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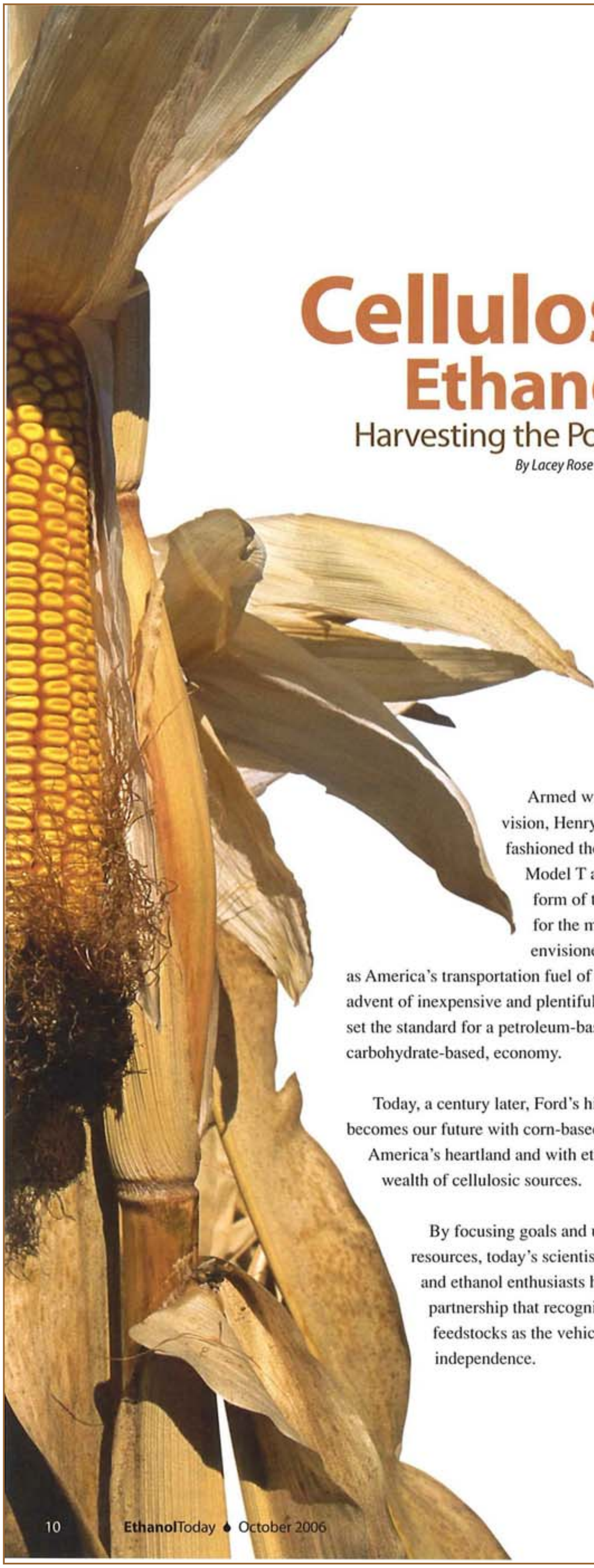

Cellulosic Ethanol
Harvesting the Potential

By Lacey Rose Horkey

Armed with a futuristic vision, Henry Ford fashioned the sturdy Model T as a reliable form of transportation for the masses and envisioned ethanol as America's transportation fuel of choice. The advent of inexpensive and plentiful crude soon set the standard for a petroleum-based, rather than carbohydrate-based, economy.

Today, a century later, Ford's historic plan becomes our future with corn-based ethanol from America's heartland and with ethanol from a wealth of cellulosic sources.

By focusing goals and uniting resources, today's scientists, researchers, and ethanol enthusiasts have formed a partnership that recognizes cellulosic feedstocks as the vehicle of energy independence.

"Cellulosic ethanol conversion technology will allow us to use lower cost, more abundant feedstocks to make badly needed liquid transportation fuel," said Dr. John Ashworth, team leader, partnership development with the National Biology Center and the National Renewable Energy Laboratory (NREL). "We are projecting as much as 60 billion gallons of total ethanol production (corn plus cellulose) per year by 2030. This would account for 30 to 40 percent of the U.S. gasoline pool."

Bill Baum, an executive vice president at the San Diego-based enzyme specialty company Diversa Corporation, agrees that corn-derived ethanol will not independently displace our nation's oil imports. "If you think about it, right now our total output is just under five billion gallons," he said. "Thirty billion gallons is still less than 25 percent of our oil imports today. You are always going to be replacing some petroleum, but you will never replace all."

Yet, the word *some* grasps the attention of a nation seeking to eliminate its dependence on foreign sources of oil. Ryan Waddington, Director of Venture Services for NextEnergy, a non-profit organization that develops alternative energy technologies (AET), says cellulosic ethanol production should support the energy diversity and economic security attributed to current ethanol production.

"Both traditional and cellulosic technologies will play a vital role in helping us achieve and exceed set goals for renewable fuel development," he said. "No one technology is likely to eliminate our oil imports, but cellulosic ethanol has the potential to play a significant role in that effort."

"We see the first adaptation of cellulosic ethanol will probably be at wet mills or dry grind ethanol plants, using the captive stalks already at the plant."

By establishing cellulose branches of current ethanol production facilities, Ashworth believes the industry can reduce the infrastructure costs that may delay the melding of production processes.

"Existing ethanol plants already have the transportation infrastructure, as well as key components such as fermentation tanks and distillation sub-systems," he said. "Adding on a cellulosic ethanol train to an existing ethanol plan will probably be more cost-effective than buildin a 'greenfield' cellulosic ethanol facility."

Although the production of corn ethanol benefits from experience, the production of cellulose-based fuels must hone an efficient, cost-effective operation. In particular, Ashworth designates three challenges as "finding low-cost feedstocks (in the range of $25 to $30 per ton delivered to the plant); getting the cost of enzyme down to the level routinely found for enzymes in corn ethanol plants; and developing a robust, industrial ethanol producing micro-organism (yea or bacteria) that can use all the biomass sugars, is highly ethanol tolerant, and can produce high levels of ethanol in a short time period."

Unlocking energy

Dr. Kevin Gray, the director of alternative fuels for Diversa, believes that "there still has to be a lot of technology developed to start up a purely cellulosic ethanol plant." He added that seizing the appropriate technology for decoding biomass decomposition will require expertise from a variety of industry leaders and scientists. "It is an aggregation of technical expertise," he said. Gray recognizes the goal of the industry as one where the complex structure of biomass can be understood without leaving a damaging economical or environmental footprint.

According to the DOE's 2006 Biofuels Joint Roadmap, "Cellulosic ethanol has the potential to meet most, if not all transportation fuel needs. However, due to the complex structure of plant cell walls, cellulosic biomass is more difficult than starch to break down into sugars."

The challenge exists because biomass material gives trees and plants their structural strength and resists decomposition. Biomass is composed of cellulose, hemicellulose, and lignin, and it resists conversion into sugar molecules that can be made into ethanol.

Unlike sugar cane or starch feedstocks, biomass conversion requires additional thermochemical pretreatment to isolate sugars. For sugar cane, fermentation quickly transforms sugar molecules into pure ethanol. With starch feedstocks such as corn, enzymatic treatment converts starch to sugar prior to the fermentation. For biomass feedstocks, however, pretreatment aids enzymatic digestion before enzyme treatment and fermentation can occur. These additional operations accrue costs in time and energy

Emalfarb says that while ethanol advocates recognize the importance of cellulose, they fail to identify the complexity of its composition and the challenge this dilemma presents. "It isn't just about ethanol; it is about making cheap, fermentable sugars which can be utilized to displace petroleum as a feedstock in manufacturing plastics and polymers as well as ethanol."

To isolate fermentable sugars, scientists have traditionally chosen hydrolysis, a combination of high temperatures and harsh acids, to break down cellulose molecules. Although the hydrolysis process successfully prepares sugar molecules for fermentation, the sensitive process' time and energy demands decrease its efficiency.

According to Baum, the key to efficiency of ethanol production lies in the conversion percentage. While the conversion of starch results in 17 to 18 percent ethanol, the conversion of biomass yields 5 to 6 percent ethanol. Baum points out that, at these percentages, the production of ethanol remains inefficient.

"It takes one hundred times more enzyme to digest cellulose compared to starch. Pretreatment is there to make cellulose more accessible as well as make it less crystalline."

"If you don't convert a large percentage of biomass, you are going to have a lot of material left over," he said. Because remaining biomass from the production process becomes a waste product, scientists strive to recover as much sugar as possible.

Gray explains that cellulose "is very crystalline in structure and very difficult to digest," he said. "It takes one hundred times more enzyme to digest cellulose compared to starch. Pretreatment is there to make cellulose more accessible as well as make it less crystalline."

After a successful pretreatment phase, a powerful mixture of enzymes attacks the biomass in search of additional sugar. Enzymes, working in mixtures known as cocktails, serve as nature's communicators by targeting the molecules for fermentation.

Baum equates the creation of enzyme cocktails to the challenge of mastering an intricate equation - a frustrating, yet exciting process of isolating key elements. "Once we know the conditions - the pH and the temperature of what we want to have the biomass coming out of the pretreatment system - then we go through our libraries looking for genes," he said.

During his nine years in research and development, Gray has explored rural farm sites and deep sea vents in search of carbohydrate-hungry enzymes. "It is very complicated, but there are lots of organisms that have been able to digest cellulose." Such organisms may provide the pathway for scientific manipulation and ethanol conversion.

"We have been able to channel energy in the pathway we want," Emalfarb said. "We put a new gene in, a new enzyme comes out. How effective these enzyme mixtures are at breaking down

The promise of biomass is nothing new. The USDA has researched prairie grasses for decades, as shown in this historical Natural Resources Conservation Service photo.

biomass into fermentable sugars and at what cost are some of the questions that Dyadic has been addressing for over a decade." He described the process of gene selection as one of matching locks and keys. "The more we understand what we want to unlock, the better we are at unlocking it."

Locating keys for specific locks demands countless experiments. Fortunately, experimenting with thermal, chemical, and biochemical techniques has enabled researchers to make significant progress toward the commercialization of ethanol production from cellulose feedstock. However, Cooper suggests that in order for enzymatic pretreatment to be practical "the enzymes have to be in a range of 10 to 20 cents per gallon of ethanol."

Baum believes that isolating the most effective enzymes at a practical price will occur within two to three years, but the industry remains "five years away from the commercialization of a process that would do the whole cellulosic process." Ashworth agrees. "We think that cost of cellulosic ethanol will approach that of corn-based ethanol in the next five to six years," he said.

Achieving economic viability

Besides the challenge of managing costs during the pretreatment stage of cellulose digestion, economic viability must be achieved by unlocking logistical and financial barriers. According to Waddington, the cellulose market needs to benefit from the large-scale infrastructure that enables the ethanol production process to run smoothly.

"Intermediaries, such as wholesalers, transporters and the like, must emerge and create an efficient market to enable wide-scale use of these materials in ethanol production," he said.

In addition to production costs and infrastructure challenges, environmental risks accompany the surge to harvest biomass feedstocks. Biomass serves as functional groundcover for harvested fields and forest floors by increasing moisture retention in the soil and preventing erosion.

Ashworth reported that the United States can potentially provide 1.3 billion tons of biomass for fuel production without threatening the environment. "USDA has demonstrated that you can take some fraction of the crop residues for fuel production (say 25 to 40 percent), return the remainder to the field, and have long term soil health."

Recalculating the food vs. fuel equation

Despite misconceptions, both soil health and corn-derived food supplies can be protected. "We have a tremendous amount of corn still left to feed animals," Baum said. "The food chain supply is not going to suffer. There is probably less than five percent of total corn grown that people eat."

Cooper says that national corn supplies have been growing in tandem with demand. Higher corn yield per acre is responsible for increased levels of corn production, though increased demand for ethanol is likely to encourage the planting of additional corn acres in the future.

"People who say we're going to run out of corn are only looking at the demand side of the equation," he said. "People are failing to look at the supply side of the equation. It's true that we're using more corn today than ever before - but we're growing more corn, too."

With more than 100 plants producing ethanol and more than 50 under construction, ethanol supplies continue to exceed yearly goals. In addition, the ethanol industry continues to improve the efficiency of ethanol production. Today, nearly three gallons of ethanol can be produced from a bushel of corn.

By examining the potential that lies within effective electricity production from biomass, increased ethanol extraction from biomass and starch feedstock, and improved distillers grain processing, the industry's impact will multiply. Furthermore, scientists and researchers continue to raise the bar on the ethanol industry's value-added products. Cooper emphasizes that advancements can be made in the co-product facet of the industry because unconvertible sugars remain locked within dried distillers grain (DDG).

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"We are going to shift from a petroleum-based economy to a carbohydrate-based economy. It is back to the future."

According to researchers from Dyadic International, ethanol producers in 2005 were left with more than 9 million metric tons of DDG. Emalfarb estimates that unlocking sugar streams from DDG could yield an additional 90 gallons of ethanol per ton of DDG.

"Approximately 50 percent of the material is cellulose and xylans," he said. "If you unlocked 80 percent of the sugars in the DDG, you would end up with approximately 810,000,000 additional gallons of ethanol. At $2.50 per gallon of ethanol, $2 billion of additional ethanol revenues could be generated without demanding additional corn. This number will only increase as additional ethanol plants come on line in the future."

Fusing resources, conquering challenges

Necessary technological advancements require countless hours of research and cooperation among branches of the industry. "It is going to take a consortium of companies," Baum said. In fact, he predicts that the success of cellulosic ethanol depends on convincing service centers and fuel stations that the economic benefits of cellulose far outweigh the profits of foreign petroleum. "In the end, the fuel companies will want to market it."

Although companies like Iogen of Canada continue to explore cellulosic ethanol pilot facilities, no cost-effective, full scale production exists. To encourage the advancement of the industry in the U.S., the DOE launched a cost-shared solicitation program (closed as of August 10) to encourage construction and production of cellulose ethanol on a commercialized level. Two or three applicants will receive 40 percent government funding for a biomass ethanol facility that achieves cellulose ethanol production by 2010 or 2011. At ACE's recent Ethanol Conference and Trade Show, Ashworth described the proposed enterprise as "the learning curve of this industry."

Cooper believes the nation must strive for efficient ethanol production and prepare for an upcoming partnership between cellulose and starch ethanol production.

"Years down the road, we are going to need cellulosic ethanol to supplement the corn harvest supplying ethanol from starch sources," he said. "It is not going to be an either/or-type scenario; it is going to be both."

Waddington says that broadening the scope of ethanol production will protect both agricultural and industrial facets of the industry.

"Having multiple feedstocks supply the ethanol production industry will increase the resilience of the system and reduce the impact of drought and pests, and also allow farmers selling into the ethanol production industry to rotate crops and take better care of their land while still reaping the benefits of a growing market," he said. "There is plenty of room for partnership between the two approaches and a growing market will create significant opportunity for both for a long time to come."

Ashworth predicts that the first smaller scale commercial plants will be operational in 2010-2011. "These initial plants will probably be co-located with existing ethanol, forest products, or food processing plants. We think that the technology to make cellulosic ethanol for $1.07 per gallon should be ready and proven at the pilot scale by 2012 and scaled up shortly thereafter."

According to Baum, the science of cellulosic ethanol resembles a well-oiled machine whose intricate parts must work together. "The entire machine has to work all together and it has to be synchronized," he said.

While the goal of full-scale production of alternative fuels from biomass has not been realized, the pieces are beginning to come together. These agricultural and mechanical pieces serve as the foundation of today's progress and tomorrow's energy independence.

"We are going to shift from a petroleum-based economy to a carbohydrate-based economy," Emalfarb said. "It is back to the future."