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Beyond corn: Ethanol's next generation

Scientists seek cheap, plentiful energy alternatives

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WEST LAFAYETTE, Ind. -- Sitting in a cluttered, windowless office here surrounded by pictures of her three grandchildren, Nancy W.Y. Ho did her best on a recent afternoon to show why everything you thought you knew about ethanol is wrong.

It's not just about distilling auto fuel from corn, explained the 71-year-old molecular biologist from China. It's about weaning America from its self-destructive oil habit by tapping the energy in everything else that grows--and rots--all around us.

Ho has spent the better part of a career at Purdue University figuring out how to rejigger the DNA of a simple form of brewer's yeast by cloning a gene nobody else had thought to clone.

Now, if you stir her creation into a beaker filled with the sugars derived from throwaway organic materials like wheat straw, switch grass, orange peels, even municipal garbage, it will gradually convert most of them into high-octane auto fuel.

"Everybody knows that [corn] is not enough," Ho said. "We have to use all the resources we can."

As the combines roll across fields throughout the Corn Belt this harvest season, the debate over ethanol has never been hotter. On Wednesday, President Bush reiterated his support for ethanol funding at a conference on renewable energy in St. Louis. But critics bemoaning the folly of hefty government subsidies over the years continue to insist that ethanol is a wasteful, extravagant boondoggle.

Producing ethanol from corn in any real volume, they say, threatens the food supply, uses too much land and creates a litany of messy environmental issues. The U.S. burns through 140 billion gallons of gasoline a year. Replacing that with ethanol is pipe dream.

Changing the game

For a growing number of scientists, entrepreneurs and policymakers, however, the constant grumbling about corn ethanol entirely misses the point. While they don't disagree that the corn-based fuel has major limitations, they insist that obsessing over them is like disparaging first-generation personal computers for being slow and unwieldy.

Breakthroughs in genetic and industrial engineering, they insist, are changing the game. Not only is technology making corn ethanol more efficient, but researchers like Ho are making striking progress toward tapping what scientists call cellulosic biomass, the vast store of non-food plant matter that grows and renews itself daily.

If they succeed, many experts believe, cellulosic ethanol could be a plentiful, cheap and easily renewable oil alternative, with few of the negatives that plague the corn-based variety.

"It's the holy grail ... if you can make it work," said John Felmy, chief economist at the American Petroleum Institute.

The question is, can you really make it work?

On a sun-baked plateau in Golden, Colo., scientists at the Department of Energy's National Renewable Energy Laboratory have been working on that question for three decades. James McMillan, a top biochemical engineer at the lab, said the outlook has never been brighter.

One measure of that promise is the unprecedented investment pouring into the industry. Most recently, British transportation magnate Richard Branson has pledged $3 billion over 10 years for research into cellulosic ethanol and other biofuels. BP PLC, the world's second-largest oil company, has earmarked $1 billion to be split evenly between research and venture financing.

Even Bush has surprised his allies in the oil business by pushing the Energy Department to dole out more than $400 million in fresh funding for ethanol-related research and development.

"This country's got to use its talent and its wealth to get us off oil," Bush said on Wednesday. "I believe, and Congress agrees, that the proper use of tax credits will help stimulate a new industry that will help our economy and help us with national security."

Strolling through a state-of-the-art test facility in Golden devoted to distilling cellulosic ethanol, however, McMillan makes it clear that the future isn't here yet. The building is a welter of pipes, tanks and valves, and as he points out the different phases of the production process he notes that crucial improvements must be made to each if cellulosic ethanol is ever going to truly compete with oil.

Looming stubbornly in front of researchers is a masterpiece of evolution: the rigid cell walls that give plants their strength and resiliency. Developed over the eons, these walls allow a slender stalk of prairie grass to bend like a ballerina in the wind yet snap back to attention to fend off cold, heat and pestilence. They help explain why a field of corn can grow over a man's head in a matter of a few short months.

The problem is, breaking down those walls is like robbing a bank. While the starch in corn kernels gives up its energy-packed sugars easily, the sugars in plant cell walls are locked into winding structures of complex carbohydrates designed to give plants backbone and protection.

Getting at those sugars in an efficient way is the secret to tapping the energy potential of cellulosic biomass, McMillan explained. Researchers long have known how to do it in the lab. But nobody has yet proved it can be done profitably in a commercial-scale plant. To get there, some of the best minds in science are creating such wonders as fungi that are genetically modified to spit out vats of powerful enzymes, and transgenic prairie grasses that are bursting with energy yet engineered to break down more easily.

"This is transformative technology," said Sharlene Weatherwax, a program manager in the U.S. Energy Department's Office of Science. "It's pretty daunting."

What's even more daunting is the economic challenge. Estimates are unreliable, but at the moment most experts believe it is probably more expensive to produce a gallon of cellulosic ethanol than an equivalent volume of gasoline. The comparison is even less favorable if you consider that ethanol produces about a third fewer miles per gallon than gasoline in typical engines. Fighting through these hurdles is attractive when oil is at $70 a barrel, but less so as the price falls. Most experts agree that corn ethanol is cost competitive when the price per barrel of oil is $40 or higher.

Despite using cheaper feedstocks to make cellulosic ethanol, the capital outlay to build more complicated plants drives up costs. McMillan said that it runs from $2.50 to $4 per gallon of capacity to build a typical cellulosic-ethanol plant. That compares with $1 to $1.50 for a corn-ethanol plant.

Plowing ahead

None of this has stopped pioneering companies like Canada's Iogen Corp. or Spain's Abengoa Bioenergy from plowing ahead with plans to build what the ethanol industry calls biorefineries. The Department of Energy has allocated $160 million to help develop three cellulosic demonstration plants. Iogen, Abengoa and several others have applied.

These ventures are highly risky but exactly what the industry needs, said Steven Koonin, oil giant BP's chief scientist. As the technology matures, he said, somebody like Iogen needs to build a plant, power through the learning curve and solve the inevitable problems that crop up.

Jeff Passmore, Iogen's executive vice president of development, is confident his company is well on the way to cracking the cellulosic-ethanol problem. But he also concedes that developing a new plant at commercial scale represents more a voyage of discovery than a hard and fast business plan.

"The more you know," Passmore said, "the more you know you don't know."

The reason Passmore and others persevere is that the knowledge gap has been closing faster over the past several years than it has for the past three decades. Breakthroughs in biotechnology are producing gains in productivity that are steadily driving costs out of each phase of the cellulosic production process.

Iogen, for instance, is using Ho's genetically modified yeast organism to address a major competitive handicap. As much as 40 percent of the sugars contained in typical forms of cellulosic biomass are of a type that normal yeast won't metabolize. Consequently, the process starts out at a 40 percent efficiency disadvantage to corn ethanol, which produces sugars that are 100 percent convertible with normal yeast.

The goal of Ho's cloning exercise was to tweak the yeast into converting both kinds of sugars almost simultaneously, boosting fermenting efficiency substantially. The result is a major step forward, but Ho and her colleague, Miroslav Sedlak, hope to do better. They are toiling to make the organism more efficient.

"With industry," Ho said. "if its not efficient, nobody is going to use it."

For Chicago native Mark Emalfarb, who founded a Florida biotech company called Dyadic International Inc., the hard work originally involved stonewashed jeans.

In the early 1990s, he ferreted out a fungus discovered on the floor of a lakeside forest on Russia's Pacific Coast. Known as chrysosporium lucknowense, or C1, the organism produced the kinds of cotton-fading enzymes that allowed denim companies to take the stones out of the stonewash process.

What the enzymes actually did was break down the plant cell walls in cotton, the same metabolic process needed to release the sugars for cellulosic ethanol. Unfortunately, the fungus produced the enzymes only in tiny amounts. So Emalfarb hired a team of scientists to bombard C1 with ultraviolet radiation until it one day mutated into a "biofactory" that could spit out enzymes in commercial quantities.

"We don't even know how the hell it happened," Emalfarb said. "It was serendipitous."

Dyadic has since introduced C1 into the same kind of high-speed robotic screening process that pharmaceutical companies use to ferret out new drugs. That means splicing different sequences of DNA into thousands of individual C1 fungi at a time and seeing what enzymes each one produces as a result of its newly altered genome.

The goal is to find enzymes, or "cocktails" of enzymes, that are particularly adept at breaking down various kinds of plant matter. Once researchers find the right enzyme recipe for breaking down, say, wood chips, they can genetically alter C1 to produce that particular blend of enzymes in quantity, something evolution might take eons to do.

"It's like Charles Darwin on steroids," said Dyadic Vice President Sasha Bondar.

Ancient discovery

Mike Himmel, a principal scientist at the National Renewable Energy Laboratory, said this sort of eye-popping research is happening across many branches of science and engineering. He recently attended a conference in Aspen, Colo., where a plant geneticist gave a paper on primordial plants that had low levels of a substance called lignin and high levels of sugar. Because the plants grew in swamps, they hadn't yet evolved the defensive structures that lignin offers modern plants.

"It occurred to me that what people are really going to be doing here is redefining modern plants to look more like ancient plants," Himmel said.

Richard Hamilton, CEO of a California plant genetics company called Ceres Inc., is trying to do exactly that. By analyzing 12,000 switch-grass genes and characterizing the genetic variation associated with each one, Ceres has created a trait database that it hopes to use to create the most effective varieties of "energy crops."

Already, Ceres and its partner, the Samuel Roberts Noble Foundation, are marking genes to increase the effectiveness of conventional breeding. But they are working to perfect cloning strategies that turn on or turn off specific genes that regulate traits like yield, drought tolerance or plant structure.

Using the fruit fly of the plant world, a rapid-growing species called arabidopsis thaliana, the company clones hundreds of transgenic plants a week. The goal is to find novel traits--plants that might break down more easily in a biorefinery, for instance, or varieties that produce more energy per acre.

That would address what Hamilton termed "the tyranny of distance," a major cost issue for would-be producers of cellulosic ethanol. If a refinery needs tons of biomass to produce fuel, he said, "by the end of the year you're driving your truck a long way to get that wheat or corn stover." If Ceres could develop a higher-yielding plant, travel distance, and cost, would shrink accordingly, he said.

When asked how long it will take to transform some of these ideas into reality, Hamilton and others in the industry tend to shrug.

"Trying to predict technology trends is a fool's game," he said. "I wish I could put my finger on just one bottleneck. But it doesn't work that way."

On the other hand, most experts in the field agree that focus is a powerful thing, especially when the federal government starts to put real resources behind an idea. As evidence that giant steps can be made in a hurry, McMillan points to two enzyme companies called Novozymes Inc. and Genencor International. They took approximately $40 million in Department of Energy funding over five years and knocked the cost of the latest enzymes down from about $5.50 per gallon to about 20 cents.

The Department of Energy has set a goal of supplying 30 percent of the nation's need for transportation fuels with ethanol by 2030, a tall order given that ethanol currently supplies about 3.6 percent of the 140 billion gallons of gasoline we consume each year.

But even some unlikely sources say the need for oil alternatives is severe enough to drive a major transformation.

"We're not going to replace oil in the next 20 years, but the resource is finite," said BP chief scientist Koonin. "The world is going to need more diverse hydrocarbons going forward. ... For many reasons it seems that this is the right thing at the right time. It's very exciting."

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Not all ethanol created equal

The vast majority of U.S.-made ethanol uses corn as its primary ingredient, but some researchers say that ethanol made from cellulosic biomass, or plant waste, is a better alternative.

U.S. ETHANOL PRODUCTION

For fuel, scale in billions of gallons

1980 '85 '90 '95 2000 '05

2005: 3.9 billion

CORN-BASED

Primary ingredient: Corn kernels

PROCESS

Grinding

Corn kernels are ground into flour, and water is added to form a "mash."

Unlocking sugars

Common enzymes are added to the mash to convert starches into dextrose, a simple sugar.

Cooking

The mash is cooked to reduce bacteria levels and then cooled.

Fermenting

Yeast is added to the mash in fermenters. After 40-50 hours, the sugar in the mash ferments into ethanol.

Distilling

Ethanol is separated from the rest of the mash and concentrated.

Blending

Ethanol is blended with about 5 percent of a denaturant to make it undrinkable and thus not subject to a liquor tax.

Finished ethanol for storage

Pros

- Starch in kernels contains easily accessible sugars to be converted to energy.

Cons

- Expanded use could lead to an increase in food prices and the need for much more cropland.

- Growing more corn and processing it into ethanol would require additional use of fossil fuels.

CELLULOSIC

Primary ingredient: Corn stalks, switch grass, wood chips, organic waste.

HOW CELLULOSIC PROCESS DIFFERS:

(Switch grass illustrated)

Unlocking sugars

Because its sugars are more difficult to extract, extensive pretreatment with acid or steam is required. Special enzymes also are used due to the stronger composition of the biomass.

Fermenting

Genetically modified yeast or another fermenting agent is required.

Pros

- Made from cheap, abundant materials.

- Expanded use of cellulosic ethanol would have no effect on the food supply.

- Production creates far fewer greenhouse gases than corn-based ethanol, in part because one of its byproducts, lignin, can be used to help power the plant.

Cons

- Requires an expensive process that is unproven on a commercial scale.

- The cost to build a biorefinery is $2.50 to $4 per gallon of production capacity compared with $1 to $1.50 for corn-based ethanol.

Sources: Renewable Fuels Association, Tribune reporting

Chicago Tribune/Adam Zoll and Phil Geib