Energy From Agriculture:
New Technologies, Innovative Programs
& Success Stories

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Cellulosic Ethanol Technology Assessment

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INTRODUCTION

The National Corn-To-Ethanol Research Center (NCERC), located on the campus of Southern Illinois University Edwardsville, is the only facility in the world that fully emulates both a wet-mill and a dry-grind commercial fuel ethanol production plant. This flexible research facility was constructed to test new technologies on a pilot scale, a critical step in assisting in the determination of their commercial viability. The NCERC is ideally suited to validate new technologies for producing ethanol more cost effectively. This capability will positively impact the economics and the speed of commercialization of technical advancements of domestically produced, environmentally friendly renewable fuel. Expansion of fuel ethanol markets by using renewable feedstocks is a national priority. Advantages of increased ethanol production include: increasing national energy independence, improving the environment, and promoting rural development. In 2005, approximately 4 billion gallons of fuel ethanol will be produced from over 12% of the corn crop. Ethanol demand is expected to more than double in the next six years. For the feedstocks to be available to meet this demand and beyond, new cellulosic conversion technologies must be moved from laboratories to commercial reality.

CELLULOSICS FOR FUEL ETHANOL PRODUCTION

Energy security, environmental stewardship and revitalization of rural America are critical to the future of the United States (US). Despite its vast natural agricultural resources, over the past century the US has become increasingly dependent on petroleum as its economic foundation. In 2004, over 63% of US petroleum supply was imported. With improvements in feedstock production and processing, the production and use of biobased renewable fuels (from corn kernel starch and corn/soybean oil) has increased dramatically in the past decade. However, this market remains small with only a fraction of other available biomass (lignocellulosics) being used to produce biofuels, thereby displacing less than 5% of petroleum imports. Policy development alone is not sufficient to ensure the growth of the industry since the current technology base for the industry is incomplete. In order to viably produce biobased fuel on any significant scale requires a low cost starting material and low cost conversion processes. In contrast to the high cost of a petroleum starting material, the biobased industry benefits from recent advancements in agricultural production technologies to provide a low cost starting material (feedstock). Despite current estimates that enough cellulosic biomass is annually produced to supply current and future use, economic methods for producing biobased fuel from cellulose is lacking. An industrial transformation in this area will only occur when technical breakthroughs create economical means of fuel production from cellulose relative to starch or petroleum. The cellulose feedstock with the fewest technical hurdles to overcome is corn kernel cellulosics (fiber). By demonstrating commercial viability in this feedstock, many of the technical hurdles critical to alternative feedstocks would be largely addressed.

Cornstarch and fiber are both made of glucose (a hexose, C-6 sugar), the starting substance converted to ethanol in the industry. However, since the glucose units in fiber are joined together differently than in starch, the hydrolysis step (saccharification) is much more difficult for fiber than for starch with today's technology. In addition, the glucose units that make up the fiber are more difficult to access since the long chains of glucose units (called cellulose) are surrounded by other sugars (called hemicelluose) and lignin, all adding to the recalcitrance of accessing the glucose in the fiber. The cellulose surrounded by hemicellulose and lignin is referred to as lignocellulose. Pretreatment of lignocellulose allows for cellulose accessibility and subsequent degradation by enzymatic hydrolysis. Once the cellulose is converted to monomeric glucose, Bakers yeast can be used to convert it to ethanol. Because of DOE focused research with two major enzyme companies, the cost of enzymes (cellulases) for generation of glucose units from cellulose, has been reduced from approximately $5 per gallon to about $0.14-$0.18/ gallon of ethanol. However, in order to enable a very low cost sugar feedstock, DOE states the cost of using cellulases must be further reduced to reach the program goal of #0.05-$0.06/lb by 2030.

Depending upon the enzymes chosen for hydrolysis of the lignocellulose, the generated sugars can be either glucose only or a mixture of sugars including arabinose, glucose, and xylose. The arabinose and xylose are C-5 pentose sugars (contained in the hemicellulose) and are not converted to ethanol by Bakers yeast. There are a few naturally occurring yeast strains that do ferment pentoses, but grow slowly and produce low ethanol yields. Strains must also be able to tolerate the inhibitory compounds generated during some pretreatment and hydrolysis methods. Optimizing this, and other lignocellulosic biomass conversions require novel approaches to separation, catalysis, and biocatalysis methods, i.e. feedstock size reduction, pretreatment, enzymatic saccharification, fermentation, and product recovery.

Another feedstock, corn stover (stalk, cob, leaves) is not currently harvested or marketed and growers would require additional payment to provide it to processing facilities. Corn stover would require the same optimizations as described above for corn fiber and thus method optimizations for fiber could potentially be applicable to corn stover. The nearest term application and of immediate benefit to the current biofuel industry is the ability to develop effective means for separating and converting corn kernel cellulosics to fuel ethanol. The technical advancements made in the conversion of corn kernel cellulosics can then be applied to the technical constraints impeding the conversion of lignocellulose to ethanol, listed above.

By solving the separation and degradation issues of corn kernel fiber, ethanol plants would have an immediate yield increase of up to 10%, increasing the current production supply of fuel ethanol from 4 B to 4.4 B gallons with no additional corn feedstock and no supply chain changes. For a single corn bioprocessing plant with an average annual production of 40M gallons of fuel ethanol, the incremental benefit would be ~4M gallons. At current fuel ethanol pricing of $2.00 per gallon, this would provide incremental revenue to each plant of $8 M annually.

In addition to the incremental revenue from the conversion of corn kernel cellulosics to ethanol, transportation costs and value of the DDGS (distiller's dried grains with solubles, a corn by-product containing fiber used for animal feed) would also be positively impacted. Fiber adds minimal incremental value as a component of the animal feed and currently represents an average of 44% of the weight of DDGS. Transportation and storage of DDGS are its largest economic hurdles. Additionally, the US Grains Council indicates that US dry grind ethanol plants produce over 5.3 million metric tons (mmt) of DDGS annually. These industry experts predict that the volume of DDGS produced will increase to over 9.4 mmt by the year 2010 – a 77% increase in the supply based on predictions of fuel ethanol production. Anticipated market saturation with DDGS thereby suggests that the optimization of the technologies to convert corn kernel fiber to ethanol is an ideal demonstration opportunity. DDGS with lower fiber, would have concomitant higher protein percentages, and thereby hypothetically generate a higher market price.

This demonstrated success would serve as a foundation and stepping stone for the broader DOE biomass objective of annually converting 1 billion tons of abundant cellulosic biomass substrates. Today, just considering corn, soybeans, wheat and sorghum in the US alone, the National Corn Growers Association indicates there is an average of 2600 lbs/acre on a dry matter basis of plant cellulosic material left on the field after harvest. While retention of a portion of this material on the soil to prevent erosion is critical, a large portion of this material could be bioprocessed. The technical advancements made in the conversion of corn kernel cellulosics to ethanol can then be applied to the technical constraints impeding the conversion of lignocellulose to ethanol. Wyman, at Dartmouth College, School of Engineering, suggests 80 million dry tons of stover could be collected annually, enough to make 6B gallons of ethanol at modest yields of 75 gal/dry ton representing 252M barrels of oil.

Tiffany and Eidman (University of Minnesota), 2004 conducted a comprehensive assessment of the economic competitiveness of ethanol produced from corn grain by the dry grind process versus ethanol produced from corn stalks (lignocellulosic biomass). Their conclusions suggest that lignocellulosic processing (estimates from the National Renewable Energy Laboratory) may be competitive with the state of the art dry grind process when corn prices approach $3.00 per bushel, which equates to an ethanol cost of about $1.40 per gallon. More recently (2005), researchers at the Eastern Regional Research Center, ARS, USDA, compared cost of ethanol production from corn grain and corn stover and reported costs per gallon of $0.96 and $1.45 respectively, based on corn at $2.25/bu. and stover at $40/ dry ton.

CONCLUSION

Expanding fuel ethanol production beyond 10% of our liquid transportation needs will require developing more abundant and lower cost feedstocks. Only lignocellulosic biomass is available in sufficient quantities to substitute for starch as an ethanol source. New policies along with improved conversion processes will be necessary to overcome the technical hurdles (supply availability and abundance, pretreatment, fractionation, saccharification, fermentation, and product recovery) that prevent the economical conversion of lignocellulosics to fuel ethanol. A robust biofuel industry based on conversion of lignocellulosic biomass is expected by 2030.