NREL Advances in Technology at the National Renewable Energy Laboratory

Technology Brief

NREL Getting Extra “Corn Squeezins”

Cooperative Agreement Uses Cellulosic Fiber to Get More Ethanol from Corn

How do you improve a technology that already helps to reduce both air pollution and America’s dependence on foreign oil? The answer to that question is at the heart of a cooperative research and development agreement (CRADA) between the National Renewable Energy Laboratory (NREL) and New Energy Company of Indiana. Using technology developed at NREL, New Energy is looking to squeeze extra transportation fuel from the corn it processes into ethanol (grain alcohol) at its plant in South Bend, Indiana. This technology for making ethanol from corn fiber was recently honored by *R&D* magazine as one of the 100 most important technological innovations of the last year.

New Energy Company of Indiana is pilot-testing use of NREL technology to convert up to 13% more of this renewable, domestic resource into ethanol, a clean-burning automotive fuel.

Ethanol made from corn is already used as an additive in about 9% of the gasoline sold in the United States. The added ethanol boosts octane and reduces carbon monoxide emissions. The Clean Air Act Amendments of 1990 require the use of oxygenated fuel additives such as ethanol in 44 cities with carbon monoxide pollution problems. This could contribute to a rise in U.S. ethanol production from about 3.8 billion liters (1 billion gallons) per year to about 11.4 billion liters (3 billion gallons) per year by the year 2000.

In a process essentially similar to that used to make “moonshine,” current technology for producing ethanol from corn uses enzymes to convert the starch of corn kernels to sugar and then uses yeasts to ferment that sugar to ethanol. But the starch is only about 72% of the corn kernel. Protein, fibrous material (cellulose, hemicellulose, and lignin), fats, and some of the starch are left over and processed into animal feeds. Under a CRADA with NREL, New Energy is building a pilot plant that will produce additional ethanol from the carbohydrates in these leftovers.

Technology’s BRIGHTEST STARS

1993 AWARD WINNER

Selected by *R&D* magazine as one of the 100 most technologically significant products of the year

The pilot plant’s initial facilities, including two 8000-liter (2114-gallon) fermentation tanks, are now complete and operational at New Energy’s plant site. Results from the CRADA should provide New Energy with all the information needed to design a full-scale production operation. New Energy currently produces 265 million liters (70 million gallons) of ethanol per year, about 7% of total U.S. production.

NREL's technology for making ethanol from corn fiber was honored by R&D Magazine as one of the 100 most important technological innovations of the last year.

Ethanol is Produced in Two Ways

There are two primary methods used for making ethanol from corn: dry milling and wet milling. Dry milling, used for about one-third of ethanol production, is designed primarily for producing ethanol. Wet milling, used for the other two-thirds of ethanol production, generates a variety of products as well as provides a feedstock for making ethanol. New Energy utilizes the dry-milling process.

In the dry-milling process, amylase enzymes are added to the dry-milled corn to liquefy it and convert it to sugar. Yeast is then added to ferment the sugar, and the resulting "beer" is distilled to extract the ethanol. The remains from the bottom of the distillation column, known as stillage, contain protein, fats, and other material in addition to the cellulose, hemicellulose, and unconverted starch carbohydrates. The stillage is dried to produce an animal feed supplement called distillers dried grains and solubles (DDGS).

Thirteen Percent Increase in Yields is Expected

The pilot plant is designed to use streams from one or more of several possible points in the dry-milling process as the feedstock for the new fiber conversion process. The beer produced by the pilot plant's fermentation of the cellulosic material and unconverted starch can then be fed back into the main distillation process. By taking advantage of this leftover material, New Energy and NREL expect to increase ethanol yields by up to 13%. Animal feed is still produced, but with reduced solids content.

The technology should work equally well, however, for the wet-milling process. In the wet-milling process, corn oil, a high protein animal feed known as corn gluten meal, another animal feed known as corn gluten feed, and starch-derived products are produced. The corn gluten meal and corn gluten feed both contain cellulose, hemicellulose, and leftover starch. As with dry milling, there are several points in the process where streams containing those carbohydrates can be used as feedstock for production of "extra" ethanol.

Lesser By-Product is More Valuable

In the usual ethanol-from-corn processes, the animal feeds made from the leftover material are valuable by-products that significantly improve the economics of the process. New Energy will still have solids left over to turn into animal feed, but instead of the reduced volume of feed having less value, it may actually be worth more. Although the total amount of feed will be reduced, the fraction of protein in the feed will be greater. Because the price of animal feed is based largely on its protein content, the more protein-rich feed should command a higher price, so the total revenue from feed sales should be about the same. At the same time, the shipping cost of the feed (much of it goes to Europe) will go down substantially, making it worth more to the producer.

Corn Fiber is Just the Beginning

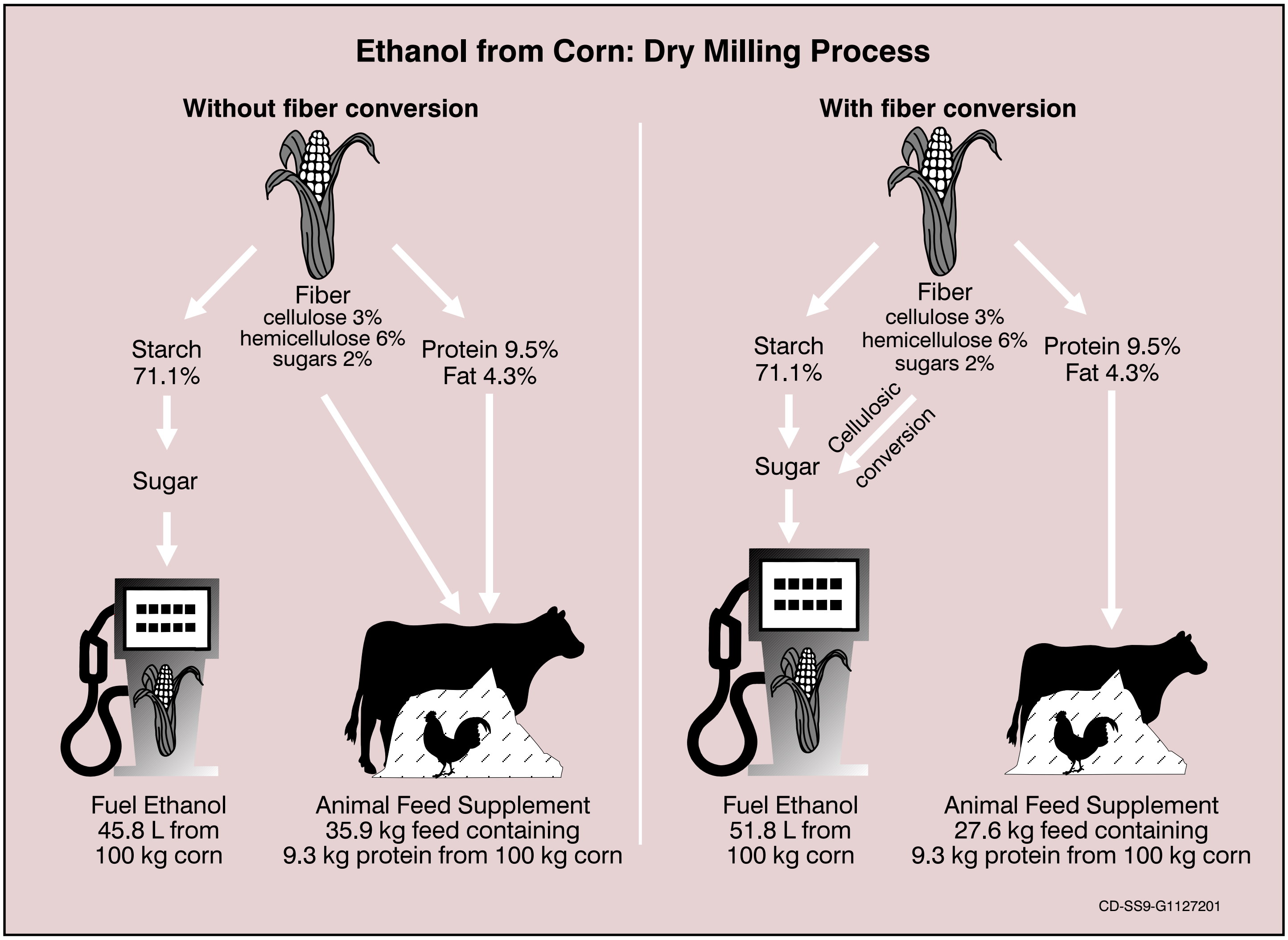
It has been estimated that ethanol production from corn kernel starch alone could probably be increased fivefold to produce about 4% of current U.S. gasoline consumption without unduly affecting grain prices. Producing ethanol from corn fiber in the kernels as well would expand that potential.

The Chemistry Involved

Like starch, cellulose and hemicellulose are carbohydrates composed of chains of sugars bonded together. But the sugars in cellulose and hemicellulose are joined in a different manner than for starch; the cellulose chains are also interconnected in a crystalline structure. These differences provide the rigidity and the indigestibility that we associate with woody materials. The common amylase enzymes that convert starch to sugar in human digestion or beverage brewing cannot work on cellulosic materials.

Researchers at NREL and elsewhere, however, have developed a sophisticated set of biotechnological tools to break, or hydrolyze, the interconnecting bonds in cellulose and hemicellulose and make it possible to produce alcohol from these carbohydrates. They have selected cellulase enzymes, which convert cellulose to sugar that can then be fermented by yeast. They have selected fungi and are also genetically engineering bacteria to produce large quantities of these enzymes.

Although hemicellulose is easier to break down into sugars than cellulose is, the primary sugar obtained, xylose, is not fermentable by common yeasts. Researchers developed two ways to overcome this problem. In one, they genetically engineered bacteria to produce an enzyme (xylose isomerase) that converts the xylose to a more easily fermentable sugar (xylulose). In the other, they are selecting yeasts and genetically engineering bacteria that can directly ferment the xylose.



By proving the feasibility of producing ethanol from the fibrous or cellulosic material in corn kernels, New Energy and NREL will be opening the door for a new industry that can potentially reshape automotive fuel production. For example, corn cobs and stover (husks and stalks) do not contain starch or have food value, but they are cellulosic and thus have promise as feedstocks for ethanol production. Beyond the corn industry, potential feedstocks are virtually unlimited, ranging from specially grown grasses or trees to wastepaper.

The ability to use this full range of cellulosic material as feedstock would enable ethanol production to meet the entire U.S. demand for gasoline at a low cost. Straight or neat ethanol requires a few adaptations in cars, but it works quite well as automotive fuel and greatly reduces polluting emissions. About 40% of the cars in Brazil use neat ethanol; the rest use a 22% ethanol blend with gasoline. Neat ethanol's only real drawback is reduced mileage per gallon (about 80% of that for gasoline), requiring more frequent fill-ups. A number of public fleet vehicles in the United States are currently testing blends with 5% or 15% gasoline added to improve cold starting of the engines.

Project is an Outstanding Opportunity

NREL sees the corn fiber CRADA with New Energy Company of Indiana as an outstanding opportunity. By marrying the developing technology of producing ethanol from cellulosic material with the established process of producing ethanol from corn starch, it may be possible to move to commercial-scale production far more quickly than could otherwise be expected. New Energy and others who produce ethanol from corn are also in a good position to produce ethanol from the cellulosic material contained in corn

The ability to use the full range of cellulosic material—from grasses or trees to wastepaper—would enable ethanol production to meet the entire U.S. demand for gasoline.

This 8000-liter fermentation tank is one of two at the New Energy pilot plant. This pilot plant could open the door for a major biofuels industry by demonstrating NREL technology for turning corn fiber or other cellulosic material into ethanol.

fiber. The corn fiber feedstock is virtually free, and much of the equipment is already in place. There is also potential to add other very low-cost feedstocks such as corn cobs, corn stover, or wastes from other corn processing industries.

NREL is particularly pleased to have the New Energy project receive the R&D 100 award, because it was NREL's first CRADA. This exciting program, authorized by the National Competitiveness Technology Transfer Act of 1989, allows industrial partners to join with NREL and other national laboratories to develop energy technologies to the point of commercialization. The NREL–New Energy CRADA, with its potential to decrease the cost of ethanol produced from corn and to prove a technology for producing ethanol from a wide range of biomass materials, clearly shows the tremendous benefits than can result from such cooperative efforts.

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Produced by the Communications and MIS Branch for the Alternative Fuels Division
NREL/MK-336-5639 (revised) 11/93

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Operated for the U.S. Department of Energy by the Midwest Research Institute

Printed with a renewable source ink on paper containing at least 50% wastepaper