Cellulosic ethanol booms despite unproven business models

Signs of consolidation in the young biofuel industry are already surfacing. Recent deals also illustrate a trend of moving away from first-generation biofuels derived from food crops such as corn, sugarcane and oilseed, and toward the next generation, made from more plentiful lignocellulosic feedstocks such as corn stover, grasses and wood chips.

In November, VeraSun Energy, a corn-ethanol company in Brookings, South Dakota, said that it is acquiring competitor US BioEnergy, of St. Paul, Minnesota, in a stock deal worth about $686 million. That same month, Basehor, Kansas–based Ethanix Energy announced its intent to acquire, for $220 million, an ethanol plant in Sutherland, Nebraska, from Midwest Renewable Energy of Joice, Iowa.

There have been other moves to put lignocellulosic ethanol on a firmer commercial footing. Broomfield, Colorado–based Range Fuels has begun construction on one of the first commercial-scale lignocellulosic ethanol plants. China has committed $5 billion to ethanol, with a focus on cellulosic technologies, and recently announced that it would not allow any further increase in starch-based ethanol production because of competing uses as food. Also, the French Agency for Environment and Energy Management, in Paris, announced late last year its plan to test three lignocellulosic biomass gasification processes and to develop the most promising of the three. Elsewhere in Europe, where biodiesel dominates the renewable-fuel market, the German government is collaborating with Forschungszentrum Karlsruhe to run a pilot plant near Karlsruhe, Germany, that can convert straw to a diesel-like fuel via synthesis gas (**Box 1**).

Most analysts agree that the growth of the ethanol industry depends on the success of next-generation technologies. To that end, the US Department of Energy (DOE), in Washington, DC, in 2007 doled out more than $1 billion toward lignocellulosic ethanol projects, with a goal of making the fuel cost competitive at $1.33 per gallon by 2012.

Leftover corn product after distilling at the Adkins Energy Ethanol Plant in Lena, Illinois. Second-generation biofuels that use alternative feedstocks are expected to replace corn-based ethanol.

"Virtually every ethanol company today is investing the resources necessary to develop a commercial cellulosic ethanol production," says Matt Hartwig, a spokesman for the Renewable Fuels Association in Washington, DC. On November 1, the formation of KiOR, a new venture in Hoevelaken, the Netherlands, marked the latest addition to the swelling group of lignocellulosic biomass-to-fuel start-ups (**Table 1**).

Scaling up operations for lignocellulosic feedstocks involves risks of its own, however. Transporting corn to ethanol biorefineries is a well-established system, and the feedstock is uniform. No matter where it grows, corn contains a certain percentage of starch that can be converted to sugar with enzymes and fermented with yeast to produce a predictable amount of ethanol. But no such system exists for lignocellulosic biomass. A wide range of feedstocks is being considered, and most don't have specific growing seasons or collection systems, not to mention that the composition of cellulose, hemicellulose and lignin—the tough materials to break down—varies within each feedstock.

Thermochemical methods, acid hydrolysis and enzymatic hydrolysis are all means of making ethanol from lignocellulose. But although enzymatic hydrolysis dominates the industry, one of its challenges is that the enzymes must be tailored to the feedstock.

Companies are seeking to provide the enzyme answers; Verenium, of Cambridge, Massachusetts, is investigating the termite gut—which is loaded with wood-degrading microbes—to identify enzymes that convert wood into sugars (*Nature* **450**, 487–488; 2007). Dyadic International, of Jupiter, Florida, is developing enzymes with a proprietary fungus that it will apply to Madrid-based Abengoa's cellulosic ethanol production process. Novozymes, in Bagsværd, Denmark, and Genencor, in Rochester, New York, are credited with significantly reducing the cost

Box 1 Beyond ethanol

US government private-sector funding for next-generation technologies typically has focused on ethanol. But as the available funds increase, other fuels and technologies may grab the Washington, DC–based Department of Energy's attention.

Making a diesel-like fuel from cellulosic feedstocks involves gasification using specific combinations of heat, pressure and steam, and then conversion of the synthesis gas into a fuel using a catalytic process such as the Fischer-Tropsch reaction. Choren in Freiberg, Germany, is employing a variation of this technique.

Some next-generation techniques involving noncellulosic feedstocks are in the works as well. LanzaTech in Auckland, New Zealand, has developed an organism that can convert industrial-waste carbon monoxide into ethanol. Greenfuels, of Cambridge, Massachusetts, along with several other companies, is working with algae to convert carbon dioxide into fuels.

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Table 1 Selected companies developing ethanol from lignocellulosic feedstocks

Company (location)	Feedstocks	Technology
Abengoa (Madrid)	Corn stover, wheat straw, milo stubble, switchgrass	Enzymatic hydrolysis; fermentation; thermochemical
ALICO (La Belle, Florida)	Wood, citrus waste, urban green waste	Thermochemical: gasification; fermentation
Bioengineering Resources (Fayetteville, Arkansas)	Urban green waste, wood chips, car tires, plastics	Thermochemical: gasification; fermentation
BioEthanol Japan (Osaka)	Wood construction waste	Enzymatic hydrolysis; fermentation (*Klebsiella oxytoca* and *Escherichia coli*)
Biogasol (Lyngby, Denmark)	Hay, grass, manure fibres, straw, paper	Enzymatic hydrolysis; fermentation
BlueFire Ethanol (Irvine, California)	Urban trash, rice and wheat straws, wood waste	Concentrated acid hydrolysis
China Resources Alcohol Corporation (CRAC) (ZhaoDong City, China)	Corn stover	Enzymatic hydrolysis; fermentation
ClearFuels Technology (Aiea, Hawaii)	Sugarcane bagasse	Thermochemical: steam reformation (similar to gasification); modified Fischer-Tropsch
Colusa Biomass Energy (Colusa, California)	Waste rice straw, rice hulls	Enzymatic hydrolysis; fermentation
Coskata (Warrenville, Illinois); company will launch January 14	Undisclosed	Undisclosed
Earthanol (Irvine, California)	Undisclosed	Undisclosed
Flambeau River Biorefinery (Park Falls, Wisconsin)	Spent pulping liquor	Alcohol sulfite cooking liquor to fractionate softwood chips; fermentation
Iogen (Ottawa, Canada)	Wheat straw, barley straw, corn stover switchgrass, rice straw	Enzymatic hydrolysis; fermentation (*Trichoderma reesei*)
Lignol Innovations (Burnaby, Canada)	Wood chips, corn stover, switchgrass	Enzymatic hydrolysis; fermentation
Mascoma (Cambridge, Massachusetts)	Switchgrass, wood	Enzymatic hydrolysis; fermentation (*Thermoanaerobacterium saccharolyticum*)
Poet (formerly Broin Companies) (Sioux Falls, South Dakota)/DuPont (Wilmington, Delaware)	Corn fiber, corn cobs	Enzymatic hydrolysis; fermentation
Range Fuels (Broomfield, Colorado)	Wood residues	Thermochemical: gasification; undisclosed catalyst
Verenium (Cambridge, Massachusetts)	Sugarcane bagasse, wood	Enzymatic hydrolysis; fermentation
Western Biomass Energy (Upton, Wyoming)/ KL Process Design Group (Rapid City, South Dakota)	Wood chips, wood waste	Enzymatic hydrolysis; fermentation

Sources: Biotechnology Industry Organization (BIO), companies

of cellulose enzymes over the past few years.

Despite these advances, skepticism from investors remains. "Every time I look at the overall economics of biofuels I just kind of go, 'Bah,'" says Robert Schrimpff, a senior associate at venture firm TVM Capital, in Munich. "Generally I've lost interest in looking for second-generation biofuel companies." He says that per acre, solar panels are much more efficient than plants at converting light into energy and that eventually the market for liquid fuels will succumb to hydrogen-electric or other energy-storage vehicles. "Even people investing in ethanol today can see that it's coming to an end."

Still, the heavy investments have enabled many companies to build production facilities and pilot plants, which produce less than 5 million gallons of fuel per year and are often aimed at R&D. "I can never judge when [a company] is on a commercial path," says Pat Gruber, CEO of Pasadena, California–based Gevo, a Caltech spin-out that is developing new routes to butanol and isobutanol. "The milestones that matter are when a pilot makes a product that is tested in the marketplace." Iogen, of Ottawa, Canada, is possibly the only company that has sold cellulosic ethanol on the market.

Until lignocellulosic ethanol becomes commercially viable, the existing corn-ethanol market is helping to build infrastructure for the next generation. All the ethanol fueling stations, petroleum-blending mechanisms and ethanol-compatible vehicles that are in place for corn ethanol will also work with cellulosic ethanol, since the two are nearly identical products. However, the supply lines for getting feedstocks to facilities and the construction of existing biorefineries do not translate to cellulosic ethanol, which will force companies to start from scratch.

Even as cellulosic ethanol seeks steady commercial footing, the ground is shifting. "What investors want to see now are projects that look beyond biofuels to byproducts," says Paul Winters, a communications director at the Biotechnology Industry Organization, in Washington, DC. Industrial chemicals, electricity and food ingredients are all potential byproducts that can help make a cellulosic plant profitable. The response to this is already underway: Lignol Innovations, in Burnaby, Canada, and Colusa Biomass Energy, in Colusa, California, are both planning to commercialize the lignin byproduct produced during their pretreatment processes. And this month, the DOE will award up to $200 million for proposals of pilot plants that can convert lignocellulosic feedstocks into some combination of transportation fuel, biobased chemicals and substitutes for petroleum-based products, says John Ferrell, a biomass manager at the DOE.

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