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Cellulosic Ethanol—Biofuel Beyond Corn

Nathan S. Mosier
Department of Agricultural and Biological Engineering
Purdue University

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Introduction

Fuel ethanol production in the U.S. is expected to exceed 7.5 billion gallons before 2012. This represents a *doubling* of ethanol production from 2004, which consumed approximately 10% of the corn produced in the U.S. in that year. Increased demands for domestically produced liquid fuel is increasing competition between animal feed and fuel production uses of corn.

Cellulosic feedstocks (wheat straw, corn stover, switch grass, etc.) can also be converted to ethanol. Overcoming the technological and economic hurdles for using cellulose to produce liquid fuel will allow the U.S. to meet both food and fuel needs.

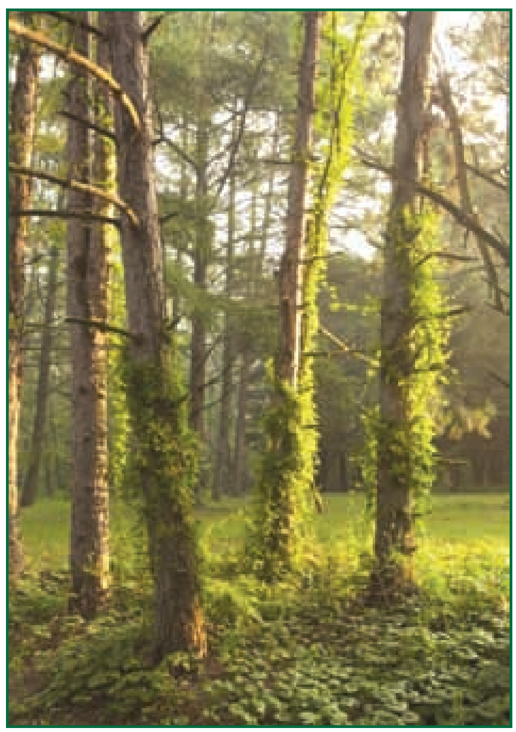
Cellulose as Ethanol Feedstock

Cellulose is a polymer of sugar. Polymers are large molecules made up of simpler molecules bound together much like links in a chain. Common, everyday biological polymers include cellulose (in paper, cotton, and wood) and starch (in food). Cellulose is a polymer of glucose, a simple sugar that is easily consumed by yeast to produce ethanol (Mosier and Illeleji, 2006).

Cellulose is produced by every living plant on the earth, from single-celled algae in the oceans to giant redwood trees. This means that cellulose is the most abundant biological molecule in the world.

A study completed by the USDA and the U.S. Department of Energy concluded that at least 1 billion tons of cellulose in the form of straw, corn stover, other forages and residues, and wood wastes could be sustainably collected and processed in the U.S. each year. This resource represents an equivalent of 67 billion gallons of ethanol, replacing 30% of gasoline consumption in the U.S (U.S. Department of Energy Biofuels: 30% by 2030 Website).

Plants use cellulose as a strengthening material, much like a skeleton that allows plants to stand upright and grow toward the sun, withstand environmental stresses, and block pests. People have used cellulose for centuries in paper, wood, and textiles (cotton and linen).



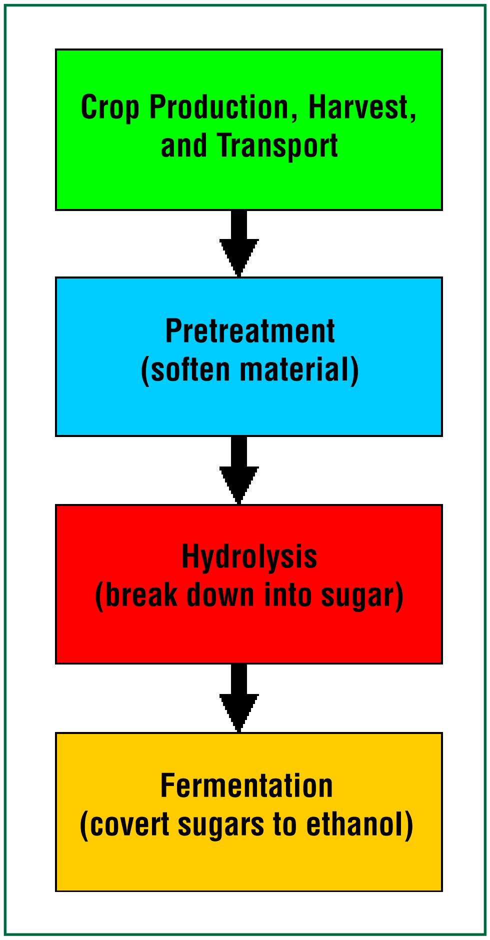


Figure 1. *Major Challenges in Producing Cellulosic Ethanol*

If cellulose chains are broken down into the individual "links," the released sugar can be used to make ethanol. This ethanol can then be purified using the same technology as corn-based ethanol production (Mosier and Illeleji, 2006). A number of technological advances are current under development to make this approach to biofuels economical.

Challenges in Cellulosic Ethanol

Using technology available today, cellulose can be converted into ethanol. The major difference between cellulosic ethanol and grain ethanol is the technology at the front end of the process. The technology for fermentation, distillation, and recovery of the ethanol are the same (Mosier and Illeleji, 2006).

The major challenges (Figure 1, page 2) are linked to reducing the costs associated with production, harvest, transportation, and up-front processing in order to make cellulosic ethanol competitive with grain-based fuel ethanol and gasoline (Eggeman and Elander, 2005). The major processing challenges are linked to the biology and chemistry of the processing steps. Advances in biotechnology and engineering will likely make significant impacts toward achieving the goals of improving efficiency and yields in processing plant material to ethanol.

Plant Biotechnology

Most of the recent biotechnological advances in crop genetics have focused on grain production. Bioenergy crops will be grown for the inedible portion of the plant (cellulose-rich cell wall material in leaves and stems) and not primarily for grain.

The tools of biotechnology are beginning to unlock the secrets of how plant cell walls are synthesized (Yong et al., 2005 and Humphreys and Chapple, 2002). This knowledge is being used to alter genes in plant that make them more productive in cellulose production and make the cellulose more easily converted to biofuels (Vermerris et al., 2005). In summary, plant genetics research and biotechnology are giving researchers the tools to increase agricultural yield of cellulosic plant material that is tailor-made for conversion to biofuels (Ragauskas et al., 2006).

Pretreatment

Pretreatment is the name given to processing done to the plant material before it is broken down into simple sugars (hydrolysis). This is done to soften the cellulosic material to make the cellulose more susceptible to being broken down. Thus the subsequent hydrolysis step is more efficient because the breakdown of cellulose into sugar is faster, higher in yield, and requires fewer inputs (enzymes and energy).

The leading pretreatment technologies under development use a combination of chemicals (water, acid, caustics, and/or ammonia) and heat to partially break down the cellulose or convert it into a more reactive form (Mosier et al., 2005). Better understanding of the chemistry of plant cell walls and the chemical reactions that occur during pretreatment is leading to improvements in these technologies which lower the cost for producing ethanol (Eggeman and Elander, 2005).

Hydrolysis

In the hydrolysis step, the cellulose and other sugar polymers are broken down into simple sugars through the action of biological catalysts called "enzymes." These enzymes are produced by fungi that feed upon dead plant matter in the natural world.

Our understanding of how these enzymes work is aiding efforts in determining what collection of enzymes working together can best hydrolyze cellulose in industrial applications (Mosier et al., 1999). Biotechnology has allowed these enzymes to be produced more cheaply and with better properties for use in biofuel applications (Knauf and Moniruzzaman, 2004).

Fermentation

The equipment and processing technology for producing ethanol from cellulose is the same as for producing ethanol from grain. In addition, yeast used in grain-based ethanol production can use glucose obtained from cellulose. However, only about 50-60% of the sugar derived from cellulose-rich plant materials is glucose. The remaining 40-50% is largely a sugar called "xylose," which naturally occurring yeast cannot ferment to ethanol.

Biotechnology has been used to genetically modify yeast (Sedlak and Ho, 2004) and some bacteria (Ohta et al., 1991) to allow them to produce ethanol from *both* glucose and xylose. These advances increase the amount of ethanol than can be produced from a ton of cellulosic material by as much as 50%. Additional improvements, based upon understanding the basic metabolism and genetics of microorganisms, are underway to increase the efficiency and rates that the microorganisms convert xylose to ethanol (Bro et al., 2006).

Conclusion

Fuel ethanol produced from non-food plant materials can contribute significantly to reducing the use of petroleum for automobile transportation in the U.S. Advances in basic science and technology across a number of disciplines are required to make the process of converting this abundant raw material into fuel economically competitive with grain-based ethanol and gasoline.

Applications of biotechnology to crops, industrial microorganisms, and industrial biocatalysts (enzymes) together with bioprocess engineering to integrate and optimize production technologies are likely to make production of cellulose-based ethanol a reality.

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