

BATTLE FOR THE BARREL

This year is shaping up to be decisive for “cellulosic” ethanol made from corn stalks and other agricultural waste, as oil companies and the ethanol industry clash over government mandates for the automotive fuel

DRIVE EAST FROM PORTLAND, OREGON, ON Interstate 84 past the 189-meter-tall Multnomah Falls waterfall, past the scores of Day-Glo-garbed windsurfers slicing through the whitecaps on the Columbia River at the town Hood River, and into the brown high-plains desert, and eventually you see what looks like a green postage stamp in the distance. As you draw near you realize its true size. It’s an irrigated oasis of more than 10,000 hectares of poplar trees aligned in tidy rows. According to James Imbler, these trees are one of the keys to a revolution in transportation fuel that’s now on the cusp of becoming reality. The poplars are committed to be the feedstock for ZeaChem, the chemical company that Imbler heads, which plans to mow them down, chop them to bits, and convert the sugars in their tissues to ethanol to be blended with gasoline and pumped into your tank. ZeaChem officials say that their chemical plant is in the final stages of development and will begin commercial production later this year, eventually producing some 94.6 million liters a year of ethanol.

ZeaChem isn’t alone in ramping up production of cellulosic ethanol, which is made from nonedible plant biomass. In Decem-

ber 2012, a company called Beta Renewables commissioned a plant near Turin, Italy, that will convert rice straw and other agricultural materials into 75.7 million liters a year of ethanol. In June 2012, INEOS Bio finished building a plant in Vero Beach, Florida, that will convert landfill waste and yard waste into 30.3 million liters of ethanol a year. And a 37.9-million-liter-a-year plant opened in Shandong, China, last year as well. Articles in *The New York Times* and elsewhere have hailed these developments as the long-awaited commercialization of cellulosic ethanol. Company executives agree. “The technology is ready to deliver,” says Guido Ghisolfi, CEO of Beta Renewables in Italy.

Perhaps. Critics of cellulosic ethanol say that they’ve heard it all before. The U.S. government ordered refineries to blend 75.7 million liters of cellulosic ethanol into gasoline between 2010 and 2012, citing annual estimates that repeatedly concluded that the fuel would be available. But cellulosic ethanol producers failed to deliver. Oil companies have responded by deriding cellulosic ethanol as a “phantom fuel.”

Now, they’re calling for such mandates to be scrapped and are enlisting their friends in Congress to make it happen.

Ethanol producers of all stripes are girding for a fight. “It’s a battle for the barrel,” says Robert Dinneen, the president and CEO of the Renewable Fuels Association (RFA) in Washington, D.C., an industry association of ethanol producers. “It will be an epic fight,” he predicts, pitting the world’s largest oil and car companies against giant agricultural firms and Midwest farmers. The winner will likely determine not only the kind of car you drive in the future, but also perhaps the future of global fuel production. This conflict is creating a pressure-cooker environment for cellulosic ethanol producers. They need to deliver millions of liters

of their fuel this year to take some of the political heat off the industry. “It’s crunch time for cellulosic ethanol,” says Brooke Coleman, executive director of the Advanced Ethanol Council in Washington, D.C.

Ironically, things might be even worse for cellulosic ethanol-makers if they succeed. This year’s mandates call for 53 million liters of cellulosic ethanol to be blended into gasoline. If producers go beyond such mandates over the next few years and flood the market with their fuel, there may be nowhere for it to go, as refiners aren’t

Online

sciencemag.org

Podcast interview with author Robert F. Service (http://scim.ag/pod_6126).

Future fuel. Poplar trees near Boardman, Oregon, are slated to be the feedstock for ZeaChem's cellulosic ethanol plant.

required to blend any excess ethanol into their gasoline. Add to this the insecurity over how the ongoing budget battles in Congress will affect U.S. national energy policy and tax breaks that the ethanol industry enjoys, and 2013 is shaping up to be the make-or-break year for cellulosic ethanol. At the National Ethanol Conference (NEC) held in February in Las Vegas, Nevada, U.S. Agriculture Department Secretary Tom Vilsack warned his audience that the road ahead looks rough. "It's a very dicey time," Vilsack said.

Higher standards

The ethanol industry seems as though it's been around forever. And in a way, it has. The fermentation of ethanol, more commonly known as alcohol, is one of humanity's oldest known technologies. Analysis of 9000-year-old clay jars recovered in China reveals that Neolithic people consumed alcohol. The use of the energy-rich molecule as a fuel dates back to the dawn of the automobile age: In 1908, the Ford Motor Company's Model T could be powered by ethanol. But eventually carmakers settled on a mixture of organic compounds even richer in energy that could be refined from oil pumped right out of the ground. Gasoline took over in America and has been king ever since.

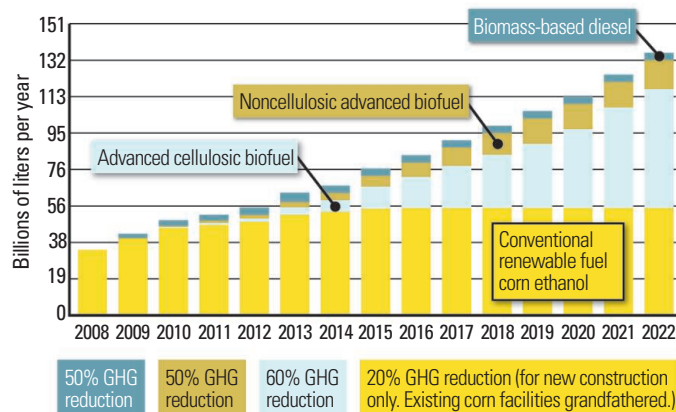
In 2005, Congress set out to change this picture. It passed the Renewable Fuel Standard (RFS) and updated it in 2007 with RFS2. The law guaranteed a market for renewable fuels by requiring blenders to incorporate increasing amounts of ethanol and other renewable fuels into gasoline, up to 136.3 billion liters in 2022 (see figure, above). By doing so, Congress hoped to reduce the country's rising dependence on imported oil, bolster rural economies that would produce the corn and other biomass that would serve as the fuel feedstock, and lower the amount of greenhouse gases pumped into the atmosphere each year.

Oil companies initially welcomed the move. The 1990 amendments to the U.S. Clean Air Act already required them to add high-octane fuel additives to help engines burn more cleanly. And in 2004, the industry began losing the use of its primary additive, MTBE, after

California and New York started a nationwide trend by banning MTBE after it was shown to be poisoning ground water. Refiners turned to ethanol instead.

RFS envisioned that, initially, the primary source of renewable fuel would come from ethanol fermented from the sugars in corn, a relatively mature technology. But growing corn requires relatively large amounts of water, fertilizer, and land. So Congress sought to cap corn's use. The amount of corn ethanol used was slated to rise from 30.3 billion liters in 2009 to a maximum of 56.8 billion liters a year by 2015. Last year, blenders added 50 billion liters of ethanol derived from corn and sugar. That meant that by 2022, the remaining 79.5 billion liters of growth in renewable fuel use had to come from "advanced" biofuels, primarily cellulosic ethanol, with relatively small amounts of biodiesel and biofuels derived from algae, among other sources. This surge in cellulosic ethanol production was originally planned to begin in 2010 with the first 378.5 million liters of the fuel, with year-by-year increases up to 60.6 billion liters a year in 2022. But the technology didn't mature fast enough. So the Environmental Protection Agency (EPA), which Congress empowered to change the RFS schedule, has had to dial back the mandates.

Renewable Fuel Standard



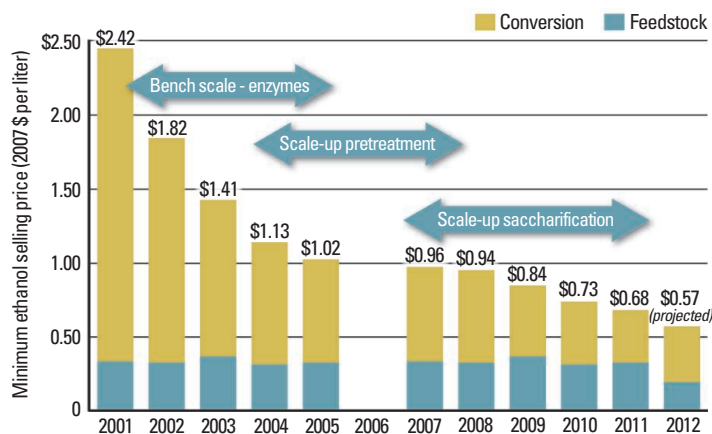
Ramping up. Current law requires fuelmakers to blend an increasing volume of renewable fuels into gasoline, lowering greenhouse-gas (GHG) emissions.

To absorb the rising ethanol production, initially the U.S. Department of Energy (DOE) and EPA permitted refiners to sell E5, consisting of 95% gasoline blended with 5% ethanol. By 2008, numerous states mandated E10, and in 2011 EPA certified—but did not require—the sale of E15 for cars built after 2001. Refiners also blend an ethanol-rich E85 for vehicles with specialized flexible-fuel engines.

But the new market for ethanol didn't immediately pave the way for cellulosic ethanol. Its development has been slow, because it's harder to make alcohol from nonagricultural biomass than from corn starch or sugar cane. That's because the leaves and stalks of plants have a more complex molecular structure made of a mixture of the biopolymers cellulose, hemicelluloses, and a woody material called lignin that prevents microbes from digesting plants as they grow. To make the sugars available for fermentation, cellulosic ethanol-makers must first grind the plant matter and separate out the lignin with acids and other chemical additives. They then need to add cocktails of different enzymes to break apart the different sugar chains, with each feedstock needing a slightly different cocktail. Finally, many cellulosic ethanol producers have had to engineer specialized microbes to convert the broader mixture of sugars in cellulosic material into ethanol. All these extra steps add to the cost.

For decades, that made cellulosic ethanol far more expensive than corn- and sugar-derived

Cellulosic Ethanol: Historic State of Technology



Steady drop. The cost of cellulosic ethanol has declined steadily thanks to improvements in technology for converting agricultural wastes into fermentable sugars.

versions. As recently as 2001, researchers from the National Renewable Energy Laboratory (NREL) estimated that cellulosic ethanol cost more than \$2.38 a liter. That price fell as researchers and companies began coming up with better enzyme cocktails and better pretreatment methods. Now, a recent NREL analysis concludes that cellulosic ethanol can be produced for just 57 cents a liter, only modestly above the cost to produce corn ethanol. A 27-cent-per-liter tax credit awarded to companies that actually sell the fuel also stands to lower the cost of cellulosic ethanol that makes it to market. And cellulosic ethanol companies and enzyme producers insist they are doing even better. “Today we are at the point where cellulosic ethanol can be made at a cost similar to corn ethanol,” says Poul Andersen, a vice president with Novozymes, the world’s largest cellulosic ethanol enzyme producer based in Bagsværd, Denmark. Beta Renewables’ Ghisolfi goes even further, saying his company can produce cellulosic ethanol for less than 40 cents a liter. That’s well below today’s price of gasoline. But because the price of gasoline depends primarily on the price of crude oil, if oil prices decline, so, too, will gas prices.

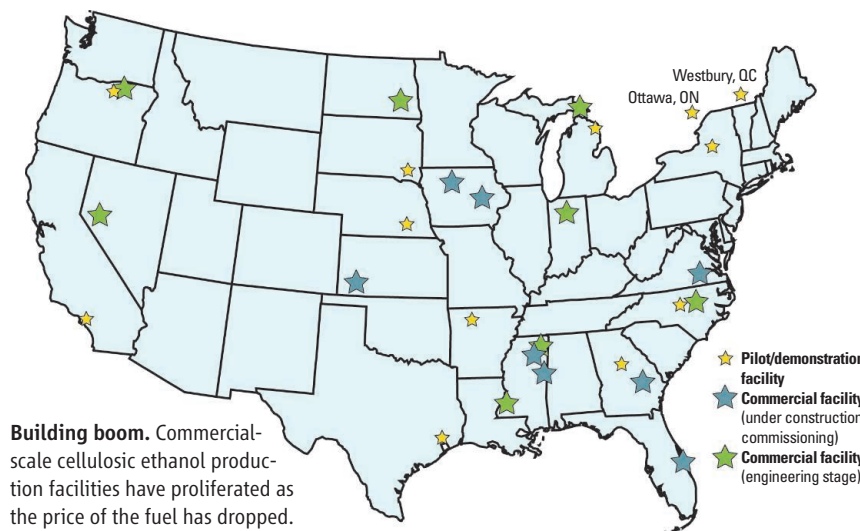
Ethanol industry leaders say that this price decline has sparked a construction boom. In 2012, the Advanced Ethanol Council, a group made up primarily of cellulosic ethanol producers, reported that eight commercial-scale cellulosic ethanol plants in the United States—such as the ZeaChem plant in Oregon—were either open, in their final commissioning stage, or under construction. Another eight commercial facilities are in the engineering stage. Outside U.S. borders, in addition to the projects in Italy and China, commercial plants are under development in Brazil, Spain, Germany, and Denmark. It will take a few years for all those plants to be built, Ghisolfi says. But change is coming. “Worldwide, there will be tens of millions of tons of cellulosic ethanol delivered regardless of the rules in the U.S.,” Ghisolfi says.

Phantom fuel

That all sounds well and good. But while the world waits, cellulosic ethanol critics in the petroleum industry complain that man-

dates for a so-far nonexistent fuel are driving up their costs. Those added costs come as a byproduct of the way EPA monitors compliance with the mandates. EPA does so by issuing renewable fuel credits, called Renewable Identification Numbers, or RINs. At the end of each year, refiners and blenders must show that they have at least one RIN for every 37.9 liters of gasoline they sell. They receive those RINs either by earning one for each gallon of renewable fuel they blend or by buying excess RINs from other companies that have more RINs than they need.

Over the past 3 years, EPA decided to keep the lowered mandates for cellulosic ethanol in order to maintain the incentive for cellulosic ethanol companies to continue commercial development. That meant that oil refiners and blenders had no way to earn those RINs and thus had to buy them to fulfill the mandates.



Oil companies objected that the requirement amounted to an added tax on their product and filed suit against EPA. In January, a federal appeals court for the District of Columbia agreed, at least in part. The court ruled that EPA can’t require blenders to pay for credits for a product that is unavailable commercially. Nevertheless, the court continued to allow EPA to set mandates for how much renewable fuels, including cellulosic ethanol, should be blended each year. And the week after the court’s decision, EPA proposed a new rule requiring refiners and blenders to blend 53 million liters of cellulosic ethanol in 2013, again citing internal market projections that the fuel would be available.

The decision drew an immediate backlash. “We are disturbed that EPA is mandating 14 million gallons [53 million liters] of cellulosic ethanol when zero gallons are available for compliance as of today,” says

Charles Drevna, president of the American Fuel & Petrochemical Manufacturers in Washington, D.C. Louis Finkel, executive vice president of the Grocery Manufacturers Association, which is also in Washington and recently came out against RFS, notes that RFS was intended to help drive the development of technology for cellulosic ethanol and other advanced biofuels. But so far, it hasn’t worked. “The technology has not come forward,” Finkel says.

With no cellulosic fuel on the market, “it’s just silly” to keep the blending mandates, says Marty Durbin, executive vice president of the American Petroleum Institute in Washington. Even worse, Durbin adds, the RFS mandate keeps rising even though U.S. gasoline sales have been declining for several years. Less gas means less ethanol needed for blending. “The pool is going down. The mandate is going up. That doesn’t make sense,” Durbin

says. “We’re not against renewable fuels. We think the [RFS] program doesn’t work.”

That’s not the only grenade being tossed by cellulosic ethanol critics. Durbin and others argue that rising ethanol mandates are putting the squeeze on food producers and consumers. “Ethanol drives up food costs,” Finkel says, though he acknowledges that other factors play a role as well. Ethanol opponents have been

swinging even harder at E15. In January, the Coordinating Research Council released a study suggesting that increasing the ethanol content of gasoline from 10% to 15% can damage engines, including causing swelling to fuel system components, erratic fuel level indicators, and faulty check engine signals. Previous testing by the industry-backed group found E15 could damage engine valves. Citing such industry studies, last year AAA and a group of auto manufacturers also warned that E15 may damage car engines.

Putting horsepower behind their studies, ethanol’s critics are now pushing for policy changes. In January, following EPA’s decision to up its 2013 mandate for cellulosic ethanol up to 53 million liters, Drevna called on Congress to repeal the RFS. It didn’t take long for members of Congress to take up the baton. In Congress, in February, Representative James Sensenbrenner (R-WI) intro-

duced a bill to limit the increase in the RFS mandate for cellulosic ethanol to 5% per year or 3.79 million liters, whichever is greater—far below the rate of growth needed to reach RFS's mandate of 60.6 billion liters per year by 2022. Senators David Vitter (R-LA) and Roger Wicker (R-MS) introduced a separate bill to roll back the EPA approval of E15, saying the fuel needs more testing.

Fighting back

Ethanol backers acknowledge that their opponents are landing blows. “We are getting hammered by the oil industry,” Coleman says. The ethanol industry is “under siege and fighting back,” Dinneen told the NEC audience, sounding like a general trying to rally his troops.

But Dinneen and other ethanol true-believers don't concede any of their critics'

2008 recession and rising fuel efficiency standards, for example, would have driven oil imports down to 48% without ethanol, and studies show that the ethanol mandate has driven corn prices up slightly. But Dinneen notes that according to the U.S. Department of Agriculture, food inflation has increased only 2.5% per year since 2005, when RFS was instituted, essentially unchanged compared with the long-term average. Crude oil prices over that same period, meanwhile, have risen 68%. And when it comes to growing corn, energy prices affect a wide variety of things, including the cost of fertilizer, transportation, and processing; the cost of



Steel in the ground. Construction crews put together the infrastructure for POET-DSM's 76-million-liter cellulosic ethanol plant in Emmetsburg, Iowa.

points. Instead, they charge that their opponents—led by oil companies—are stepping up their attacks because renewable fuels are eating away at their market share. “You're being tested in the courts. You're being tested in the halls of Congress,” Vilsack says. “Why now? I believe there is a reason: You are winning. And the folks on the other side are concerned.”

In response, proponents of the new fuel muster studies and figures of their own. Far from being a failure, says Geoff Cooper, RFA's vice president for research and analysis, RFS is the most successful energy legislation ever enacted. In just 8 years, he says, it has prompted the growth of an industry that now supplies 10% of all the transportation fuel in the country. It's directly created 70,000 jobs; increased household farm revenues by \$28.9 billion; helped lower oil imports from 60% of U.S. transportation fuel in 2006 to 41% last year; and, according to a recent analysis using a computer model developed by DOE researchers, cut greenhouse gas emissions by 33.4 million tons in 2012 alone, equivalent to removing 5.2 million cars and trucks from the road.

Those numbers come with caveats. The

ingredients makes up only 14% of food's final cost to consumers.

Not only is ethanol already lowering oil imports and helping farmers, but its impact is also expected to grow sharply over the next decade, Cooper says. For example, in the November 2012 issue of *Biofuels*, Gbadebo Oladosu, an environmental economist at Oak Ridge National Laboratory in Tennessee, and colleagues looked at the expected impact of RFS2 on the U.S. economy over the next decade. They conclude that adding renewable fuels will be responsible for a 3% decline in oil prices by 2015 and a 7% decline by 2022. That decline in energy costs is expected to boost the U.S. gross domestic product by 0.8%, or \$120 billion, over that same period. “It's a great American success story,” Cooper says.

As for industry complaints that cellulosic ethanol RINs amount to a tax, Dinneen notes that the credits have cost oil refiners and blenders just \$25 million over 3 years—less than one-fiftieth of 1% of their profits over the same period. Besides, ethanol proponents say, the \$4 billion to \$5 billion a year in permanent tax breaks that oil companies receive for things like oil drilling and profits

earned overseas have long tilted the market in the companies' favor.

In response to possible engine damage from E15, RFA and other groups note that studies suggesting engine damage were funded by oil and auto companies, and they point out several technical flaws in the studies themselves. Besides, Dinneen says, E15-burning vehicles in the United States have already driven more than 10 million kilometers—the most extensive testing of any fuel mixture in history.

Dinneen says proposed legislation to end incentives for cellulosic ethanol amounts to a bald attempt by oil industry backers to take down the competition and insists it won't work. Shane Karr, the vice president for federal government affairs at the Alliance of Automobile Manufacturers in Washington, D.C., says that he, too, believes it's “extremely unlikely” that any RFS repeal or reform will make it through while Barack Obama is president, unless it winds up being tucked into a large budget package or the like. Still, clearly the pressure is building. And cellulosic ethanol producers as well as makers of other “advanced” biofuels are feeling the need to get commercial production

rolling. “We need to get advanced biofuels into the market,” Vilsack says. “That will mute some of the criticism and erase some of the skepticism.”

The road ahead

If Imbler, Ghisolfi, and other cellulosic ethanol company CEOs are right, the spigots are ready to be opened. But if they do, that could spell a very different sort of trouble. That’s because corn ethanol producers already supply enough fuel to fill the entire volume needed for E10 gasoline. Gas stations aren’t required to sell E15, and so far only a handful of them do. That means that unless cellulosic ethanol can be made cheaper than corn ethanol, there will be nowhere for the cellulosic ethanol to go, a situation industry insiders call the “blend wall.” “The blend wall is the big issue for 2013 and 2014,” says Wallace Tyner, an agricultural economist at Purdue University in West Lafayette, Indiana. “There’s no place for cellulose to go,” he adds.

The blend wall, it appears, has already arrived. This year RFS requires blenders to use 52.6 billion liters of ethanol, 2.65 billion liters more than the amount of ethanol needed for E10. That extra 2.65-billion-liter requirement is intended to encourage retailers to move to E15 and other higher ethanol blends. But so far, all it seems to be doing is driving up the cost of RINs. RIN prices have jumped from an average of 2 to 3 cents per RIN in January to 75 cents per RIN last month. The price spike, observers say, is forcing blenders to look to buy RIN credits when they run out of room for their renewable fuel.

But Dinneen and other RFS proponents call for patience and say that the market will handle the blend wall if given a chance. As cellulosic ethanol comes onto the market, the price of ethanol should drop. So refiners will be able to make more money by blending E15 instead of by buying costly RINs, Dinneen explains. “The marketplace will work if you don’t change the RFS,” Dinneen says. This year is critical, he says, because it is the first in which RFS mandates adding more ethanol than E10 fuel can absorb: “This is where the rubber meets the road, and the policy hits the marketplace.”

Even if cellulosic ethanol companies manage to avoid the blend wall over the next year, other obstacles are looming further out. To incorporate into gasoline the 60.6 billion liters of cellulosic ethanol that RFS calls for by 2022, refiners will need to up their blend mixture to 20% to 25% ethanol. “We’re nowhere close to doing that today,” says

Michael Pacheco, associate laboratory director of the National Renewable Energy Laboratory in Golden, Colorado.

To work with higher ethanol blends, carmakers will need to modify their engine designs. That’s doable. In fact, Brazil has required such designs for years to work with a wide variety of high-ethanol blends. As well, carmakers are already redesigning their engines in an effort to comply with higher U.S. mileage standards instituted last year. But carmakers say that they are wary of tailoring engines to work with ethanol for two key reasons. The first is low demand from consumers. Flexible-fuel cars that run on E85 have been meager sellers in the United States, because the fuel mixture is not universally available and there are few incentives for car buyers to make the switch. And unless demand rises for other novel designs, companies say they can’t make money. “If there is no market pull, we will stop building those cars,” says Stuart Johnson, a senior manager for Volkswagen Group of America in Herndon, Virginia.

The second problem for carmakers is that they need to be sure the fuel blends for the new engines will be widely available. “If we are going to build dedicated vehicles, we need a dedicated fuel supply,” says Coleman Jones, biofuel implementation manager with General Motors in Franklin, Michigan. Fuel refiners say it works both ways: If cars that run on high-ethanol blends aren’t widely available, there’s no reason to offer the fuels at all gas stations.

This has created a classic chicken-and-egg problem between the car companies that will build the cars only if they are sure there will be a fuel supply in place and the fuel refiners who will distribute the fuel only if they know they have cars on the road to use it. The problem is so acute, Pacheco says, that automakers are more comfortable with pushing more expensive electric car designs, because they know that they won’t face the fueling problem.

Pacheco, who in the early 2000s worked on DOE studies that inspired RFS, now

wishes that he and other analysts had pushed harder for Congress to make the use of biofuels mandatory. That would have solved the problem of demand from the get-go, he says. “I was naive to think that the industry would start to prepare for the change,” Pacheco says. “I really underestimated the lack of support from the auto industry. They have effectively dug in their heels.”

Cellulosic ethanol boosters say there’s still time to take action. For starters, Imbler argues, Congress could give all alternative energy producers a huge lift by making permanent the tax credits they’ve been renewing on an annual basis. This would give investors confidence that a single set of rules would be in place for the duration of their investment. Pacheco is pushing a different approach. He says that he and his NREL col-



New kid. In 2011, EPA began allowing gas stations to sell E15. So far, only a handful of stations in the United States offer it.

leagues are working to convene a meeting of representatives from oil companies, refiners, carmakers, and gas stations to begin to hammer out the transition to higher octane fuel blends. Finally, station owners such as Scott Zaremba, who sells E15 at all seven stations he owns in Kansas, says in making the transition to higher ethanol fuel blends, there’s no option other than to talk with concerned customers one-on-one every day. “Nothing is easy,” Zaremba says, “but I believe in it.”

The question is whether Zaremba and his fellow retailers can convince consumers quickly enough to buy the millions of liters of cellulosic ethanol headed their way. If not, an industry that is only now getting up to speed may soon resemble the piles of waste it’s trying to use to revolutionize the future of transportation.

—ROBERT F. SERVICE