Sustainable Energy Parks on Mine-Scarred Lands in Appalachia

Market Opportunities for Switchgrass

Prepared for:
West Virginia University, Water Research Institute

Paid for through EPA grant funding - Assistance ID No. TR-83418501-0

MARSHALL UNIVERSITY
CENTER FOR BUSINESS AND ECONOMIC RESEARCH

Sustainable Energy Parks on Mine-Scarred Lands in Appalachia

Market Opportunities for Switchgrass

Authors:

Principal Investigator:

Christine Risch

Researchers:

Emily Hagan
Kyle Adkins (graduate assistant)

Center for Business and Economic Research
Marshall University
One John Marshall Drive
Huntington, WV 25755

Phone: (304) 696-2313 • Fax: (304) 696-6088

Acknowledgements:

This report was supported by West Virginia University's Water Research Institute, with funding by the U.S. Environmental Protection Agency.

Disclaimer:

Table of Contents

Table of Tables

Table of Figures

Introduction

Biomass is an underutilized energy resource throughout the U.S. and one that could contribute toward meeting societal goals of ecological sustainability and increased energy independence. Several years ago, federal employees and their contractors developed a plan to expand use of biomass resources that came to be termed "The Billion Ton Vision." The joint U.S. Department of Energy and U.S. Department of Agriculture vision entails a shift in natural resource production that creates an expanded market for biomass products. To accomplish this expansion land use change is expected to result from conversion of cropland, idle cropland and pasture cropland to production of perennial crops such as switchgrass or hybrid poplar (U.S. Department of Energy and U.S. Department of Agriculture 2005). A less evaluated land use change is conversion of former surface-mined lands to perennial crop production.

At the core of motivation to establish supply of biomass for use in production of heat, electricity and transportation fuel is its short time availability compared to fossil fuels. Biomass is renewable and sustainable as its growth is based on solar energy, while fossil fuels took millions of years to appear. A transition to sustainable fuel supply will eventually be mandatory.

One way to expand demand for biomass is through policy. The Energy Information Administration (EIA) has projected that under a 15 percent national renewable energy standard wood and other forms of biomass will comprise the largest share of electricity generated by renewable resources. Under such a scenario the EIA's projection is that by 2030 biomass used for energy production would be triple its 2007 levels. This conclusion is based on the quantity of biomass resources available and includes biomass both from dedicated biomass plants and existing coal plants co-firing with biomass fuel (Energy Information Administration 2007).

Switchgrass is a perennial energy crop that is a much less used type of biomass compared to wood-based biomass. Switchgrass is often selected as the crop of choice for many reasons. It is hardy and can grow in adverse conditions. It requires relatively little nitrogen enrichment or fertilizer, can be harvested more than once a year and only needs replanting once every ten years. Switchgrass also has the secondary benefits of natural soil carbon sequestration, the ability to absorb pollutants in the local watershed, and can provide the soil with a barrier to erosion and nutrient depletion. Because of these features, its production is a closed-loop system, meaning that any carbon emitted through burning it will be offset by what it absorbs via photosynthesis.

Overall benefits to a rural community of producing switchgrass are increased economic activity, improved air quality through carbon sequestration, improved water quality through nutrient absorption and land reclamation through soil build up. If reasonable yield can be established it is also a good use of low cost marginal land. In West Virginia, former surface-mined land is abundant and has limited alternative uses after mining is complete.

Summary of Findings

There are three opportunities to use switchgrass in energy conversion systems: 1) co-firing with coal in power plants, 2) as the feedstock for cellulosic ethanol production and 3) as a material for stove pellets. None of these potential markets are presently commercial, although substantial efforts have been made to establish co-firing in the region using various forms of biomass. Environmental policy decisions made in the next several months will greatly influence the level of opportunity in the co-firing market. Uncertainty regarding the potential future regulation is presently suppressing utility interest in expanding use of biomass.

In terms of potential volume the best regional market opportunity is in co-firing with coal in power plants. American Electric Power-Ohio is currently capable of utilizing up to ten percent biomass in several coal-fired power plants. Through this research it has been made clear that in spite of a large request for proposal issued by AEP in 2010 there are presently no stable markets for switchgrass in the region. Some of the reasons for lack of market are due to the physical properties of switchgrass and its uncompetitive production costs. The cost of getting switchgrass to market is a large barrier to taking advantage of this potential market. Material handling is an additional barrier to intensive use that has been only partially addressed by the industry.

Other regional utilities have taken a similar route. Ohio Edison/First Energy announced in November 2010 that they were going to close their R.E. Burger coal-fired plant instead of converting it to operate on biomass. The utility had planned to convert the facility to co-fire using a blend of coal and mixed biomass, including energy crops, and to get up to 100 percent biomass within a couple years. The announcement was made to close the plant by December 31, 2010 in order to comply with an original EPA order to either close, repower or retrofit. The firm cited low power prices as the reason for deciding not to invest in retrofitting the plant to burn biomass (PRNewswire 2010).

In the electricity market biomass must compete with wind power because renewable portfolio standards do not contain a biomass mandate. Although wind and closed-loop biomass systems are both eligible for the same production tax credit of $22/MWh, wind is a resource with extremely low operating costs. While regional firms have demonstrated the ability to deliver a switchgrass product to a power plant for a price a utility is willing to pay, the material properties of the products have not been ideal and the long-term proposed prices have not been competitive. Utilities must still seek the energy that can be procured at the lowest cost to their customers or risk being unable to fully recover costs.

The markets for cellulosic ethanol and stove pellets are addressed in less detail here as they are seen as being further from feasible. Although it is the best near-term option to produce sustainable transportation fuel, the cellulosic ethanol market has not progressed beyond the pilot stage and that pilot is not in the region. A market for grass stove pellets does not exist in the area, and grass pellets are primarily being promoted in more agricultural areas of North America.

Emerging Market Opportunities for Switchgrass

Biomass co-firing

Co-firing involves replacing coal with biomass in an existing power plant, blended with coal or alone, usually with only minor changes to generating equipment. Compared to the coal it replaces, biomass reduces sulphur dioxide (SO_2), nitrogen oxides (NO_x) and other air emissions and there is little or no loss in efficiency from adding biomass (U.S. Department of Energy 2006). Assuming a large scale power plant uses a 5:1 to 6:1 ratio of coal to biomass fuel the CO_2 saving will be over 100,000 tons/year and the SO_2 savings will be greater than 1,700 tons/year (Federal Energy Management Program 2004).

A primary benefit to using biomass for power generation is that it provides base load power. This is a significant feature in the renewable arena, as wind and solar energy are both intermittent and can only generate power when available. By contrast, biomass is stored and is fed into a power plant as needed, just like coal.

The Chariton Valley Biomass Co-firing project is a switchgrass co-firing project at the Ottumwa Generating plant in Iowa. That project has been in the works following an initial feasibility study in 1996 (Prairie Lands Biomass Project 2010). It is still not fully commercial but is moving in that direction. That project was developed under the Biomass Power for Rural Development, a joint USDA and DOE solicitation and by the Chariton Valley Resource Conservation and Development, a rural development non-profit. Motivation for the project was to expand the market for farmers in southern Iowa and to induce new use for land in the Conservation Reserve Program, the purpose of which is to reduce soil erosion through grass planting (Cooper, Braster and Woolsey 1998).

Other biomass co-firing and straight switchgrass firing tests have been conducted in Vermont. Tests comparing switchgrass to reed canary grass and mulch hay found that switchgrass had the lowest ash content, NO_x emission and particulate emissions of the three (Vermont Grass Energy Partnership 2011). However, compared to wood, it was found that switchgrass has higher emissions. While superior for actual emissions per unit, wood-derived fuels are usually open-loop systems and thus do not have the benefit of net-zero lifecycle carbon emissions.

The regional market for biomass for co-firing in coal-fired power plants has been stalled in recent months. There are several reasons but the most important is the inability of the fuel to compete with wind. As a follow-up to a Request-For-Proposals (RFP) issued in February 2010, American Electric Power has done co-firing tests with 100 percent switchgrass grass pellets and pellets pre-blended with coal. Pre-blended pellets have emerged as the preferred fuel, but the cost of the fuel to date has prevented AEP from considering long-term use at this time or entering into a term deal with a biomass supplier as originally requested in the RFP (American Electric Power 2010). Table 1 summarizes AEP's stated plant-level biomass capabilities.

Table 1: AEP Biomass Supply Specifications by Plant (as of February 2010)

Plant	Megawatt Capacity	Maximum Chip Mesh Screen Size	Maximum Pellet Size (Inches)	Maximum Biomass Blend (%)	Acceptable Transportation
Picway	100 MW	3	2 in.	10%	Truck
Muskingum 1,2,5	1425 MW	6	2 in.	4%	Truck, Rail
Muskingum 3,4	Included with plants 1,2,5	4	2 in.	10%	Truck, Rail
Conesville	1300 MW	6	2 in.	4%	Truck, Rail
Gavin	2600 MW	6	2 in.	4%	Barge
Cardinal	600 MW	6	2 in.	4%	Barge, Truck, Rail

(American Electric Power 2010).

Of these plants, the Gavin and Cardinal plants are probably the most cost-effective for receiving biomass produced in West Virginia because of their location. Both plants are located on the Ohio River and utilize barge delivery. Both plants also consume substantial quantities of coal produced in West Virginia, so there are existing contracts in place that could be modified or renewed to include biomass. In addition, both plants also consume some quantity of Wyoming coal which has lower energy content and are thus accustomed to using fuels with varying energy value. Table 2 provides a summary of 2010 coal consumption for these plants, including the Muskingum plant as it uses West Virginia coal although it does not accept barge deliveries.

Table 2: Coal Consumption by AEP's Cardinal, Gavin & Muskingum Plants in 2010, by Source & Grade

COAL SOURCE	Cardinal		General Gavin		Muskingum	
	Tons	mmbtu /Ton	Tons	Mmbtu /Ton	Tons	mmbtu /Ton
Colombia	164,664	23.73				
Kentucky	53,057	23.90	61,316	23.78		
Ohio	2,175,651	24.30	2,011,665	24.34	989,431	21.08
Pennsylvania					63,006	26.23
West Virginia	1,255,403	23.83	4,146,377	24.63	1,837,891	24.68
Wyoming	216,550	17.66	1,577,424	17.51		
Other	59,992	Na	40,023	na	28,403	na
TOTAL	**3,925,317**		**7,836,805**		**2,918,731**	

(US EIA 2011).

Forces Impacting the Co-Firing Market

Utilities make fuel purchase decisions based on their fleet of generating equipment and federal regulations regarding emissions and use of renewables. Co-firing choices are affected by all three of these factors. Renewable fuel mandates have spurred widespread use of wind energy, fueled by the low cost of that resource. Compared to wind, biomass requires an extensive series of steps to produce, transport and handle the fuel, making its use much more complex and more expensive.

AEP has stated that they need to obtain biomass within the price range of $6.5 to $7/mmbtu to be competitive with purchasing renewable energy credits in the market. The utility also stated that long-term prices proposed to them have been in the range of $8 to $10/mmbtu for biomass.

Biomass Form and Handling

Co-firing with switchgrass pellets has been tested fairly extensively by AEP-Ohio in 2009 and 2010. The utility has tested wood chips of various varieties as well as switchgrass pellets and powder in its plants. Regional power plants are not set up to handle bales of grass (American Electric Power 2010), as the Chariton Valley co-firing project in Iowa does, so biomass must be received as pellets or powder. The Chariton Valley co-firing project switchgrass bales to dust at the Ottumwa power plant after which it is blown into the furnace along with coal (Prairie Lands Biomass Project 2010).

At the plant level, uncertainties exist with regard to the level of emissions that would result from using various types of biomass and impacts on on-site air quality issues. In spite of observations that many forms of biomass reduce NOx emissions relative to coal, AEP maintains concern regarding the ultimate level of NOx emissions. Compared to other types of emissions the change in NOx output is more uncertain as it is based on temperature and moisture, so it is harder to predict what will actually be emitted (American Electric Power 2010).

In terms of material handling, plant on-site grinding equipment does not work as well with biomass compared to coal as it grinds less uniformly. AEP also states that there were issues with some forms of switchgrass as some pellets turned to dust easily, causing concern with potentially violating on-site air permit conditions. Conversely, some pellets would not grind and jammed plant equipment.

Biomass ground to 35-mesh powder has a btu value similar to pelleted biomass. Delivery in this form would avoid the cost of pelletizing, but is not expected to be an ideal product. According to AEP, biomass powder did perform better in the plant, but there were still issues with dust control (American Electric Power 2010).

There is also a storage issue with biomass that expands if it gets wet, as occurs with wood stove pellets. Any special storage required on-site at a power plant would also add costs, decreasing ability to compete with wind.

The following quote from a utility engineering blog illustrates the primary issues with co-firing from a plant perspective. "In most of our applications it is more expensive to co-fire biomass. An exception to this might be very low cost sander dust or sawdust mixed at the coal pile. With direct injection of biomass, our system pays an efficiency penalty for introducing cold transport air into the furnace" (Segrest et al 2003).

Due to handling issues, separate injection of the biomass material may be best as that would allow the plant more control of the biomass burn rate. It would also allow more flexibility with regard to the types of biomass used as long as it is of the right size. On the other hand, separate injection has its own efficiency problems as noted above.

Torrefaction is a newer method of preparing biomass for co-firing that is receiving increased attention. The University of Leeds describes the process as "pre-roasting" as the plant matter heated to around 300 degrees centigrade prior to delivery. This process makes the biomass drier with more energy value per ton, and thus much cheaper to transport and more efficient to grind (E-Energy Market 2011). According to Leeds, torrefied biomass also has a longer shelf life which makes it a more desirable substitute for coal.

AEP is investigating the potential to use torrefied biomass and is open to testing in this form. The utility finds the product additionally attractive because it may be able to withstand getting wet, something conventional pellets and unprocessed biomass can't handle very well. Currently, the cost of torrefaction is believed to be prohibitive and has been estimated at $120 per ton (Lowe, President - Midwestern Biofuels 2011).

As shown in Table 2, West Virginia coal producers are already significant suppliers to two biomass-capable plants in the AEP system. Leveraging an existing long-term power plant supply contract would be an ideal way to develop biomass delivery for co-firing, no matter what form is used. Inclusion of biomass could allow extension of an existing contract with a blended product of the ground biomass and coal. It would also be advantageous to develop a set of biomass suppliers with some redundancy to make up for any yield shortages. Suppliers could provide multiple types of biomass including grass bales, wood residue and whole trees.

Cost of Production

Sustainable supply with a competitive long-term price is the key for potential biomass users, something that is not available right now. Costs will probably decline as yield and supply increase, but this is not yet a reality.

Switchgrass production costs are the largest component of the cost of delivering switchgrass to a power plant. Variation in estimated costs by state and region is typically found largely in land rents, which represent the opportunity cost of using the land for other purposes. This cost can be quite large if energy crops displace row crops (Jain et al, 2010). For former surface-mined land which has no agricultural value rents will be significantly lower. If decent yield can be established there will be minimal competing uses for many of these sites in West Virginia.

The West Virginia Governor's Task Force on Co-Firing concluded that in order to be economically viable, biomass must cost less than half as much as coal (State of West Virginia 2000). With calculated production costs between $40 and $50 per ton, the industry is far from that cost, as minemouth coal prices peaked at around $37 per ton in 2009 (US EIA 2011). More detail regarding production costs is examined in a separate section.

MACT

An important coincident issue impacting utility co-firing decisions is new EPA regulation regarding use of Maximum Achievable Control Technology (MACT) when using biomass in boilers. The MACT rule is derived from legislation created in the Clean Air Act of 1990. The specific section of the Act in question is section 112(j) that asserts when there is no national standard for air pollution that states must create case by case standards. The MACT rule was established in 1994 and has been updated in 1999, 2001, 2002, 2003 and most recently last year. The rule was designed by the EPA to enhance the health of areas near incineration facilities (Environmental Protection Agency 2011).

The most recent MACT amendment sets stricter policy on the amount of mercury, hydrogen chloride, particulate matter, carbon monoxide and dioxin that can be emitted from a boiler facility. The rule would reduce these emissions by approximately 50 percent. The EPA estimates the health benefits from the new rule would save between $18 and $44 billion in annual health costs in the United States (Environmental Protection Agency 2011). Biomass has been able to evade these standards previously because of its classification as a "multi-fuel" boiler which as a technology emits a lower percentage of these harmful byproducts then traditional incinerators. The new rule would bring some biomass boilers into the emission control requirements by changing their classification from "multi-fuel" to incinerators.

The Biomass Power Association had stated that it believes that if the biomass industry were included in these new emission regulations, that the cost to the industry through refitting boilers and updating technologies using MACT would be in excess of $7 billion and would have a dire effect on the biomass industry as a whole (Gibson 2010). The EPA disagreed with the BPA and estimates the cost of conversions using MACT to be closer to $3.6 billion rather than $7 billion (Environmental Protection Agency 2011).

The latest and final version of the EPA rule is titled the National Emission Standard for Hazardous Air Pollutants (NESHAP) for Industrial, Commercial and Institutional Boilers and Process Heaters and was published on March 21, 2011. Biomass is included as a fuel subcategory that is subject to the rule. It is expected to have the most impact on coal and biomass-fired boilers because natural-gas fired boilers must only conduct an annual tune-up to be in compliance (Burns & McDonnell 2011). In addition, uncertainty still exists because the EPA included a notice of reconsideration when the rule was published, meaning that the EPA will seek public comment on some issues and may reconsider their application. In terms of switchgrass use, the most important reconsideration applies to the establishment of standards for biomass and oil-fired area source boilers based on generally available control technology (Ballard Spahr, LLP 2011). Thus, biomass-fired boilers may not have to use maximum available control technology and may instead be able to use generally available technology that would substantially lower the cost of compliance.

The EPA is quoted as saying that ".. the final rule does provide some good incentives for coal to look at co-firing with biomass as part of a less-expensive compliance strategy." In the final rule coal and biomass boilers are combined into one solid fuel category, which will give biomass boilers more flexibility to burn various types of biomass (Gibson, MACT Madness 2011). This is expected to impact large biomass boilers favorably compared to the previously proposed version of the rule, although the actual requirement has not been set.

Renewable Energy Credits

Renewable Energy Credits (RECs) are environmental commodities which represent the generation of one megawatt-hour (MWh) of electricity through a renewable energy source (Berkshire Photovoltaic Services 2010). Also known as Renewable Energy Certificates or green tags, RECs generated by a renewable energy provider can be sold or traded either directly or through the REC market. As 27 states and D.C. get closer to full implementation of Renewable Portfolio Standards (RPS), which require a portion of electricity generated to come from renewable sources, the production and acquisition of RECs will become more important. Four other states have implemented an alternative energy portfolio standard (AEPS), of which some have separate renewable mandates.

There are both voluntary and mandatory (compliance) REC markets. The voluntary REC market takes place when RECs are purchased out of choice rather than regulation. The compliance REC market is driven by state statute or regulation. Utilities can obtain RECs by owning a qualifying renewable energy facility, by purchasing RECs as part of a power purchase agreement or by purchasing RECs separately (unbundled), either directly from a renewable energy generator or in the market (Pew Center on Global Climate Change 2011).

The fact that electric utilities in RPS states can buy RECs to meet the RPS requirement is a significant feature of compliance that greatly impacts a utility's interest in co-firing. A benefit of purchasing RECs is that they can be resold if desired, as long as the credits are sold separately. RECs are environmental attributes and while attached to actual generation can be sold separate from energy. This makes purchasing RECs potentially more advantageous for a utility than generating its own renewable energy.

The price of RECs is area-specific and varies dependent on the availability of renewable resources in market boundaries and the level of state standards needing to be met. In some states REC prices may be close to the alternative compliance payment rate, but when a new generator becomes available prices fall. Expectations that energy efficiency credits, also known as "white tags," will make up an increasing share of RPS compliance may depress future REC prices (SNL Financial 2010).

Recent national REC prices ranged from $5 per MWh to $56 per MWh with an average REC price of $19.88 per MWh (The Green Power Network 2010). The renewable resources used to generate the RECs to calculate these prices included the following resources in whole or combination: solar, wind, biogas, biomass, geothermal, hydro and landfill gas. Five prices made reference to solely wind while another 12 were generated solely from new wind. One instance each mentioned solar and new solar for generation source, while one REC generator used solely new biogas. REC prices are dominated by wind.

A study released by the Energy Information Administration (EIA) reported that the market value for RECs between 2020 and 2030 would be approximately $19 per MWh (in 2005 dollars), stating that this would be the purchase price of RECs from the federal government (Energy Information Administration 2007). In 2011 prices, $19 is equal to nearly $22. Thus, with an energy value of 3.412 mmbtu per MWh, a $22/MWh REC equates to $6.45 per mmbtu. As AEP says they do not want to pay more than $6.5/mmbtu, this value is clearly tied to REC prices.

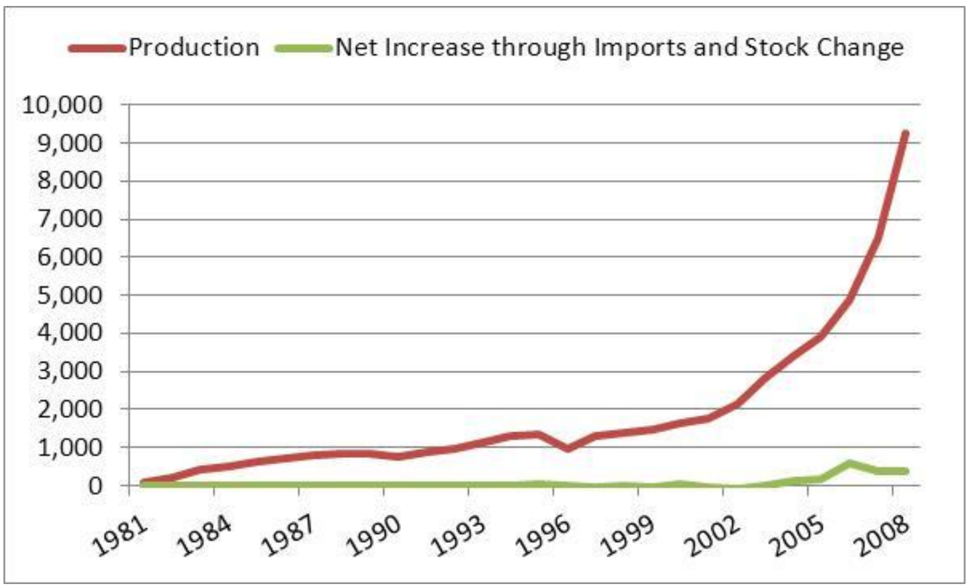
Given that AEP-Ohio is presently compliant with the State of Ohio's standard through at least 2015, it has little reason to invest in additional generating resources. Ohio's alternative compliance payment is $45/MWh ($13/mmbtu), so biomass co-firing is competitive with that penalty, but it is not competitive with expectations regarding the market for RECs. In addition, Ohio utilities have many options for acquiring credits as they are not restricted to credits created or sold in the State of Ohio (Ohio Public Utilities Commission 2009). Ohio utilities are allowed to trade credits with the Midwest Renewable Energy Tracking System (M-RETS) and the (PJM-GATS). Those two tracking systems include every state in the control territories of the PJM Interconnection and the Midwest Independent Transmission System Operator (MISO). Credit transfers are also accepted from the Michigan Renewable Energy Certification System

(MIRECS) into PJM-GATS. Essentially, Ohio utilities can obtain RECs from almost every state between North Dakota and New Jersey as well as the province of Manitoba.

Cellulosic Ethanol

Since the early 2000s the market for ethanol-based transportation fuels has witnessed a steady increase and is projected to continue that trend. In 2009 the estimated size of the corn-based ethanol industry was 11 billion gallons per year and is projected to reach over 35 billion gallons per year by 2020 (Urbanchuk 2010). Ethanol produced from switchgrass has so far only been produced in small demonstration batches, although a pilot plant is about to begin operation. The growth of corn-ethanol production is illustrated in Figure 1 below.

Figure 1: U.S. Total Production and Consumption of Fuel Ethanol (Million Gallons)



EIA Annual Energy Review, 2009.

The potential future of the biofuel industry has been closely evaluated by the U.S. Department of Energy (DOE) and the United States Department of Agriculture (USDA). In their joint "Billion Ton Vision" report the two agencies reported that in 2005 the biomass industry accounted for three percent of the nation's energy consumption and proposed that this figure should reach over 30 percent by 2030 (U.S. Department of Energy and U.S. Department of Agriculture 2005). In terms of share of transportation, biofuel was expected to have a four percent share in 2010, increasing to 10 percent in 2020 and 20 percent in 2030. The agencies claim that the contiguous United States can support this vision and has access to well over 1.3 billion tons of biomass material that does not fall under current government property or reside on high-value agricultural land.

The Energy Independence and Security Act of 2007 mandates production of 136 billion liters of renewable fuels by 2022, of which 79 billion liters should be from non-corn biofuels and cellulosic ethanol (U.S. Energy Information Administration 2007). As the current biofuels industry is dominated by corn-based ethanol production, reaching this goal will require many new facilities.

Nationwide there is little production of ethanol from switchgrass or from any intentional energy crop. The closest production location is the 250,000 gallon USDOE-sponsored pilot-scale facility in Vonore, TN that is soon to be in operation. This facility is supported by the Oak Ridge National Laboratory (ORNL), which has been involved in regional testing concerning the costs and yield of switchgrass plots. The pilot plant is in the process of converting its feedstock from corn stover to switchgrass as soon as it stabilizes the enzymatic process (Downing, 2011). Unfortunately, the distance to the Knoxville area will prevent any West Virginia producers from supplying that facility as the plant has ample access to switchgrass within 50 miles of the site. As part of the project the University of Tennessee and ORNL are providing area farmers with subsidies and technical assistance to help meet switchgrass demand for the pilot plant. Nearly 7,000 acres of switchgrass are currently in production.

A cellulosic ethanol-capable facility in Madison, PA is presently using wood chips as its feedstock. That facility uses a fuel-flexible gasification process and is capable of using switchgrass. The plant is a research and testing facility run by Westinghouse Plasma Corporation. It is not a dedicated ethanol producer. Both feedstock and product (electricity, steam or ethanol) are used and produced according to customer request (Reese 2011).

A recent study of the potential for producing cellulosic ethanol in the Midwest concluded that the greatest sensitivity that influences cost of production is the value of alternative production on agricultures land (Jain et al 2010). In the Midwest that value is driven by the prices of corn and soybeans, which represent the most common agricultural products in the area. The study estimated break-even prices for switchgrass between $88 and $188 per ton of dry matter in the eight-state region. Break-even prices for miscanthus were estimated at between $53 and $234 per ton of dry matter. For both grasses the State of Missouri had the lowest potential costs.

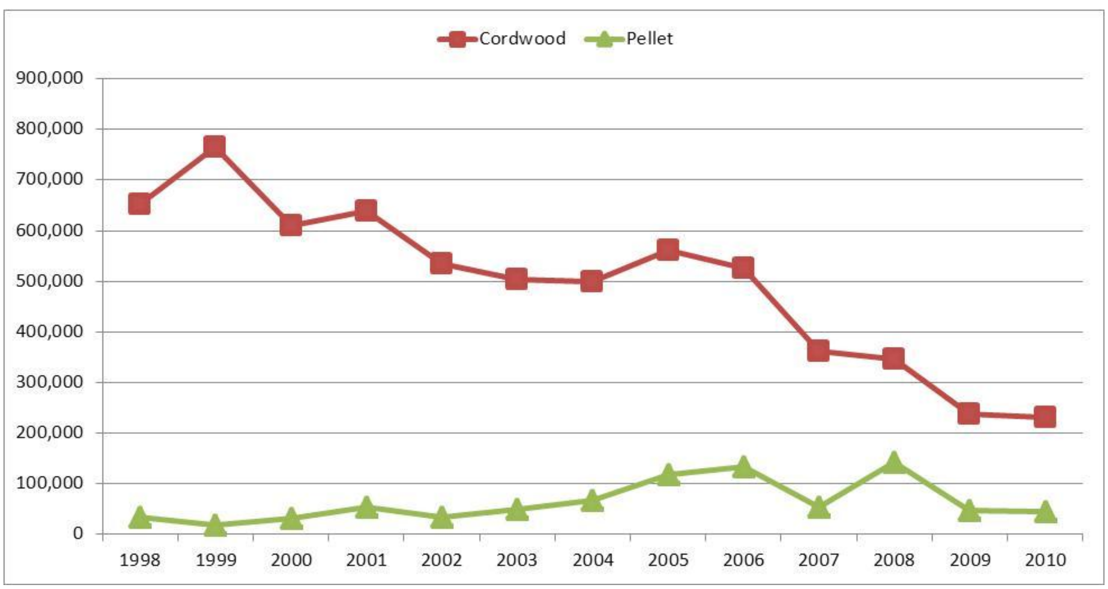
The capital costs of a cellulosic ethanol production facility are also higher than for a corn-ethanol refinery. Capital costs for a small-scale cellulosic ethanol plant with a capacity of 50 to 69 million gallons per year are estimated to be between $200 and $375 million (2005 dollars). This compares unfavorably to corn-based ethanol capital costs of $67 million for a facility of similar size (U.S. Energy Information Administration 2007).

Due to higher production costs cellulosic ethanol can’t compete directly with corn-based ethanol to supply mandated ethanol consumption. The price of oil is thus the next important factor in evaluating the ability of cellulosic ethanol to achieve market share. According to Purdue University researchers, current technology produces cellulosic ethanol at a price of $120 per barrel (Service 2010). The price of refined petroleum would have to equal this cost of production for cellulosic ethanol to be compete with conventional gasoline. Crude oil has traded between $80 and $110 per barrel over the last few months, and average gasoline prices have ranged between $2.90 and $4.00 per gallon. The cellulosic ethanol refining process may thus be closer to being competitive but presently it must still be subsidized due to uncertainty surrounding production costs and future petroleum price volatility. As pointed out in a recent editorial, biomass is currently the only real source of sustainable liquid fuels, which will be necessary for decades even if electric vehicles and hydrogen fuel cells gain significant market share (Lynd and De Brito Cruz 2010).

Stove Pellets

Fuel pellets made from grasses are not marketed in the area. Due to West Virginia's supply of hardwoods and long-standing wood products industry there is an established market for wood pellets. Nationwide demand for pellet stoves jumped in 2008 with some growth likely attributed to a federal tax credit for such purchases and some due to high natural gas and petroleum prices. Only select types of stoves are capable of burning grass pellets as effectively as wood although some stoves are capable of burning multiple fuels. Figure 2 illustrates the volume of shipments of cordwood and pellet stoves in the U.S. in recent years, omitting data for gas stoves which show a decline similar to that of cordwood.

Figure 2: U.S. Hearth Appliance Shipments, 1998 to 2010



(Hearth, Patio & Barbecue Association 2011).

The wood pellet industry is referenced here as it presently serves the residential and commercial sectors with a system and fuel products that would be nearly identical to grass pellets in terms of delivery and use. Major differences may exist in the maintenance that may be required of a grass stove compared to a wood stove and in the feed rate of the pellets.

In spite of recent jumps in materials prices, regional wood pellet manufacturers are presently not seeking alternative materials to use in production. As there is yet no significant or stable supply of switchgrass or any other perennial grass this is not surprising. Industry analysis states that the wood pellet industry faces growth constraints due to limited availability of wood waste such as sawdust (US Department of Agriculture 2009) (Webb 2011). If demand for self-sufficiency in home heating grows and the wood products industry is not able to keep up with that demand a niche for grass stoves and pellets could emerge. But it will be an entirely new industry.

Multiple analyses and statements suggest that current users of wood pellets would not be able to switch to using grass pellets in their existing stoves. The Biomass Energy Resource Center states that “pure grass pellets should not be sold for use in residential pellet stove heating appliances designed to burn wood because of the high ash content of grass pellets and their corrosive flue gas.” The center states that grass pellets can be used with appropriate equipment such as those using “adjustable feed rates, traveling grates to break up clinkers, appropriate air and emission controls, and corrosion resistant materials such as stainless steel (Prairie Lands Biomass Project 2010).” Clinkers are incombustible residues that form in systems not specifically designed to handle high ash fuels and can reduce performance.

Cornell University has done testing on grass-pellets in various stoves. Its website states that “grass pellets most likely will not work in any stove that does not have a specific adaptation to deal with some type of non-wood ash” (Cornell University 2010). Cornell has produced a report on types of stoves that work best with grass pellets. Stoves tested include various corn and wood pellet stoves and a gasifier.

Canada’s REAP (Resource Efficient Agricultural Production) program promotes use of grass pellets with advanced pellet stoves designed to burn grass. REAP state that “in these systems, grass pellets or briquettes are used much like wood pellets and can provide fuel conversion efficiencies and particulate emissions in the same range as modern oil furnaces” (REAP-Canada 2011).

REAP sees grass pellets as having strong potential to displace heating oil in residential and commercial settings with user-friendly devices. It also encourages production of perennial energy crops as an efficient way to use low cost marginal farmland for solar energy collection. REAP maintains a list of grass- compatible boiler manufacturers.

There are many different types of stove pellets made with different combinations and types of wood. According to stove manufacturer Dell-Point, there are over 70 different companies in the United States that manufacture pellets. The Pellet Fuels Institute is the industry's trade association and regulates the size and content of pellets, particularly ash. A pellet is considered premium if it contains less than one percent ash content, and it is considered standard if it contains less than three percent ash (Dell-Point Technologies n.d.). Grass pellets by contrast generally contain four to five percent ash (Cornell University 2010).

The Vermont Grass Energy Partnership considers the potential to develop a market for residential use of grass pellets a worthy of study (Vermont Grass Energy Partnership 2011). The organization believes the potential displacement of on-farm use of propane and heating oil with grass pellets to be "a logical opportunity" as many farms can produce their own perennial grasses. This may also be an opportunity for West Virginia farmers, particularly broiler growers, who rely on propane to heat their houses at a cost that is often one-third of total annual costs (WVPGA 2011).

Wood pellet manufacturers in the West Virginia include:
Hamer Pellet Fuel (based out of Kenova, WV)

- Facility in Elkins, WV
- Facility in Mount Hope, WV
- Both plants manufacture a premium grade pellet made from hardwood sawdust

Lignetics

- Located in Glenville, WV.

Wood pellet retailers in West Virginia include:

- Lowes - Currently carry wood pellets and wood stoves
- Home Depot - No longer carries wood pellets or stoves, but carried the products in 2009
- Kenny Queen Hardware in Lavalette, WV - carries wood pellets and stoves
- Other miscellaneous hardware stores throughout the State.

There is currently no market for switchgrass pellets, although with proper equipment and stable supply one could be created. The wood pellet market is the closest comparable market and provides some good lessons. The experience of the wood pellet industry shows that consumers will only depend on a stove as an alternative to fossil-based heating if the price and supply of pellets are stable.

Costs of Production

The costs of growing and transporting switchgrass apply to any of the three potential markets. The cost of delivering a ton of switchgrass is used here as a proxy for the price a producer would have to receive to break even.

Key Variables

- **Yield Per Acre –** Switchgrass yield varies considerably by land type. Tennessee switchgrass plots on agricultural land are seeing yield of 7.5 to 8.5 tons per acre (Downing 2011). In Kentucky, yield on bottom land of 4 tons per acres has been achieved but surface mines do not produce as well (Lowe 2010). Yields have been observed as low as 2 tons per acre (Minix 2010).
- **Production Costs –** Estimates for cost of production have been thoroughly studied by Oak Ridge National Laboratory, although yield is a crucial component of final costs. A primary variation in costs is from land rents, which are based on the opportunity cost of using the land for another venture. In West Virginia, the opportunity costs may be quite low as there are numerous former surface-mined lands available for development. Sites that do not possess wind resources and that are relatively distant from urban areas will have the lowest rents.
- **Delivery Costs –** The maximum distance to transport baled grass to a pelletizing or blending facility is recommended to be 50 miles. The grass must be transported by truck and incurs both fixed and variable costs. Using the Oak Ridge cost estimates and assuming 50 miles for one-way transport, transportation costs are 14 percent of total delivered costs. The closer to the plants the lower the costs.
- **Pelletizing costs –** The range of pelletizing costs depends largely on capital equipment. Midwest BioFuels has been able to pellet grass for about $20 per ton (Lowe 2011). In other areas it has been estimated at $40 to $60 per ton, including profits (Porter 2008).
- **Energy Value –** Conventional pelletized grass pellets contain energy content of 14 to 16 mmbtu per ton (Jeff Lowe). Usable energy content is generally lower due to conversion efficiency, often falling to 11 mmbtu per ton (Porter 2008). Torrefied pellets cost more per ton but produce a product with 9,500 to 11,000 btu per pound (19 to 22 mmbtu per ton). These values exceed that of Powder River Basin coal. The lack of moisture in the torrefied pellet creates the high energy content. Prior to torrefaction, raw material is dried to 10 percent moisture content or less to promote the process. After torrefaction moisture content can be less than three percent (Mitchell and Elder 2010).

Oak Ridge National Laboratory (ORNL) manages a large switchgrass growing operation in Tennessee, the volume of which will be used in a cellulosic ethanol pilot refinery. Given the lab's extensive history with switchgrass production their cost estimates are among the best available. Using figures compiled and published by ORNL the cost of switchgrass production is summarized in Table 3 below (Oak Ridge National Laboratory 2009). These figures do not include the cost of establishment. It is assumed that establishment costs would be fully subsidized.

Table 3: Switchgrass Production, Storage & Transport Costs

Variable costs (Fertilizer) – Nitrogen, Phosphorus, Potassium and Lime = $78.74/acre. With interest on variables costs = $81.10/acre.	$81.10/acre
Harvest Costs - Harvest costs are the sum of the mowing and conditioning plus the combined operations of pickup and transport to the field edge. These costs include the fixed costs of equipment: tractor, mower-conditioner, forage harvester, windrow pickup head and high dump forage wagon. It incorporates hourly rates for specific equipment plus acreage covered per hour.	$65.32/acre
Overhead - Overhead includes such items as: office expense; fuel, lube, and utilities (not previously included in the machinery cost estimates); maintenance and repairs on buildings; machinery and equipment (not previously included in the machinery cost estimates); and farm insurance (not previously included in the machinery cost estimates). ORNL uses the average of that published by the American Agricultural Economics Association (AAEA) for corn, soybeans and alfalfa.	$13/acre
Land Rent – Using the state average for pastureland rather than for cropland. Rental rates on former surface-mined land in West Virginia could be lower than this.	$12/acre
Total Production Costs: The study assumes a yield of 4.02 dry tons/acre, which places the total in-field production costs at $42.86/dry ton. With a yield of two tons/acre the cost doubles.	$42.86/ton
Storage costs are based outside storage on a prepared gravel surface with a reusable tarp for cover. These are assumed to apply to the entire tonnage produced and include expected dry matter loss of about six percent.	$12.86/ton
Transportation costs depend on distance to a pelletizing facility, represented by hours of use for a single flatbed tractor trailer. Estimated costs incorporate truck purchase cost, diesel fuel, labor and variable mileage costs and are based on a range of miles traveled of between 45,000 ($80/hr) and 150,000 ($65/hr) per year. $80/hr is used here. Trucks are assumed to load at 60,000 lbs per trip.	$88,889 per year
Estimated Total Production and Transport Costs – For switchgrass production of 10,000 tons per year on a 2,500 acre plot.	$646,039
Total Costs/Break Even Price per Ton – Given the assumptions above, this is the delivered price a facility would have to receive to break even. This simulation assumes no profit in order to focus on actual incurred costs.	**$65/ton**

An agricultural and processing operation of this size would provide 20 to 25 jobs to the local community.

The Densified Product

Regional commercial densification facilities have been able compress switchgrass to about 45 lbs/ft^3, producing a pellet product with an energy value of about 7,500 btu per pound (Lowe 2010). This equates to a per ton energy content of 15 mmbtu, a value approaching that of Power River Basin coal, which typically contains 17 to 19 mmbtu per ton. Midwest has been able to deliver pelleted biomass to a coal loading facility for $75 to $80 per ton. However, given that AEP is not willing to pay more than $90 per ton for the delivered product, this production price does not allow much room for profits or for final transportation to the power plant.

Simply grinding the baled switchgrass into a 35-mesh powder accomplishes the same goal as pelletizing as the resulting energy value per pound is the same as with pellets. While the pelleting costs could then be avoided, the powdery material creates problems with dust and handling as it may lose energy value if it gets wet, necessitating special covered transport and storage post preparation. Pre-blending a 35-mesh product with coal may not solve these problems, and coal can get wet without affecting volume.

Alternative production cost data provided by Biomass Energy Resource Center (BERC) gives a profit-inclusive price of $114 to $154 per pelleted ton in the Midwest (Porter 2008). Because of the Chariton Valley co-firing project, many reports are available about the costs of switchgrass production in Iowa. BERC's estimates for production and pelletizing are:

- $50/ton baled (assume $100/rent & 5 tons/acre yield)
- Average FOB farm: $70-90/ton (assume $100-200/acre profit)
- Trucking costs: $4.68/ton (30 miles @ $3.75/loaded mile)
- Average FOB pellet mill: $74.68-$94.68/ton
- Costs to pellet: $40-$60/ton
- Total Costs: $114 - $154/ton pelleted.

If the profitable price for a ton of pelleted switchgrass is $114 to $154, with an energy content of 15 mmbtu per ton, that equals $7.60 to $10.30/mmbtu. This amount is about equal to the $8 to $10/mmbtu AEP-Ohio has stated they have been offered for long-term supply of biomass and which is unacceptably high for them (Weaver 2011). Given that AEP is a primary player in the market for regional co-firing, their desired delivered price of $6.50 per mmbtu must be a target price for any near or mid-term supply.

Compared to surface-mined lands in West Virginia, the mid-west has higher rents per acre as the land is more valuable for agriculture and comes with a greater opportunity cost. This concept is supported by several studies that evaluate energy crops. A recent study by the University of Illinois states that while yield is a critical factor in the competitiveness of bioenergy feedstock the yield of what they displace is also important (Jain et al 2010).

In West Virginia, lower land rent may make up for lower switchgrass yield compared to higher-yield production in Iowa. Using the Oak Ridge production figures and average pastureland rent of $12 per acre, yield of 3.4 tons per acre gives the same per ton production cost as 5 tons per acre yield in Iowa with rent of $100 per acre ($50 per ton).

When fuel preparation costs are added to the cost of production, storage and transport, the profitability of this potential venture becomes severely restricted. The range of preparation expenses include those for grinding, pelletizing and possibly blending with coal. For illustration, costs of $10, $15 and $20 are used to show how tight this stage of production is when holding field production and transport costs constant. Even these relatively low costs, compared to other estimates, restrict profitability in current markets. Table 4 shows estimated break-even prices for production of switchgrass fuel, assuming the production, storage and transport costs to be binding, so the only variable is preparation costs using baled grass. The break-even price is measured after final preparation but prior to final shipment to the plant. Final shipment costs are estimated at $3.20 per ton and represent a barge rate of $2 per ton for loading and $0.015 per ton for transport.

The shaded rows of Table 4 show combinations of yield and preparation costs that result in a fuel product below AEP's desired price of $6.50 per mmbtu. This table shows that if possible to keep preparation costs to $15 per ton or less, the product can be delivered to a power plant at a price that AEP is willing to pay, as long as yield is three tons per acre or more. If preparation costs are $20 per ton then yield must be closer to four tons per acre (3.3 tons per acre equates to $6.50 per mmbtu in this model). If yield is only two tons per acre even a very low preparation cost of $10 per ton, which would likely omit the pelleting step, is too expensive.

Table 4: Comparison of Potential Costs to Deliver Switchgrass for Co-Firing ($/mmbtu)

Yield: (tons per acre)	Pelletizing/ Grinding /Blending Costs ($/ton)	Break-Even Prepared Price ($/ton)	At Power Plant $/mmbtu (prepared $ + final transport)
4	$20	$85	$5.85
3	$20	$99	$6.80
2	$20	$127	$8.71
4	$15	$80	$5.52
3	$15	$94	$6.47
2	$15	$122	$8.38
4	$10	$75	$5.19
3	$10	$89	$6.14
2	$10	$117	$8.04

Meeting these costs is only one aspect of satisfying the utility's requirements. The material handling, emissions and fuel performance needs must also be satisfied. Midwestern Biofuels was able to produce pelleted switchgrass in a range of $75 to $80 per ton, which would not have exceeded AEP's per mmbtu price threshold for delivered fuel. However, the fuel handling issues associated with use of the product at the plant were not conducive to continued use without modification. In addition, accepting a long-term contractual price at this level may not have resulted in the level of profitability required to maintain a facility like Midwestern.

The cost of torrefaction, a pelletizing process with additional production steps that include application of heat, has been estimated at $80 to $112 per ton in 2005 (Bergman 2005). In 2011 dollars that is about $90 to $130. Thus, while torrified biomass pellets may meet a utility's handling and energy input requirements it is unlikely that this product would meet a utility's price target unless other costs were reduced or yield was above that presently achieved in Tennessee and Iowa.

Table 5 provides estimates of yield and preparation costs associated with a more expensive pellet preparation process. This simulation assumes that harvested switchgrass will be stored at the production facility and that those expenses are part of the $65 to $85 per ton costs. For these costs to meet the $6.50/mmbtu price goal yield must be at least nine tons per acre and preparation costs must be less than $75/ton. Yield in the range of 9 to 15 tons per acre has been seen for miscanthus, which has been observed to have yields twice that of switchgrass (Jain et al 2010).

Table 5: Alternative Yield, Preparation Costs and Associated Delivered Costs ($/mmbtu)

Yield: (tons per acre)	Pelletizing/ Grinding /Blending Costs ($/ton)	Break-Even Prepared Price ($/ton)	At Power Plant $/mmbtu (prepared $ + final transport)
15	$85	$ 105	$ 7.23
12	$85	$ 108	$ 7.42
9	$85	$ 113	$ 7.74
15	$75	$ 95	$ 6.57
12	$75	$ 98	$ 6.76
9	$75	$ 103	$ 7.08
15	$65	$ 85	$ 5.90
12	$65	$ 88	$ 6.09
9	$65	$ 93	$ 6.41

REC prices are expected to remain the fall-back for obtaining RPS compliance for the next five to ten years. Due to the plethora of available wind power and expected continuance of that availability, REC prices are likely to be tied to wind prices and remain low for this time period. As suggested in Table 5, if REC prices were to increase to around $8 per mmbtu the options for biomass supply would become greatly expanded. With higher REC prices competing suppliers would have more room to deploy more expensive production processes, such as torrefaction, and to make more profits.

Non-Market Amenities

Beyond the potential economic benefits of using mine-scarred lands to produce switchgrass for the biomass industry there are additional benefits to growing switchgrass that may make it worthwhile to pursue. This may be especially relevant to surface-mined lands with poor soil and few productive options.

The areas that surround the fields will gain ecologically. High in importance among these gains is soil conservation. With proper management soil can store and sequester carbon. A long-term study of former surface-mined land in southeast Ohio found that reclamation of the land by initially seeding to grass, followed by planting trees dramatically increased the carbon concentration in the soil and stocks (Nyamadzawo 2008). This is significant because it shows that grasses are capable of restoring organic carbon to soils that have been damaged by mining. Higher carbon and nitrogen content was found in reclaimed mine soils compared to an un-mined reference site, suggesting that active reclamation of disturbed lands using grasses can greatly improve soil quality (Nyamadzawo 2008).

Perennial plants acts as a natural means of carbon sequestration and through the switchgrass' s extensive root system the nearby watershed that may have been polluted by years of mine runoff may be absorbed out of the water table. The rate of CO_2 absorption has been calculated from the carbon content of switchgrass at 1540.5 grams CO_2 per kilogram of switchgrass (Qin et al 2004). Once the grass is burned the carbon is released into the air but is assumed to result in net-zero emissions because of the closed-loop system that grass regrowth creates using photosynthetic uptake of carbon at the same rate as combustion for power generation.

The amount of carbon that can be sequestered by a switchgrass stand is related to its volume and maturity. "The sustainable amount of biomass that can be removed from the field is directly related to the amount of carbon in the soil, the amount of macronutrients removed in the biomass, and the mass left in the field to protect the soil from erosion" (CAST 2010). By one estimate, the credit for soil carbon dioxide sequestration was 179.9 g/kg switchgrass, but it was found that after growing switchgrass on the same fields for 15 years CO_2 accumulation in the soil would reach a saturation value (Qin et al 2004).

The level of greenhouse gas mitigation through switchgrass production is dynamic and measuring it would require accounting for changes in production, rates of growth and harvest. For example, net nitrous oxide emissions could be positive or negative depending on uptake by switchgrass root systems and on nitrogen application required to fertilize the crop. Estimates of nitrogen application required for switchgrass production list Appalachia as having the lowest minimum requirements (45.39 kg/ha) of ten regions evaluated, with maximum requirements (90.79 kg/ha) closer to the average of the regions (Marshall and Sugg 2010). These figures may or may not apply to mine-scarred land with disturbed soils.

The other benefit of using mine-scarred sites as a sustainable energy park is the benefit to the local communities. These areas have existing infrastructure from the mining companies that once provided jobs for the local people. Switchgrass fields would be a modest source of income for the local populace where these mines were once located. A new source of revenue is badly needed in areas that may have been damaged financially by the mining company's absence. Depending on yield, a 2,500-acre switchgrass or miscanthus production system would directly employ 20 to 50 people.

Concern has been expressed over the potential for switchgrass production to have negative competing effects if its production displaces production of food and feed crops (Marshall and Sugg 2010). This would generally only occur if it was produced on non-marginal agricultural land. West Virginia may be in an advantageous position for switchgrass production, particularly on surface-mined land, as its relative lack of intensive agriculture will not create competition for land use with conventional crop production.

Switchgrass stands may also be managed as wildlife habitat, but may require special procedures that would preclude optimal production. Harvesting can still occur and can even contribute to habitat maintenance. Harvesting must be timed appropriately to ensure that animals are only minimally affected (University of Georgia n.d.).

Conclusions

Of the three identified market opportunities for switchgrass, none are presently established. With ample yield, accompanied by a demonstrated stable production price and an appropriate price-material combination, a niche could be created for switchgrass in any of these markets if external factors were also present or absent. Price is not the only barrier to developing this market. Supplying a customer-based material that satisfies a particular system's input parameters is equally important.

For co-firing, external factors are wind energy prices, effective tax credits and regulation of emissions. When wind energy reaches a saturation level, possibly around 2020, the price of RECs in the market could rise and cause biomass-based energy to be more competitive. To support more expensive pellet preparation processes such as torrefaction, REC prices of around $8 per mmbtu combined with high yields of at least nine tons per acre may be needed. Increasing the tax credit for closed-loop biomass could also promote more competitive supply. And lastly, the final EPA decision regarding what type of emissions control equipment must be used for biomass emissions must also be settled, although there are indications that maximum available control technology will not be required.

For cellulosic ethanol the price of petroleum-based transportation fuels is still a primary determinant. If crude oil prices remain at more than $100 per barrel for a couple years, lenders may become willing to invest in refineries using alternative feedstock. For now, even with a federal mandate and tax credits the large capital costs of building a refining facility dedicated to energy crop refining is seen as too risky for the private sector to take on. A parallel regulatory issue is that it is not mandatory to use additional ethanol in vehicles beyond what is already supplied by corn. Vehicles exist that are capable of using 85 percent ethanol (E-85) but they are not the automotive industry's standard offers.

For stove pellets, a consumer trend for self-sufficiency in home heating driven by higher heating oil, natural gas and electricity prices may create demand for grass pellets if the market for wood pellets is saturated. Additional tax policy such as credits given against purchase of pellet stoves could also create demand.

Use of biomass-based energy resources involves considerably more operating activity compared to other renewable resources. Biomass resources must be developed and the ability to sustain supply must be demonstrated. This is in many ways more challenging than using wind and solar resources that are already available. However, biomass is the only type of renewable fuel that can provide base load electricity and liquid transportation fuel. The growth of biomass can also provide modest employment benefits to rural areas, an important quality for areas that severely lack economic options.

References

American Electric Power. *Biomass Coal Blend RFP.* 2010. https://www.aepohio.com/global/utilities/lib/docs/b2b/rfp/2010coalbiomass/AEP_Biomass_Coal_Blend_RFP_021210.pdf.

American Electric Power, interview by Christine Risch. *C. Banner, Engineer* (December 9, 2010).

Ballard Spahr, LLP. "EPA Issues New Rules for Controlling Air Pollution from Industrial Boilers." *Ballard Spahr, LLP.* March 29, 2011. http://www.ballardspahr.com/alertspublications/legalalerts/2011-03-29_epa_issues_new_rules_controlling_air_pollution.aspx.

Bergman, P.C.A. *Torrefaction for biomass co-Firing in existing coal-fired power stations "Biocoal".* Petten: Energy research Centre of the Netherlands, 2005.

Berkshire Photovoltaic Services. "Renewable Energy Credits (RECs) and Solar Renewable Energy Credits (SRECs) Overview." *Berkshire Photovoltaic Services.* 2010. http://www.bpvs.com/RECS%20for%20website%202q10.pdf (accessed February 21, 2011).

Burns & McDonnell. "An Overview of the EPA's Industrial Boiler MACT Rule." *Engineering, Architecture, Construction, Environmental and Consulting Solutions.* March 2011. www.boilermact.com.

CAST. "Convergence of Agriculture and Energy: IV. Infrastructure Considerations for Biomass Harvest, Transportation, and Storage." *CAST Commentary .* September 2010. http://www.cast-science.org/websiteUploads/publicationPDFs/Convergence%20of%20Ag%20and%20Energy%20IV170.pdf.

Comer, Kevin. "Cofiring Coal with Switchgrass: The Chariton Valley Biomass Project." *Public Policy Virginia, Biofuels Meeting.* Charlottesville, VA: ANTARES Group Incorporated, 2006.

Cooper, J., M. Braster, and E. Woolsey. *Overview of the Chariton Valley Switchgrass Project: A Part of the Biomass Power for Rural Development Initiative.* BioEnergy '98, 1998.

Cornell University. *Grass Bioenergy.* 2010. http://www.grassbioenergy.org/.

Coyle, William T. *Next-Generation Biofuels Near-Term Challenges and Implications for Agriculture.* U.S. Department of Agriculture , 2010.

Dell-Point Technologies. *Pellet Stove.* n.d. http://www.pelletstove.com/right.html.

Downing, Mark, interview by Christine Risch. *Group Leader, Bioenergy Resource and Engineering Systems Group, Oak Ridge National Lab* (January 21, 2011).

E-Energy Market. *Torrefaction key to renewable power generation.* January 2011. http://www.e-energymarket.com/nl/nieuws/single-news/article/torrefaction-key-to-renewable-power-generation.html.

Energy Information Administration. *Impacts of a 15-Percent Renewable Portfolio Standard.* Washington, D.C.: U.S. Department of Energy, 2007.

Environmental Protection Agency. *MACT Boiler Final Rule.* 2011. http://www.epa.gov/airquality/combustion/.

—. *MACT Boiler Rule History.* 2011. http://www.epa.gov/ttn/atw/boiler/boilerpg.html.

Federal Energy Management Program. "Biomass Co-firing in Coal-Fired Boilers." 2004.

Gibson, Lisa. "BPA: IB MACT ruling threatens biomass industry." *Biomass Power & Thermal*, 2010.

—. "MACT Madness." *Biomass Power & Thermal*, March 22, 2011.

Graham et al. "The Economics of Biomass Production in the U.S." 1995. http://bioenergy.ornl.gov/papers/bioam95/graham3.html.

Hearth, Patio & Barbecue Association. *Hearth, Patio & Barbecue Association.* 2011. http://www.hpba.org/statistics/hearth-shipments-2010/Hearth%20Shipments%202010.pdf.

Jain et al. *An Integrated Biogeochemical and Economic Analysis of Bioenergy Crops in the Midwestern U.S.* GCB Bioenergy, 2010.

Lowe, Jeff, interview by Christine Risch. *President - Midwestern Biofuels* (March 9, 2011).

Lowe, Jeff, interview by Christine Risch. *President, Midwestern Biofuels* (December 3, 2010).

Lynd and De Brito Cruz. "Make Way for Ethanol." *Science*, November 26, 2010: 1176.

Marshall, Liz, and Zachary Sugg. *Fields of Fuel: Market and Environmental Implications of Switchgrass to Grass for U.S. Transport.* WRI Policy Note, 2010.

Minix, Brandon, interview by Christine Risch. *formerly of Midwestern Biofuels* (November 5, 2010).

Mitchell, Dana, and Tom Elder. "Torrefaction? What's that?" *Fueling the Future: 2010 Council on Forest Engineering Annual Meeting.* June 2010. http://frec.vt.edu/cofe/documents/2010/Mitchell_Elder_torrefaction.pdf.

Nyamadzawo, G. , M. Shukla, and R. Lal. "SPATIAL VARIABILITY OF TOTAL SOIL CARBON AND NITROGEN." *land degradation & development*, 2008: 275–288.

Oak Ridge National Laboratory. *Cost Methodology for Biomass Feedstocks: Herbaceous Crops and Agricultural Residues.* Oak Ridge: UT-Battelle, 2009.

Ohio Public Utilities Commission. "Alternative Energy Portfolio Standard: Chapter 4901:1-40." Ohio, December 19, 2009.

Parrish, D.J., and J.H. Fike. "Establishing and Managing Switchgrass as an Energy Crop." Plant Management Network, February 2008.

Perrin et al . *Farm-Scale Production Cost of Switchgrass for Biomass.* Bioenerg. Res, 2008.

Pew Center on Global Climate Change. "Renewable & Alternative Energy Portfolio Standards." *Pew Center on Global Climate Change.* February 11, 2011. http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm (accessed February 23, 2011).

Porter, Pamela. "Bioenergy: Opportunites and Challenges for Local, Renewable Grass Energy in the Midwest." *Vermont Grass Energy Symposium.* Vermont: Biomass Energy Resource Center, 2008.

Prairie Lands Biomass Project. *The Chariton Valley Biomass Project* . 2010. http://www.iowaswitchgrass.com/home.html.

PriceWaterHouseCoopers. *Stay Informed: 2008 Utilities and Power Industry Technical Update.* PriceWaterHouseCoopers, 2008.

PRNewswire. *FirstEnergy Corp.* Akron, Ohio, November 17, 2010.

Qin et al . *Switchgrass as an Alternate Feedstock for Power Generation: Integrated Environmental, Energy, and Economic Life-Cycle Analysis.* Texas A&M University, 2004.

REAP-Canada. *Resource Efficient Agricultural Production.* 2011. http://www.reap-canada.com/index.htm (accessed January 25, 2011).

Reese, Stephanie, interview by Christine Risch. *Operations Manager, Westinghouse Plasma Corporation* (January 27, 2011).

Segrest et al . *Engineering Chat on Biomass Co-firing.* January 2003. http://www.treepower.org/cofiring/chat2003Jan.html.

Service, Robert. "Is There a Road Ahead for Cellulosic Ethanol?" *Science*, August 13, 2010: 784-785.

SNL Financial. "Development of energy efficiency credits could depress RECs markets." *SNL Financial.* September 24, 2010.

State of West Virginia. *Final Report of the Governor's Task Force on Co-Firing.* State of WV, 2000.

The Green Power Network. "Renewable Energy Certificates (RECs): Retail Products." *U.S. Department of Energy.* August 2010. http://apps3.eere.energy.gov/greenpower/markets/certificates.shtml?page=1 (accessed January 27, 2011).

U.S. Department of Energy and U.S. Department of Agriculture. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.* Washington, DC: U.S. Department of Energy, 2005.

U.S. Department of Energy. "Biomass Energy Databook Edition 1 ." September 2006. http://apps.ornl.gov/~pts/prod/pubs/ldoc3512_biomass_data_book_edition_1.pdf.

U.S. Energy Information Administration. *Biofuels in the U.S. Transportation Sector.* October 15, 2007. http://www.eia.doe.gov/oiaf/analysispaper/biomass.html.

University of Georgia. *Management Recommendations for Switchgrass Production.* n.d. (accessed 2011).

Urbanchuk, John M. "Economic Importance of the Renewable Fuels Industry: Today and Tomorrow." *U.S. Department of Energy Biomass Conference March 2010.* Washington, DC, 2010.

US Department of Agriculture. *North America's Wood Pellet Sector.* Madison: US Forest Service, 2009.

US EIA. *Coal Supply, Disposition and Prices, AEO2011 Reference Case .* Washington, 2011.

Vermont Grass Energy Partnership. "Technical Assessment of Grass Pellets as Boiler Fuel in Vermont." *Biomass Energy Research Center.* 2011. http://www.biomasscenter.org/images/stories/grasspelletrpt_0111.pdf.

Weaver, Ashley, interview by Christine Risch. *Fuels, Emissions & Logistics - American Electric Power* (January 12, 2011).

Webb, Todd, interview by Christine Risch. *Sales Manager, Hamer Pellet Fuels* (March 8, 2011).

Wright, L.L., R.D. Perlack, and A.F Turhollow. "Switchgrass Production and Economic Costs in Selected U.S. Regions." *Biomassa and Energia* 3, no. 1 (2006): 57-67.

WVPGA, interview by Christine Risch. *West Virginia Poultry Growers Association* (February 2011).