**VARIETY** Biobased fuel and chemical firms are investigating new sources for plant sugars.

POET-DSM (CORN STOVER), BETA RENEWABLES (GIANT REED), WIKIMEDIA COMMONS (GRAIN SORGHUM), RENMATIX (WOODCHIPS), GREENWOOD TREE FARM FUND (HYBRID POPLAR), USDA (NAPIER GRASS, ENERGY CANE, SWITCHGRASS)

# CHASING CHEAP FEEDSTOCKS

Biobased chemical companies seek **RAW MATERIALS** that can beat corn and natural gas

MELODY M. BOMGARDNER, C&EN WASHINGTON

**ON THE HOT,** dry agricultural land of California's Imperial Valley, 17 new varieties of an unusual crop are being tested on a 100-acre plot. If the tests are successful, the valley's bounty of lettuce, cantaloupes, and broccoli may someday be joined by plants that are converted into fuels and chemicals.

The crop, energy cane, is a less sweet cousin of sugarcane. It is a perennial grass that was developed by plant scientists to create a large amount of biomass quickly. Canergy, a biofuels start-up, plans to grow enough energy cane to power one or more commercial-scale fuel ethanol plants starting in 2016.

Although the valley is known for producing fruits and vegetables, more than half of its 450,000 acres are actually devoted to crops such as Sudan grass, used for hay. If enough farmers decide to add energy cane to their crop rotation, the region would produce a huge amount of biomass.

"It grows extremely well there—we're expecting phenomenal yields," says Timothy R. Brummels, Canergy's chief executive officer. He estimates that 1,800 to 2,200 gal of ethanol per year can be made from 1 acre of energy cane, compared with about 400 gal from 1 acre of corn.

Energy cane is a dedicated energy crop, a category of plants that also includes the giant reed *Arundo donax,* napier grass, switchgrass, and hybrid poplar. Investments in energy crops are one part of a larger push by the biobased fuel and chemical industry to secure cheap, abundant feedstocks. Chemical companies can use the material to produce acrylic acid and butadiene, for example.

For chemical firms seeking to make products from plants and other biomass, the push has a new urgency because of the abundance of shale gas in the U.S. This new source of natural gas, when used as a feedstock by the traditional chemical industry, is expected to bring down costs for many petrochemicals and make it difficult for biobased chemicals to compete.

Like most traditional ethanol producers, biobased chemical firms such as Genomatica, Gevo, and Myriant have built their processes to take in sugar from corn or sugarcane. Those sources carry downsides. For instance, prices rise and fall along with other commodities such as petroleum, and the supply of sugar may not be ample enough to meet the needs of high-volume chemical makers.

To ensure the viability of their industry, they are eager to replace those food sugars with a cheaper, more stable cellulose-based raw material. Executives say they are watching the growth of the cellulosic ethanol industry closely. Its success would pave the way to securing new cellulosic feedstocks for chemicals, they believe.

"Just about every one of our chemical partners is interested in the potential for using biomass feedstocks," says Christophe Schilling, CEO of Genomatica. "The motivation comes from a couple of different potential advantages—the first one is the potential for lower-cost feedstock. It still needs to be proven, but that is the hope. Then it is the stability of a secure supply of feedstock that doesn't have the volatility of hydrocarbons or commodity agriculture." Schilling adds that getting feedstock from nonfood sources is also important.

**THANKS TO** a half-decade of effort by the ethanol industry, clues are now emerging about how a cellulosic feedstock supply chain for chemicals would take shape. One thing is certain: The route is more complicated than for fossil-fuel feedstocks. "Part of the challenge is that shale gas is shale gas no matter where on Earth it comes from. But biomass is different with each crop," says Brian Balmer, chemical industry principal at the consulting firm Frost & Sullivan.

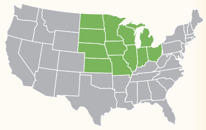
For that reason, making inexpensive sugars from plant-based feedstocks has become its own specialty. Canergy, Genomatica, and Gevo have partnered with Beta Renewables, which is a joint venture between the engineering firm Chemtex, owned by Italian chemical maker Mossi & Ghisolfi; private equity firm Texas Pacific; and enzyme maker Novozymes. The biobased chemical makers are interested in Beta Renewables' process for breaking down cellulose with steam and enzymatic treatment to release sugars.

## CONTENDERS The success of these ethanol crops will be influenced by regional growing conditions.

### CORN STOVER (stems, leaves, and cobs)

**Type:** Agricultural field residue

**Region:** Primarily midwestern U.S.



**Land-use impact:** None, if sufficient stover is left on the field to preserve soil nutrients

**Yield:**
**1–3 dry tons** per acre

**Life cycle $CO_2$ emissions:**

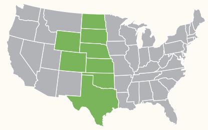
**23 kg** $CO_2$ per million Btu

**5 kg** $CO_2$ per million Btu if facility burns lignin for steam and power generation

### GRAIN SORGHUM (*Sorghum bicolor*)

**Type:** Feed grain for livestock

**Region:** Primarily the hot, dry plains from Texas to South Dakota; usually grown in rotation



**Land-use impact:** May displace sorghum grain used to feed livestock, thereby causing farmers to increase corn acres planted while decreasing planting of competing soybean acres

**Yield:**
**3–4 dry tons** per acre

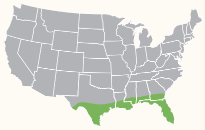
**Life cycle $CO_2$ emissions:**

**47 kg** $CO_2$ per million Btu

### GIANT REED (*Arundo donax*)

**Type:** Perennial grass

**Region:** Florida and southern portions of Texas, Louisiana, Georgia, Alabama, and Mississippi



**Land-use impact:** Unknown, but will probably be planted on least productive land first; has potential to become an invasive species

**Yield:**
**15 dry tons** per acre, with no nitrogen fertilizer applied after the first year

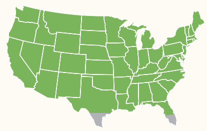
**Life cycle $CO_2$ emissions:**

**11 kg** $CO_2$ per million Btu

### HYBRID POPLAR (hybrid of *Populus* genus members)

**Type:** Fast-growing hardwood

**Region:** All of the continental U.S. except for the southern tips of Texas and Florida



**Land-use impact:** Small; poplar plantations are currently grown for paper pulp and lumber

**Yield:**
**10 dry tons** per acre

**Life cycle $CO_2$ emissions:**

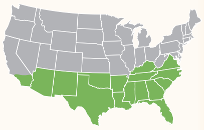
**9 kg** $CO_2$ per million Btu

**SOURCES:** Corn stover: Poet, Argonne National Laboratory/DOE; Grain sorghum: UC Davis, EPA; Energy cane: EPA; Giant reed: EPA; Switchgrass: EPA; Napier grass: EPA; Hybrid poplar: ZeaChem; Comparison life cycle $CO_2$ emissions: EPA, Argonne National Laboratory/DOE

**ENERGY CANE (hybrid of *Saccharum officinarum* and *S. spontaneum*)**

**Type:** Perennial grass related to sugarcane

**Region:** South-central and southeastern U.S.



**Land-use impact:** Likely to be grown on land otherwise used for pasture, rice, commercial sod, cotton, or alfalfa

**Yield:** +
**More than 7 dry tons** per acre unfertilized,
**11–20 dry tons** per acre fertilized

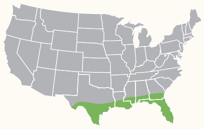
**Life cycle $CO_2$ emissions:**

**17 kg** $CO_2$ per million Btu

**NAPIER GRASS (*Pennisetum purpureum*)**

**Type:** Perennial bunchgrass

**Region:** Florida and southern portions of Texas, Louisiana, Georgia, Alabama, and Mississippi



**Land-use impact:** Likely to be grown on land otherwise used for pasture, rice, commercial sod, cotton, or alfalfa

**Yield:**
**14–18 dry tons** per acre

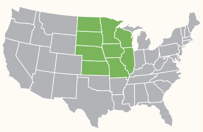
**Life cycle $CO_2$ emissions:**

**19 kg** $CO_2$ per million Btu

**SWITCHGRASS (*Panicum virgatum*)**

**Type:** Perennial bunchgrass

**Region:** Midwestern prairie states



**Land-use impact:** Displaces primarily soybeans and wheat and to a lesser extent hay, rice, sorghum, and cotton

**Yield:**
**Up to 5 dry tons** per acre

**Life cycle $CO_2$ emissions:**

**13 kg** $CO_2$ per million Btu

**Comparison life cycle $CO_2$ emissions**

**Gasoline:**

**98 kg** $CO_2$ per million Btu

**Corn ethanol:**

**62 kg** $CO_2$ per million Btu

**Sugarcane ethanol:**

**45 kg** $CO_2$ per million Btu

POET-DSM (CORN STOVER), WIKIMEDIA COMMONS (GRAIN SORGHUM), BETA RENEWABLES (GIANT REED), GREENWOOD TREE FARM FUND (HYBRID POPLAR), USDA (ENERGY CANE, NAPIER GRASS), SHUTTERSTOCK (SWITCHGRASS)

Beta Renewables is already using the process to produce ethanol from wheat straw and *A. donax* at its commercial-scale biorefinery in Crescentino, Italy. Chemtex plans to build a facility in Clinton, N.C., that will run primarily on a mix of energy crops that includes *A. donax* and use the Beta Renewables technology.

Beta Renewables says its process can deliver sugar from biomass for 10 cents per lb, a substantial discount from today's corn-derived sugars, which cost around 18–20 cents per lb, notes Michele Rubino, the company's chief operating officer.

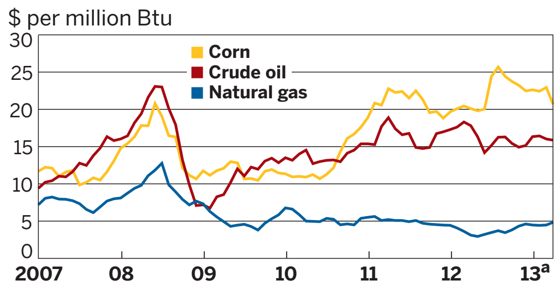
**THAT IS A PRICE** that pleases Gevo's CEO, Patrick R. Gruber. "I hope he's right. To make it big we will want cellulosic sugar," he says. "To get more carbon per unit of land is better for everyone." Gevo makes isobutyl alcohol from corn-based sugar. The output of Gevo's first plant, in Luverne, Minn., is being used as a solvent and in jet fuel for the U.S. Air Force, but isobutyl alcohol is also a candidate to be an intermediate for *p*-xylene in Coca-Cola's project to make 100% biobased soda bottles.

Biobased chemical maker Myriant is working to adapt its organisms to squirt out succinic acid on a diet of cellulosic sugar, which contains both five- and six-carbon molecules. However, Alif Saleh, Myriant's vice president of sales and marketing, says chemical industry customers have not yet demanded a switch away from corn sugar.

Such a move "would need customers to require it—the food-versus-fuel issues have not hit this industry yet, though that could change rapidly." Saleh's view is that it will take a long time for cellulosic sugars to be cost-effective for Myriant.

Although demand for ethanol and other biofuels is enhanced by policies such as the Renewable Fuel Standard in the U.S. and the Renewable Energy Directive in the European Union, Rubino points out that chemicals must compete on price alone. "The whole industry has to take off on ethanol, and that is going to be the motive for the next three to four years," he says. "Once ethanol allows us to build and exploit the learning curve and get the crops producing, then you will see biobased chemicals come in."

**TREND BREAKER** Natural gas is much cheaper than other feedstocks.




a Data available through April only.
**SOURCES:** Energy Information Administration, USDA, C&EN calculations

Achieving Beta Renewables' 10-cent-per-lb economics requires close alignment of facility location, size, and feedstock choice, according to Rubino. "That can come about in a number of ways, but you start by understanding and exploiting the available biomass." For companies operating in an active area for food crops, residues such as corn stover, wheat straw, or sugarcane bagasse are prime choices.

That is the strategy of cellulosic ethanol partners Poet and DSM. Poet, a corn-based ethanol producer, and DSM, a Dutch maker of enzymes and other products, are building a joint-venture facility called Project Liberty in Emmetsburg, Iowa.

Poet-DSM is contracting with farmers to obtain 285,000 tons of corn stover for its 25 million-gal-per-year plant. The companies need lots of local growers, so they have started a major outreach campaign, including advertising on local radio stations. DuPont plans to collect stover from a 30-mile radius for its similarly sized facility in Nevada, Iowa. Neither firm has disclosed its cost to make sugar.

**"Shale gas is shale gas no matter where on Earth it comes from. But biomass is different with each crop."**

& VIDEO ONLINE See how Canergy is testing out energy cane, a new energy crop, in California's Imperial Valley at http://cenm.ag/cane.

An alternative is to grow biomass on purpose by planting energy crops on agricultural land that cannot be economically used for food crops. That so-called marginal land may be ideal for some types of energy crops, particularly perennial grasses. By not shifting land use away from food production, companies can also defuse much of the concern about the impact of biobased fuels and chemicals on the food supply—the crux of the food-versus-fuel debate.

"For us, having a base load of a dedicated energy crop is a pretty nice way to set up the supply chain," Rubino argues. "It gives us high density, high yields, and requires less land. We base the facility off of that and take additional locally available residues from agriculture or mills."

**THE RELATIVELY MODEST** amount of land needed to grow dedicated energy crops is appealing to biobased chemical makers. According to the Environmental Protection Agency, *A. donax* should produce as much as 15 dry tons of biomass per acre. In contrast, DuPont estimates it will collect 2 tons of corn cobs, leaves, and stems per acre. Of course, that land also produces corn.

Obtaining feedstock can be further simplified by contracting with companies that control large amounts of land or biomass. In July, Beta Renewables signed a long-term agreement with Murphy-Brown, a livestock subsidiary of Smithfield Foods that is arranging for energy crops to be grown on land where hog farmers spray animal waste. The high-yielding perennial grass crops will help take up the excess nitrogen in the waste.

Similarly, cellulosic sugar firm Renmatix has signed a development agreement with UPM, a pulp and paper firm, to develop sugars from UPM's woody biomass. Renmatix CEO Mike Hamilton says the most cost-effective biobased chemicals will be manufactured on a site near the feedstock, perhaps at a pulp and paper mill.

"If people are planning to ship low-value biomass around the country, that is not an effective process," Hamilton says. "If you can assemble the end-to-end value chain, that is where the economics are optimized to compete with fossil-fuel chemicals."

Hamilton and other biobased chemical makers know that newly abundant natural gas is challenging the economics of their business. Indeed, the rise of shale gas will create biobased winners and losers, experts say. "What biobased chemical makers should focus on is the higher carbon chain lengths that you don't get in natural gas," Frost & Sullivan's Balmer advises. Two- and three-carbon biobased chemicals, in contrast, will struggle to be competitive because petrochemical versions can be made from natural gas.

"The rise of natural gas is a fascinating situation," Genomatica's Schilling says. "In our case, we benefit because of the products we make." The firm has developed sugar-based routes to butadiene, which is used to make synthetic rubber, and to 1,4-butanediol, a raw material for urethanes, plasticizers, and coatings.

The petrochemical industry has historically made 1,4-butanediol, butadiene, and other four-carbon chemicals by processing by-products from ethylene facilities that consume crude-oil-based feedstocks. But ethylene plants that run on ethane and propane extracted from natural gas produce a much smaller $C_4$ stream. In the past few years, experts say, prices for 1,4-butanediol and butadiene have significantly increased, and the trend should continue for the foreseeable future.

Still, traditional companies aren't going to cede territory to biobased chemical makers without a fight. For example, one company, TPC Group, is planning to make butadiene via butane dehydrogenation at a plant it owns in Houston. And the seven giant shale-gas-based petrochemical plants that have been announced for the U.S. are going to flood the market with chemicals of all sorts.

At Renmatix, competing with chemicals made from shale gas has been on Hamilton's mind lately, but he believes he is on the right side. "First, natural gas is not renewable. Second, it is also a volatile commodity, whereas biobased materials are significantly more reliable. Where there is competition, the least volatile, more long-term option will win." ■