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Energy Production with Biomass: What Are the Prospects?

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The advantages and limitations of the U.S. ethanol industry have both become apparent during the current period of high petroleum prices. One advantage is that ethanol is cost-reducing as a gasoline additive and as a gasoline replacement using E85 (motor fuel blends of 85 percent ethanol and just 15 percent gasoline). However, corn supply limits ethanol's role in energy markets; ethanol-based corn demand will surpass exports when the 7.5 billion gallon Renewable Fuel Standard is fully implemented; and even if the Midwest were to secede from The Union, the entire Midwestern corn crop could only supply two-thirds of regional gasoline demand with ethanol. Clearly, a broader resource base and other processing technologies are needed if bioenergy is going to expand its role in the national energy scene.

There are wide ranging assessments of biomass-energy's potential role in expanding our national energy supplies. Those accustomed to pumping liquid petroleum scoff at the idea that an energy industry could be based on bulky crops or residues from farm land or forest. Or biotechnologists sometimes multiply laboratory processing yields times the physical intensity of biomass on land times land area, resulting in an enormous estimate for biomass energy potential. Somewhere in between zero and the enormous estimates we should find reality.

This paper examines the primary factors that limit the potential size of a biomass-energy industry in the United States. First, the fraction of the existing biomass that can be economically harvested from farmland is reviewed. Second, the current and potential processing technologies and practices are discussed. And finally, the unknowns and uncertainties of bioenergy supply that could be shaped by public policy are also reviewed.

Recent Studies of Biomass Supply

Current thinking with regard to energy crops is that switch grass, willow, and poplar hold the most potential. Switch grass yields are highest in the southeastern United States, where sunshine and rainfall are ample. Poplar may be the energy crop choice in the north-central states with extensive sunlight in summer. Willow yields appear highest in the middle/east section of the U.S. where there is extensive rainfall. Most research evaluating the extent of economically accessible biomass supply has looked at adding these new crops on the boundary of existing commercial agriculture.

Crop residues from existing crops, mainly corn and wheat, could also provide significant amounts of biomass because residue mass roughly equals the volume of the crop. Crop residues intrigue industry because costs are lowest for this unused resource. Also, residue and food crop production are complementary, whereas growing crops for energy use instead of food production can reduce food supply. Finally, our research suggests that harvesting residue from crop production can be consistent with soil quality maintenance, when reduced tillage and other appropriate conservation measures are taken (Gallagher et al., 2003b).

Energy crops on commercial cropland are a marginal enterprise, owing to values and yields that are moderate in comparison to food crops. Fortunately, the farmland that can contribute to bioenergy production extends beyond commercial cropland. Many biomass crops are sustainable on land that is not suitable for annual crops; switch grass is established once and harvested for several years, and agro-forestry crops are planted and harvested on a 10-year rotation. Furthermore, willow is water-tolerant and even thrives with wet feet. Hence, the land base for biomass

Table 1. Biomass from agriculture: Potential supply and cost.

Source:	Volume (mil. ton)	Typical Farm Entry Price ($/ton)
Crop residues	142	15-25
Crops	188	35-45
Subtotal	330	
Midwest/East pasture	261	30-40
Forested farmland	155	30-40
Total	746	

crops extends to farmland with steep slopes and to some wet lowland areas that are generally not used for annual crops. Caution should be used when considering pastureland from the Great Plains states because inadequate rainfall could severely limit biomass yield. Commercial forestland should also be excluded because the infrastructure for harvest does not exist and other industries already compete for the land.

Bringing together several recent studies, my estimate of economically accessible biomass supply is given in Table 1 at 330 to almost 750 million tons. Initial supply prices range from a low of around $15/ton for corn residues to $35/ton for commercial cropland. Conversion of the first 330 million tons from current land use to biomass production might occur within five years, by harvesting residues, switching crops, and returning some CRP land to production. The conversion of pasture and forested farmland may be a longer-run proposition; dominated by agro-forestry crops, conversion could easily take 15 or 20 years. Conversion of this land would likely occur after a prolonged period of high energy and biomass prices. Complete use of marginal lands for energy would also intensify land competition with pasture for livestock, increase land use values, and significantly increase biomass costs from marginal lands, according to my preliminary estimates. Otherwise, one-half to two-thirds of the marginal lands could be used for biomass production without significant increases in land values. More biomass supply from commercial cropland could also be obtained at moderate price increases and without extensive increases in land values, but it would likely get more expensive to maintain the status of the CRP program.

Processing Technology Situation

There are five major crop-based processes for producing bioenergy products. The characteristics of these processes are summarized in Table 2. Characteristics include pretreatment and secondary processing, technical status, product yield, and cost when available. The processes are ordered according to market readiness. Processes (1) and (2) are operating today. Process (3a) has operated in a commercial setting with coal in South Africa, but not with biomass. The integrated pretreatment and secondary processes of (3b) and (4) are apparently technically feasible. But only a few batches have been made successfully with process (4) in a non-laboratory setting. Process (5) has potential for the future.

In general terms, the present technical challenge for biomass processing is to break down long and complex cellulose and hemi-cellulose molecules into smaller components that are more useful chemicals and energy products. A complicated pretreatment process is not required for agricultural crops because the wood-like component is not present. Otherwise, cellulose can be burned without pretreatment. But, conversion to liquid chemicals and fuels requires an extensive pretreatment process, which is difficult and expensive. This fact helps explain the pattern of market readiness and costs found in Table 2.

Ethanol production from corn, process (1), is now widely adopted, but the development of this industry took about 30 years. A subsidy was initiated in the mid 1970s to encourage plant construction. This resulted in moderate improvements in fiber conversion yield, reductions in operating costs due to lower energy use, and reduced enzyme cost. In addition, the industry reached economies of scale that lowered capital costs. Then the stage was set for the recent wave of adoption, which occurred very quickly in response to profits, high energy prices, and the increased demand provided by the renewable fuel standard.

The production of electricity and byproduct heat from burning biomass, process (2), is another process that operates commercially today. In California, rice straw is the biomass input and Denmark uses wheat straw. The biomass industries in both California and Denmark depend on government subsidies to continue operating. The reported electricity production costs from California compare favorably to recent consumer prices of electricity.

Gasification with catalytic conversion to a set of chemicals that includes ethanol, process (3), was developed in Germany during WWII. Gasification with a coal input was also used in South Africa while it faced an oil embargo. Optimizing yields with biomass input continues to be an active area of engineering research.

Processes (4) and (5) are both based on the fermentation of sugars, including the 5-carbon and 6-carbon sugars that occur when the wood-like material in biomass crops is broken down. The development of geneti-

Table 2. Actual and anticipated bioenergy crop-based processes.

Raw Material	Pretreatment Process	Pretreatment Products	Secondary Treatment Process	Secondary Treatment Products	Technical Status	Yield[c] Current	Yield[c] Potential	Production Cost[d]	Capital Cost
(1)Commercial crops[a]	Mechanical	Glucose	Fermentation	Ethanol	Operating	106	106	$1.12/gal	$1.10/gal
(2)Biomass[b]	None		Combustion	Steam/ Electricity	Operating			$0.07/kw-hr	
(3a)Biomass[b]	Gasification	Syngas: H_2 CO	Catalysis: Fischer-Tropsch, Pearson	Ethanol Methanol Proponal	Commercially Feasible	63	137	expensive	
(3b)Biomass[b]	Gasification	Syngas:	Fermentation	Ethanol Electricity	Technically Feasible			Unknown	$2.40/gal
(4) Biomass[b]	Hydrolysis with acid	Glucose Xylose	Fermentation	Ethanol	Technically Feasible	52		$1.80/gal	$4.70/gal
(5) Biomass[b]	Hydrolysis with base		Fermentation	Ethanol	May be available in future	----	120	$0.75/gal	$2.40/gal

[a]Corn, wheat, or sugar; [b]Crop residues, switchgrass, poplar, willow, or MSW (municipal solid waste); [c]In gallons fuel per ton of biomass input; [d]Includes annual allowance for capital repayment.

Table 3. Biomass-fuel processing plants: Commercial and quasi-commercial facilities in North America.

Location	Process	Fuel Capacity (mil. gal.)	Primary Input	Yield (gal/ton)	Status
Ottawa, Canada	Process (4): acid hydrolysis & fermentation	1	wheat straw	72	occasional short operation periods
Lacassine, LA	Process (4): acid hydrolysis & fermentation		woodchips bagasse		under construction
Pollock, LA	Process (3a): Gasification & catalysis	110	woodchips	58	planning
Knoxville, Tennessee	Process (3b): gasification & fermentation	13 (& 14 Mega-Watts of electricity)	Municipal solid waste	59	planning

cally engineered bacteria that can ferment all of these sugars with high yields is one of the most promising technological developments in biomass processing. One view of the problem in process (4) is that the pretreatment process used to break woody materials into sugars uses acid. The genetically engineered bacteria or yeast do not tolerate residual acid left from the pretreatment process, inhibiting ethanol yields. Process (5) represents a potential solution to this problem, using pretreatments with non-acidic solutions. Ideally, this pretreatment will allow actual sugar yields to reach potential. If the experimental pretreatment in process (5) were to become technically feasible, very high ethanol yields and low production costs could be obtained.

Technology Adoption: Barriers and Prospects

Referring to table 3, there are no full-scale biomass/biofuel plants operating in North America, but there are plans to construct one facility in Louisiana. There are two demonstration scale plants, a wheat straw fermentation plant operating in Canada, and a municipal solid waste gasification/fermentation plant planned for Tennessee (Table 3). Looking at the cost estimates in Table 2, one can conclude that producing ethanol from processes other than crop fermentation have not been adopted because the profit picture has not been favorable.

Biomass processing could become profitable in the future with improvements in technology. The U.S. Department of Energy (DOE) has emphasized research on fermentation ethanol for some time. In addition, DOE has recently developed several projects that are aimed at reducing the high cost of pretreatment enzymes and fermentation bacteria, an important barrier to adoption. One project aims at reducing enzyme costs from $.50/gallon to about $.10/gallon. Some of the major energy and chemical processing companies involved in this project anticipate that a few commercial processing plants based on improved hydrolysis pretreatment will be built by 2010 and technology development will be complete by 2015. However, some critics in the corn processing industry challenge this conclusion, observing that biomass ethanol has been 5 years away for about 20 years now. Further, it is important to realize that licenses for enzymes and genetically engineered bacteria are the scarce fixed factor where rents to new technologies reside. Based on experience in the corn-ethanol industry, it could take 20 years to get enzyme costs down.

Hence, it is going to take a number of technical advances before biomass-fermentation adoption becomes economical. First, if we could get a yield improvement comparable to the one that occurred in the corn-ethanol industry over the past 30 years, biomass yield would approach 90 gal/ton. Second, enzyme costs for biomass-ethanol must fall to the low levels of the corn-ethanol industry. With these advances, biomass ethanol might approach the breakeven point with the corn-ethanol process. But biomass-ethanol's high capital costs relative to corn processing would still remain. It could take very cheap biomass, like corn residues, or high corn prices to offset the capital costs.

The biomass-energy processing sector could evolve in several directions as the technological possibilities become known. Eventually, biomass fermentation (processes 4 and 5) will either become commercially successful or be judged as an unsolvable puzzle. A similar evaluation will occur for producing transportation fuel using the gasification process with biomass feedstocks (process 3). If neither fermentation nor gasification lead to low cost production of transportation fuels, attention could shift back to the existing biomass-electricity industry (process 2) and the biomass energy industry would serve local electricity needs for rural communities and rural processing plants.

Shaping the Role of Biomass-Based Fuel in the National Energy Picture

The eventual role of biomass-ethanol in national energy supply depends upon the success of fuel processing technologies and the extent of prolonged energy price increases. Three scenarios indicate the qualitative range of outcomes. First, if there are no further improvements in fuel technology, biomass ethanol could supply about 10% of national gasoline consumption using crop residues and available cropland. Assuming sustained high energy prices under this scenario, 20% of gasoline consumption could be replaced with large-scale conversion of suitable pasture and forested farmland. But, biomass-ethanol would still be on the margin even at currently high fuel prices. Second, if costs could be reduced about $0.25 per gallon with moderate improvements in fuel technology, then gasoline replacement could be up to 15%, assuming no major land conversion and 30% with major land use conversion. Third, if someone really solves the biomass pretreatment problem and further cost reductions of $1.05 per gallon were achieved, then biomass fuel could replace 20% of gasoline without major land conversion and about 45% with land conversion. In short, biomass fuel by itself won't solve America's energy problems, but it could be a significant part of the solution.

In turn, the biomass-fuel industry that we get in 30 years depends on our public investment today. With increased public research support, we increase the odds of a moderate improvement or a quantum leap in processing technology. Further, improving current processes deserves increased emphasis; biomass power could replace some natural gas used for electricity consumption and corn-ethanol production; and gasification/catalysis may be a very practical fuel technology for biomass. If someone solves the fermentation pretreatment problem, so much the better! Finally, the emerging demonstration plants deserve support because average production costs are inversely related to an industry's cumulative output; learning-by-doing has been important for other processing industries; it will be important for biomass energy, too.

This time, America's energy problem may be a prolonged state of higher petroleum prices instead of a market disruption; oil price outlook reports do remain high beyond the intermediate term. Oil processors are investing in Canadian oil sands, a process with costs similar to E85. But, the private sector interest in biomass energy is still limited in comparison. Perhaps biomass energy is too distant for serious consideration by the commercial energy sector. Or perhaps the profit vision of a multinational corporation with its resource base and human capital grounded in the petroleum industry does not see the critical role of biomass in America's energy future. Therein a justification for an oil profits tax may lie, especially if revenues are spent on biomass energy for America's future.

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