of Producing Switchgrass for Biomass in Southern Iowa by Duffy and Nanhou; Management Guide for Biomass Feedstock Production in the Northern Great Plains and Management Guide for the Production of Switchgrass for Biomass Fuel in Southern Iowa by Alan Teel)

19 UW Center for Dairy Profitability: draft/unpublished enterprise switchgrass budget prepared by UWEX's Ken Barnett and shared with this study.

20 Personal communication, T.J. Morice, Marth Wood Products. April 11, 2008

21 Wood Pellet Manufacturers and Suppliers Active In Wisconsin. Focus on Energy. 2008. REN 6043-011808

22 http://www.sawyercountydevelopment.org/downloads/Pellet%20plant.pdf

23 Pellet mill costs and investment costs per ton provided by Pellet-Ex Corporation http://www.pelletex.com/

Appendix 1

Marginal Land in Dane County

Township	Corn & Soybeans	Pasture	HEL Land	Corn & Soybeans on HEL	Corn & Soybeans on HEL	Corn & Soybeans on WQMAs	WQMA	WQMA in Corn & Soybeans	Warm Season Grasses
	acres	acres	acres	acres	%	acres	acres	%	acres
Albion	11,857	4,753	3,841	1,638	42.6%	1,453	5,394	26.9%	126
Berry	4,720	5,070	15,655	2,485	15.9%	1,480	6,833	21.7%	295
Black Earth	6,967	3,929	9,343	1,241	13.3%	1,635	4,600	35.5%	82
Blooming Grove	1,568	4,948	3,318	267	8.1%	144	5,442	2.6%	3
Blue Mounds	2,749	8,054	15,411	1,901	12.3%	359	5,847	6.1%	452
Bristol	11,861	4,853	2,275	949	41.7%	2,190	4,712	46.5%	38
Burke	3,537	7,653	3,542	333	9.4%	458	5,489	8.3%	0
Christiana	11,916	4,727	4,790	1,786	37.3%	1,841	5,634	32.7%	106
Cottage Grove	6,956	7,720	5,131	1,169	22.8%	1,423	6,524	21.8%	88
Cross Plains	6,239	5,384	15,103	3,357	22.2%	1,630	6,159	26.5%	105
Dane	8,724	3,672	10,893	2,862	26.3%	1,678	5,069	33.1%	106
Deerfield	8,656	5,185	5,660	1,484	26.2%	1,209	4,912	24.6%	264
Dunkirk	12,038	3,932	4,728	1,930	40.8%	1,500	5,001	30.0%	77
Dunn	5,520	5,241	6,050	1,560	25.8%	633	5,395	11.7%	138
Fitchburg	8,040	5,125	8,322	2,119	25.5%	870	4,327	20.1%	74
Madison	4	460	3,455	0	0.0%	0	4,824	0.0%	0
Mazomanie	1,979	1,716	931	30	3.3%	492	3,100	15.9%	45
Medina	8,551	5,781	6,049	1,929	31.9%	1,969	6,670	29.5%	249
Middleton	2,847	7,039	10,335	1,143	11.1%	440	4,700	9.4%	18
Montrose	6,409	7,076	10,098	1,893	18.8%	1,765	6,947	25.4%	114
Oregon	8,735	6,778	7,610	1,660	21.8%	1,532	4,376	35.0%	102
Perry	2,646	10,803	18,214	2,162	11.9%	348	6,410	5.4%	527
Pleasant Springs	9,934	4,894	5,168	1,963	38.0%	1,364	5,066	26.9%	25
Primrose	5,223	8,399	14,550	2,473	17.0%	1,446	6,421	22.5%	126
Roxbury	5,952	3,794	12,941	2,562	19.8%	2,984	11,165	26.7%	5
Rutland	9,951	7,090	4,985	1,518	30.4%	1,619	5,730	28.2%	44
Springdale	4,540	8,755	18,082	3,472	19.2%	772	5,466	14.1%	625
Springfield	8,699	4,173	10,245	2,741	26.8%	2,226	6,506	34.2%	38
Sun Prairie	9,968	4,994	3,092	984	31.8%	1,617	4,797	33.7%	18
Vermont	1,869	5,327	16,628	1,289	7.8%	283	5,685	5.0%	401
Verona	4,846	7,928	12,761	2,287	17.9%	1,446	8,240	17.6%	169
Vienna	11,564	3,722	6,896	3,084	44.7%	931	2,107	44.2%	10
Westport	6,321	5,158	5,377	1,549	28.8%	672	6,148	10.9%	5
Windsor	9,636	4,923	3,114	1,097	35.2%	1,135	4,772	23.8%	8
York	12,042	4,534	3,224	1,407	43.6%	1,778	4,860	36.6%	61
TOTAL	**243,063**	**193,589**	**287,814**	**60,323**	**23.7%**	**43,321**		**22.7%**	**4,544**

** Pasture etc. includes: pasture, non-ag., range, waste, farmstead

HEL (highly erodible land) is from soil data and includes both HEL and PHEL (potentially highly erodible) lands.

Cropland data (corn, soybeans, alfalfa, pasture) from NASS 2006 data.

WQMAs (Water Quality Management Areas) are defined as areas 300' from stream or 1000' from lake.

Warm Season Grasses from Dane Co. Land Conservation Division CTS database (practice codes = 327E, 327W, 327Y, 393P, 393Q, 643Y, 645U)

Appendices

Appendix 2.

Chemical Characteristics of Switchgrass (1 of 2)

Fuel Property	Units	Switchgrass	Switchgrass	Switchgrass, Blackwell	Switchgrass
Cite:		Samson et al (2005)	Samson et al (2005)	DOE Biomass Feedstock Composition Database (2007)	Wright et al., (2006)
Dry Matter	%				
Energy	units	18.2 – 18.6 GJ/MT (7961 BTU/t)	19.1 GJ/MT (8219 BTU/t)		18.3 GJ/t (7875 BTU/t)
Moisture	%				
Ash	%	4.5-5.2	2.0-3.2	5.56 (Cave in Rock) 6.42 (Blackwell)	4.5-5.8
Ash fusion temperatures	degrees Celcius				1016.00
Storage Density	kg/m3				
baled					
chopped					
chips					
pelleted					
Nitrogen (N)	%	0.46	0.33		
Calcium (Ca)	%				
Potassium (K)	%	0.95	0.06		
Chlorine (Cl)	%				
Sulfur (S)	%				0.12

Appendix 2.
Chemical Characteristics of Switchgrass (2 of 2)

Fuel Property	Units	Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass
Cite:		Phyllis Database, Energy Research Centre of the Neth-erlands)	MGE	McLaugh-lin et al., (1996)	Dayton et al., (1995)	EIA Annual Outlook 2006 DOE/EIA-0383 (2006)
Dry Matter	%					
Enegy	units	18024 kj/kg HHV/16767 kj/kg LHV	17380 kj/kg HHV	17.4 MBTU/MG-1 (7474 BTU/t)		7341 BTU/lb
Moisture	%		5.85	15.00	8.16	
Ash	%	10.10	4.59	4.5-5.8	4.59	
Ash fusion temperatures	degrees Celcius			1,016		
Storage Density	kg/m3					
baled				133 (6x5' round bale); 105 (4x5' round bale)		
chopped				108		
chips						
pelleted						
Nitrogen (N)	%					
Calcium (Ca)	%					
Potassium (K)	%					
Chlorine (Cl)	%		0.11			
Sulfur (S)	%	1.9 (SO3)	0.08	0.12		

Appendix 3.

Boiler Manufacturers: Greater than 1 million BTU (1 of 2)

Company Name	Heating Capacity BTU/hr		Heating Process		Heat Delivery				Installation		Intended Application								
	Smallest	Largest	Direct Combustion	Gasification	Space Heating (stove)	Central Hot Air	Central Hot Water	Central Steam	Indoor	Outdoor	Residential	Farm Shops	Garages	Warehouses	Livestock/Poultry	Crop Drying	Greenhouses	Indsutrial Applications	Institutions
Advanced Alt. Energy Corp.	100,000	100 million	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AE & E-Von Roll, Inc.			•	•				•	•	•						•		•	•
Alternative Green Energy	10 million	200,000	•			•		•										•	
Braymo Energy Corp.	2 million	100 million	•			•	•	•		•				•	•	•	•	•	•
Burns Best	60,000	300 million	•	•					•	•	•	•	•	•	•	•	•	•	•
Chiptec Wood Energy	400,000	70 million		•	•	•	•	•	•			•	•	•	•	•	•	•	•
Detroit Stker Co.	30 million							•										•	•
Energy Products Idaho	20 million	500 million	•	•				•	•	•								•	
Energy Unlimited, Inc.	5 million	100 million	•					•										•	
McBurney Corp.	30 million		•					•										•	
Messersmith Manufacturing	500,000	17 Million	•				•	•	•				•	•			•	•	•
Pro-Fab Industries	100,000	3 million	•				•			•	•	•	•	•	•		•	•	•
Ryte Heating Systems	200,000	2.5 million	•			•	•			•	•	•	•	•	•	•	•	•	•
Sola-Gen Inc.	500,000	100 million				•	•	•	•	•								•	•
Vidir Biomass, Inc.				•		•	•	•			•	•	•	•	•	•	•	•	•
Zilkha Biomass Energy, LLC	3.4 million	34 million	•							•								•	

Citation: Agricultural Utilization Research Institute. www.auri.org

Appendix 3.

Boiler Manufacturers: Greater than 1 million BTU, (2 of 2)

Company Name	Fuels									Fuel Feed Mechanism					Ash Removal		Dual Fuel Option	
	Shelled Corn	Corn Cobs	Crop Residue	Sawdust	Wood Chips	Wood Pellets	Poultry Litter	Straw	Grasses	Gravity	Conveyer	Traveling Grate	Auger	Manual	Automatic	Manual	Yes	No
Advanced Alt. Energy Corp.	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	
AE & E-Von Roll, Inc.	•	•	•		•		•		•			•		•			•	
Alternative green Energy				•	•	•		•		•	•		•		•		•	
Braymo Energy Corp.	•	•	•	•	•	•	•	•	•				•	•	•			•
Burns Best	•		•	•	•	•	•						•		•			•
Chiptec Wood Energy		•	•	•	•	•					•		•	•	•			•
Detroit Stoker Co.	•	•	•	•	•	•	•	•	•		•		•	•	•		•	
Energy Products Idaho	•	•	•	•	•	•	•	•	•									•
Energy Unlimited, Inc.	•	•	•	•			•	•	•					•		•		•
McBurney Corp.	•	•	•	•	•	•	•	•	•				•	•	•	•	•	•
Messersmith Manufacturing				•	•	•				•			•	•	•			•
Pro-Fab Industries	•		•	•	•	•				•			•	•	•	•	•	
Ryte Heating Systems	•		•	•	•	•				•			•		•		•	
Sola-Gen Inc.	•	•	•	•	•	•	•	•	•				•	•	•	•	•	
Vidir Biomass, Inc.			•	•	•	•	•	•	•							•	•	
Zilkha Biomass Energy, LLC	•		•	•	•	•									•		•	

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Appendix 4.

Boiler Manufacturers: Less than 1 Million BTU, (1 of 2)

Company Name	Heating Capacity BTU/hr		Heating Process		Heat Delivery				Installa-tion		Intended Application								
	Smallest	Largest	Direct Combustion	Gasification	Space Heating (stove)	Central Hot Air	Central Hot Water	Central Steam	Indoor	Outdoor	Residential	Farm Shops	Garages	Warehouses	Livestock/Poultry	Crop Drying	Greenhouses	Indsutrial Applications	Institutions
Alpha American Co.	75,000	168,000	•	•		•			•		•	•							
American Energy Systems	12,000	68,000	•		•	•			•		•	•		•			•		•
Big M Manaufacturing	100,000	150,000	•			•	•		•		•	•	•						
Biomass Combustions	450,000	800,000	•	•		•			•					•				•	
Bixby Energy	8,000	60,000	•			•			•		•	•	•						
Central Boiler	50,000	500,000	•	•			•			•	•	•	•	•	•		•		
Dectra Corporation	350,000	1 million		•		•	•		•	•	•	•	•	•			•	•	•
Energy King	30,000	140,000	•			•	•		•		•								
Golden Grain Corn Stoves	40,000	170,000	•			•			•		•	•	•	•	•		•	•	
Grove Wood Heat	100,000	1 million	•	•		•	•		•		•	•	•	•	•	•	•	•	
Hawken Energy	157,000	550,000	•	•		•	•		•	•	•	•	•	•	•	•	•	•	•
Heatmoor	100,000	900,000	•				•			•	•	•	•	•	•		•	•	
Heat Source	100,000		•				•			•	•	•	•	•	•		•	•	
Ja-Ran Enterprises, Inc.	100,000	200,000	•			•			•		•	•	•	•	•	•	•	•	•
LDJ Manufacturing	100,000	165,000				•	•		•		•	•	•	•	•		•	•	•
LMF Manufacturing	100,000	170,000	•		•	•	•		•		•	•	•	•	•	•	•	•	•
L. R. Equipment Corp.		200,000	•			•	•				•	•	•	•	•			•	
Meyer Mfg. Co.	120,000	180,000	•			•			•		•	•	•	•					
Mitchhart Mfg., Inc.	100,000	150,000	•			•	•		•	•	•	•	•	•	•	•	•	•	•
NESCO, Inc.	30,000	70,000			•						•	•					•		
Northwest Mfg.	70,000	210,000	•				•			•	•	•	•	•	•	•	•	•	•
Pinnacle Stove Sales	150,000	400,000				•	•		•	•	•	•	•	•	•		•	•	•
Year-A-Round Corp.	150,000	900,000	•			•	•		•			•	•		•		•	•	•

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Appendix 4.

Boiler Manufacturers: Less than 1 Million BTU, (2 of 2)

Company Name	Fuels										Fuel Feed Mechanism						Ash Removal		Dual Fuel Option	
	Shelled Corn	Corn Cobs	Crop Residue	Sawdust	Wood Chips	Wood Pellets	Wood Logs	Poultry Litter	Straw	Grasses	Gravity	Conveyer	Residential	Traveling Grate	Auger	Manual	Automatic	Manual	Yes	No
Alpha American		•					•				•		•	•				•	•	
American Energy	•				•	•				•	•		•	•		•	•			•
Big M Manufacturing	•					•	•				•		•	•	•		•			•
Biomass Combustions		•		•	•						•					•		•	•	•
Bixby Energy	•					•					•		•	•	•		•			•
Central Boiler	•	•				•						•	•	•	•	•		•	•	
Dectra Corp		•									•	•	•	•	•	•			•	
Energy King	•					•					•		•	•				•		
Golden Grain Corn Stoves	•					•	•				•		•	•	•	•		•		•
Grove Wood Heat, Inc.	•	•		•	•	•		•	•	•	•		•	•	•	•		•		•
Hawken Energy, Inc.		•	•	•	•	•					•	•	•	•	•	•		•		
Heatmor	•	•				•						•	•	•	•	•		•		
Heat Source	•					•						•	•	•	•	•				•
Ja-Ran Enterprises	•										•		•	•	•	•		•		•
LDJ Manufacturing	•					•	•				•		•	•	•	•		•		•
LMF Manufacturing	•					•				•	•		•	•	•	•	•		•	•
L.R. Equipment Co.	•												•	•	•	•		•		•
Meyer Mfg. Co.						•					•		•	•						
Mitchhart Mfg., Inc.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•
NESCO, Inc.	•												•	•				•		•
Northwest Mfg.	•						•					•	•	•	•	•		•		•
Pinnacle Stove Sales	•					•	•			•	•	•	•	•	•	•		•		•
Year-A-Round Corp.	•					•	•				•			•	•			•	•	

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