Is Ethanol

By Matthew L. Wald

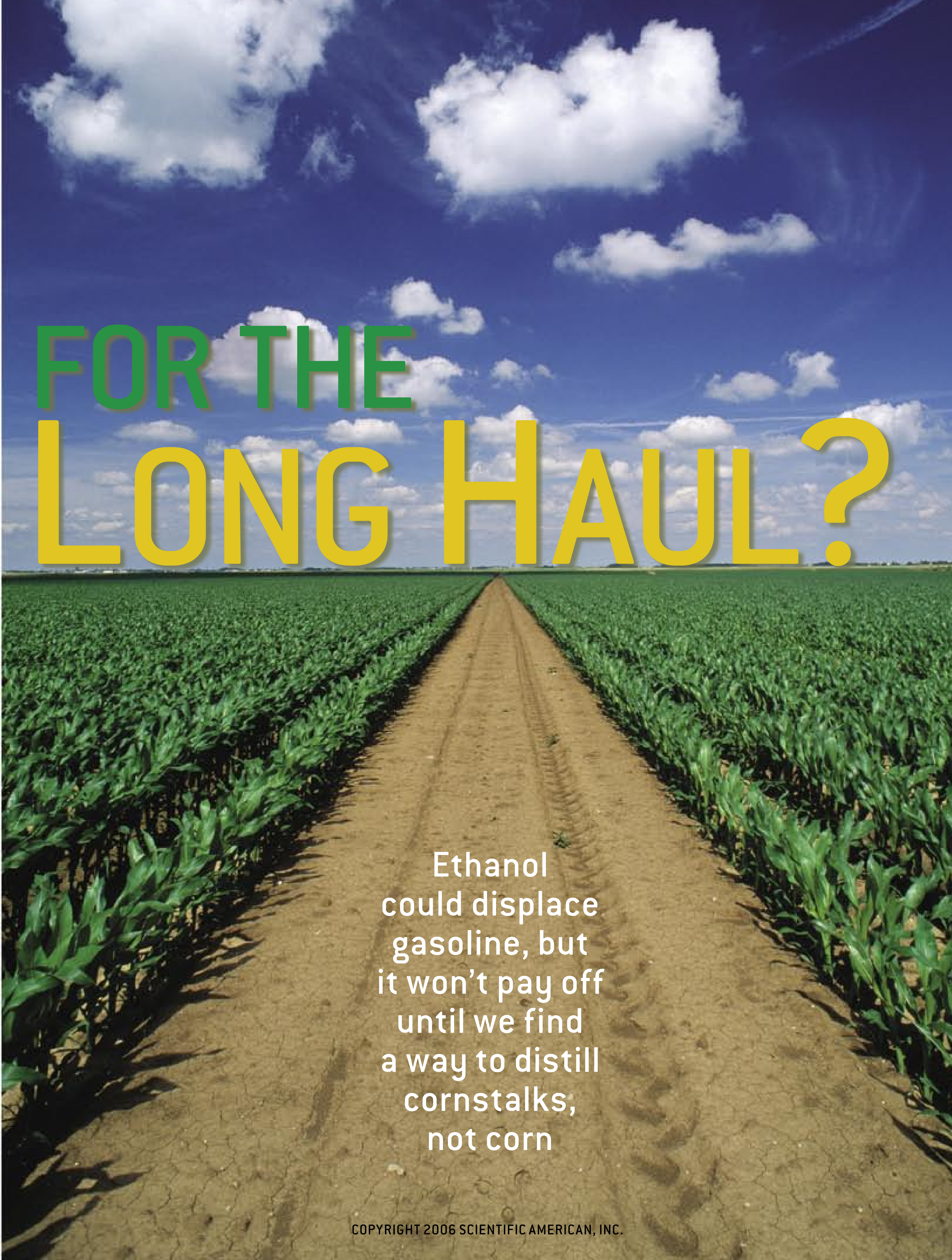
The airport terminal in Sioux Falls, S.D., could be anywhere, until you reach the baggage claim area. Between the carousels is a green and white Indy-style race car, covered with decals that indicate it runs on ethanol. Approach the rent-a-car booths, and you will see a sign taped to the countertop reminding customers *not* to pump E85, the ultraethanol blend sold locally, into the rental cars because they are not designed for it and it will ruin their engines.

This is ethanol country, the center of the national push to turn carbohydrates into hydrocarbons.

The U.S. has gone on an ethanol binge, anticipating a fuel transition unrivaled since electric utilities set out 40 years ago to build hundreds of nuclear power plants. In August 2005 Congress passed a major energy bill

© BIOS Barbier Elyas/Peter Arnold, Inc.

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.



FOR THE LONG HAUL?

Ethanol could displace gasoline, but it won't pay off until we find a way to distill cornstalks, not corn

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.

calling for production of 7.5 billion gallons of ethanol a year by 2012, up from about four billion gallons at the time, to help displace imported fuel. Industry analysts say the nation will be burning that much ethanol long before the deadline, thanks to government tax rules and subsidies—and especially if oil prices stay high—because the cost to convert plant matter into ethanol is far below the $2.50 a gallon that gasoline was fetching last fall.

Indeed, according to the Renewable Fuels Association, domestic ethanol production was more than five billion gallons in 2006. That quantity is small compared with gasoline and diesel consumption of about 140 billion gallons annually, but it is up 50 percent in one year. Andy Karsner, the assistant secretary of energy for efficiency and renewable energy at the DOE, says that because of the market pull exerted by the high price of oil, developers are scrambling to build ethanol plants. There is an ethanol boom, he says, "a little like the Pennsylvania oil rush in the 1850s."

But is the rush worth it? Not the way we generate ethanol now. All the fuel ethanol sold commercially in the U.S. comes from corn kernels, and it is energy-intensive to produce. Some studies indicate that refining a gallon of ethanol takes more energy than it provides when combusted. Even the positive studies demonstrate only a slight net energy gain. Other research shows that the ethanol-from-corn cycle reduces greenhouse gases marginally or not at all compared with gasoline from crude.

Ethanol will not make economic or environmental sense until refiners perfect methods to derive the fuel from cellulose, not corn. Cellulose is the woody material that forms the stalk of a corn plant and the bodies of trees and other plants such as grasses, which require less energy to tend and harvest. But although scientists understand the biology-based processes that convert the sugars tied up in cellulose, companies trying to make ethanol from these materials have so far not reached commercial viability. Sugarcane is the ultimate plant source, far richer than cornstalks and grasses in the sugars that are distilled into ethanol, but the U.S. does not have the climate or cheap labor to exploit that crop the way Brazil has.

Making ethanol production from cellulose practical will require agricultural advances and major improvements in industrial processing. Without those steps, ethanol will remain a cumbersome product with little net benefit, and the country will remain dependent on foreign oil.

Ironically, to make "domestic" corn ethanol, the U.S. will have to increase imports of natural gas.

Renewable? Not Really

MOST ETHANOL PRODUCED in the U.S. is sold as a kind of Hamburger Helper for gasoline. It may constitute up to 10 percent of the blend, the most that conventional engines can handle without damage. In some locales, primarily the farm belt, drivers can find the E85 blend—85 percent ethanol and 15 percent unleaded regular gasoline. This mix requires specially equipped "flexible fuel" engines designed to tolerate it. Otherwise the ethanol—the same form of alcohol as in distilled liquor—eats away at the seals in the engine and fuel system. Several million vehicles are so equipped (although many owners do not know it), but there are only a few hundred places that sell E85, and the fuel supply chain is expanding slowly.

Nevertheless, ethanol from corn is surging in part because it has a strong bipartisan constituency of farm-state senators and representatives in Washington, D.C. It also has support from people outside agriculture who believe the country

Overview/*Myth and Reality*

- Although politicians are aggressively pushing ethanol from homegrown corn as a substitute for foreign oil, the conversion makes little energy sense. It requires copious amounts of fossil fuels, and even if 100 percent of the U.S. corn supply was distilled into ethanol it would supply only a small fraction of the fuel consumed by the nation's vehicles.
- Studies show that producing ethanol from corn creates almost the same amount of greenhouse gases as gasoline production does. Burning ethanol in vehicles offers little if any pollution reduction.
- Deriving ethanol from cellulose—cornstalks and the straw of grains and grasses—consumes far less fossil fuel than ethanol from corn kernels. But companies have had trouble coaxing the natural enzymes needed for conversion to multiply and work inside the large bioreactors required for volume production. More promising organisms are being discovered; ethanol's long-term viability depends on their success.

DON FOLEY (*opposite page*)

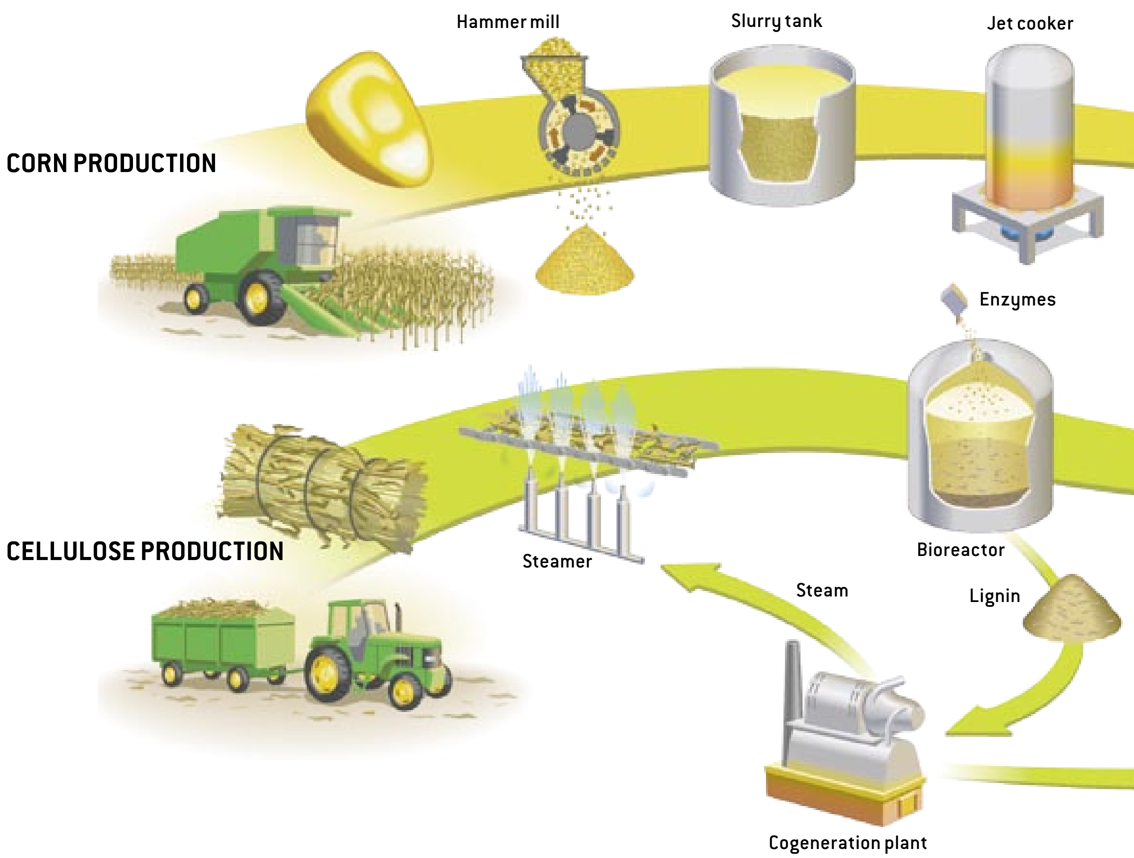
COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.

FROM WELL TO WHEEL: HOW FUEL IS MADE

Many steps are required to convert oil into gasoline and corn into ethanol and to deliver them to the local pump. Some stages are energy-intensive, consuming volumes of fossil fuels.

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.

The initial steps in converting corn or cellulose into ethanol differ significantly. Corn is ground, cooked and mashed before entering a fermenter. Cellulose is steamed to expose fibers that enzymes then convert into sugars in a bioreactor. Companies are still looking for bioreactions that are efficient on a large scale, but one payoff is the lignin that remains behind, which can be burned to cogenerate steam and electricity. The distillation of either raw material creates stillage, a valuable by-product that can be processed into animal feed.



should be less dependent on imported oil. Advocates argue that ethanol is a renewable fuel, because the corn can be grown year after year. The Renewable Fuels Association has a slick pamphlet that implies that consuming 7.5 billion gallons a year means 179 million fewer barrels of foreign oil. That level would equal about 15 days of imports—a start, if not a cure-all.

But there is less to ethanol than meets the eye. The first problem is that a standard barrel (42 gallons) of ethanol is worth about 28 gallons of gasoline because it contains only 80,000 British thermal units (Btu) of energy, versus about 119,000 for unleaded regular. If you fill your tank with E85, you will run dry about 33 percent sooner. Even if a gallon of ethanol were cheaper at the pump, drivers would have to buy many more gallons to go the same distance.

The other earworm in the ointment is that the U.S. lacks some of the resources to produce ethanol. The country has corn in abundance, spreading out in all directions from the Sioux Falls airport. But manufacturing ethanol requires copious amounts of natural gas. Basically, ethanol for fuel is produced the same way that ethanol for liquor is made. Yeast eats sugar and gives off alcohol and carbon dioxide. The output is distilled, vaporizing the alcohol, then capturing and recondensing it. Natural gas is used for heating at various steps. Producing a gallon of ethanol, with its 80,000 Btu of energy, currently requires about 36,000 Btu of natural gas.

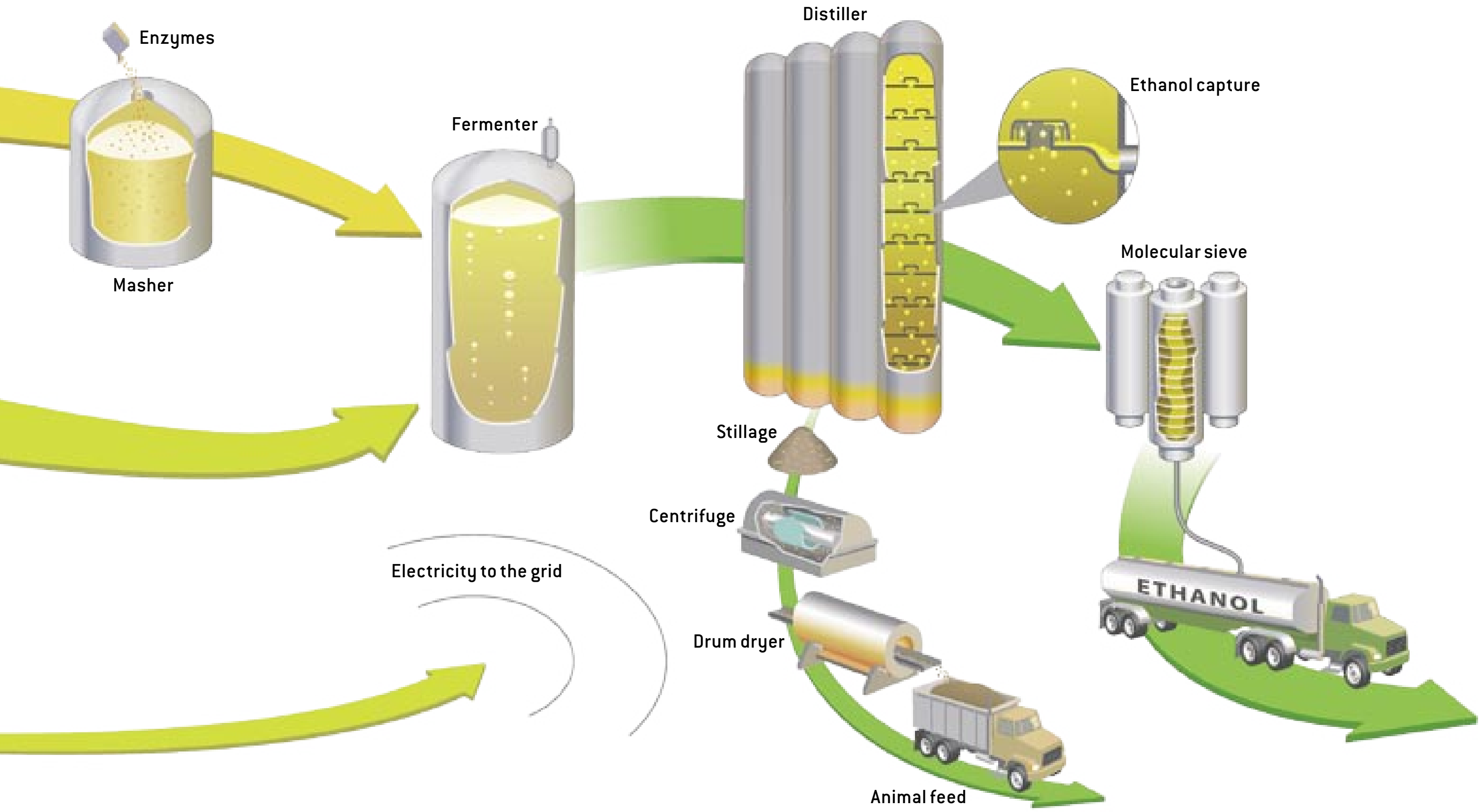
In the 1990s, when Congress tried to prop up farm-state economies with laws that encouraged refiners to make more ethanol, natural gas was cheap, averaging around $3 per million Btu. Last winter the price hit $14. Furthermore, high demand pushes natural gas prices up for everyone. Although ethanol backers say their fuel is part of a sustainable energy future, using so much natural gas may not be sustainable, even in the present. American production is falling, and Canadian production is not sufficient to match consumption. Ironically, to make "domestic" ethanol, the U.S. will have to increase natural gas imports from outside North America.

As an alternative, some ethanol producers are burning coal, which fits nobody's definition of clean and renewable. Using coal releases so much carbon dioxide that driving a mile on that ethanol is worse for climate change than driving a mile on plain old gasoline. In theory, a distillery could produce heat with electricity purchased from a power company, but for many U.S. utilities, that would mean burning more coal and natural gas to supply the demand.

Ethanol requires other forms of energy, too. The obvious

GEORGE RETSECK

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.



one is diesel fuel for trucks that haul it to market—and it is sometimes a very long haul, because ethanol is not shipped in pipelines like gasoline and diesel are. Pipelines are readily contaminated with water, which does not mix with gasoline or diesel but does bind with ethanol, ruining its fuel value. Diesel fuel also runs the combines that harvest the corn. And the corn is usually fertilized with chemicals made with natural gas.

These considerations are key to the calculation of a "net energy balance" for ethanol. The figure is the subject of lively debate. David Pimentel, a professor of agriculture at Cornell University, asserted in 2005 that it takes more energy to make a gallon of ethanol than the fuel produces when burned. Critics argued he had assigned too little value to by-products, some of which can be fed to livestock (displacing the need to grow some corn), and that he had billed ethanol for extraneous energy costs, including the value of the food eaten by workers at ethanol plants. But the consensus among the analysts is that even if the net energy value of ethanol is positive, the margin is small. That same year a large study by the American Institute of Biological Sciences concluded that ethanol from corn yielded only about 10 percent more energy than was required to produce it. That finding compared with a 370 percent energy yield from sugarcane as harvested in Brazil.

Michael Wang, an environmental scientist at Argonne National Laboratory's Center for Transportation Research, has calculated that making a million Btu of ethanol requires 740,000 Btu of fossil fuels, when considering all the steps in the chain—fertilizing fields, harvesting the corn, distilling its starch into alcohol, and so on. Ethanol is promoted as a farm product, but it is largely a product of fossil fuels.

The greenhouse benefit of ethanol is even smaller. Writing in *Science* in January 2006, Alexander E. Farrell, an assistant professor of energy and resources at the University of California, Berkeley, declared that the effect on greenhouse gases was "ambiguous." After reviewing various studies, Farrell and his co-authors concluded that ethanol made with natural gas is marginally better than gasoline production for global warming pollutants, but ethanol made with coal is worse. Burning

THE AUTHOR

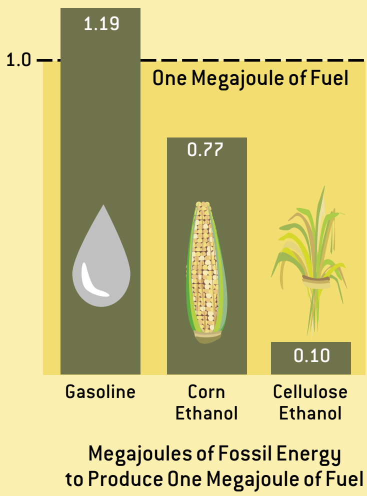
MATTHEW L. WALD is a reporter at the *New York Times,* where he has covered energy topics since 1979. He has written about oil refining, electricity production, electric and hybrid automobiles, and air pollution. Wald is currently assigned in Washington, D.C., where he also tracks transportation safety and other subjects. This feature article is his third for *Scientific American*.

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.

TAKES FUEL TO MAKE FUEL

Vastly different amounts of fossil fuel (natural gas, oil and coal) are burned to produce gasoline and ethanol, considering all the steps from drilling or farming to final delivery. The numbers below are averages derived from six studies by California Institute of Technology researchers.

JUNGLE ROT from Guam (the fungus *Trichoderma reesei*) helps to break down cellulose into sugars that can be readily distilled into ethanol.



a gallon of gasoline releases about 20 pounds of carbon dioxide, counting the contributions from the car engine as well as the refinery. The comparable figure for ethanol is a matter of some dispute, but it varies from slightly better to slightly worse, depending on how the ethanol is made. Promoting a switch to ethanol on the basis of limiting emissions of climate-changing gases is deceptive.

Life Cycle or Political Cycle?

UNFORTUNATELY, net energy and pollution considerations may not have played much of a role in the federal government's 2005 setting of a "renewable fuel standard" for 2012 or in giving ethanol a 51-cent-per-gallon tax break. "Congress didn't do a life-cycle analysis; it did an ADM analysis," says one federal official with long-term experience in energy and pollution. He is referring to Archer Daniels Midland, the agricultural products giant, which has for years been a driving force behind ethanol policy.

Life-cycle analysis of fuels does seem to be a new idea to the people who set energy policy. For the first time, instead of assessing the payoff of converting low-value Btu to high-value Btu (such as coal to electricity or crude oil to gasoline) simply on the basis of price, analysts are starting to regard the energy losses and pollution releases along the way.

Whether such assessments will inform policy is another question, however. For example, a broad-based coalition of biofuels, wind and solar power advocates has formed an umbrella group calling itself "25 × '25." They want 25 percent of the nation's energy to come from renewable sources by 2025. Dozens of members of Congress are endorsing the group, yet at a news conference last spring in Washington, D.C., held to introduce the organization, its leaders could not even say whether wind, solar, ethanol or direct combustion of biomass would be the largest source. There was little desire to blemish the concept with arithmetic.

Some of the sudden interest in ethanol is actually an unintended consequence of a failed policy effort to tinker with the recipe for gasoline. In the 1980s some states began requiring certain oxygen levels in gasoline, an ill-advised attempt to make cars burn cleaner. In response, most refiners added methyl tertiary butyl ether (MTBE)—and not ethanol—to gasoline. (Critics said the politicians' hidden motivation was to help farm states by boosting ethanol use.) Over the ensuing years, inspectors found that whenever gasoline leaked into the dirt, MTBE—a possible carcinogen—readily migrated into local drinking water.

In the 2005 Energy Act, Congress eliminated the rule that encouraged MTBE, and refiners dropped the stuff because of potential liability problems. But the refiners needed another high-octane substitute and feared new initiatives calling for oxygen levels, so they rushed to ethanol. American oil refineries also happen to be short on capacity, so adding ethanol would stretch the volume of gasoline they produce, forestalling the need to build costly new plants.

The Stalk, Not the Ear

ONE OTHER fundamental problem plagues the current scheme for ethanol: corn. The crop is in surplus right now, but even that is not nearly enough to quench a significant portion of the country's thirst for fuel.

Pimentel wrote in a letter to Senator John McCain of Arizona in February 2005 that making 3.4 billion gallons of ethanol was consuming about 14 percent of America's corn crop. At that rate, he pointed out, 100 percent of the nation's corn crop would supply only 7 percent of the fuel consumed by its vehicles. Even if the corn crop grew much bigger somehow, U.S. farmers could never grow anywhere near the amount of corn needed to fuel the nation. And critics say any acceleration in agriculture should be used to raise crop exports or feed the world's starving people.

DANIELA NAOMI MOLNAR; SOURCE: CALIFORNIA INSTITUTE OF TECHNOLOGY (*graph*); VTT TECHNICAL RESEARCH CENTER OF FINLAND (*micrograph*)

COPYRIGHT 2006 SCIENTIFIC AMERICAN, INC.

A solution would be to derive ethanol from cellulose. Cellulose forms the stalk of a corn plant, the straw of grains, and the body of other plants not typically thought of as crops, such as some fast-growing grasses. Much more cellulose exists than corn kernels; according to the Department of Agriculture and others, massive harvesting of cellulose across the nation could generate enough ethanol to replace one third of the gasoline the U.S. consumes.

In energy terms, distilling ethanol from the sugar in cellulose instead of corn is a double play. For corn, the cellulose itself can be thought of as nearly "free"—it takes very little more work to harvest the stalk and requires no extra fertilizer. Farmers say they must plow under some of the stalks, cobs and leaves to reinvigorate the soil but can harvest most of this plant matter. Switchgrass, the favored grass for ethanol, requires minimal fertilizer.

Second, when the sugar is removed the remaining material, lignin, burns well. The North American research leader in cellulose ethanol, Iogen Corporation in Ottawa, Ontario, predicts that when it builds a commercial-scale plant, energy from burning the lignin will provide enough surplus heat to boil water to generate electricity. Rather than robbing food crops to make fuel, cellulose ethanol begins with agricultural waste and ends with two marketable products: transportation fuel and electric power. Net emissions of carbon dioxide per mile driven from cellulose ethanol are near zero—or perhaps below zero, if the co-produced electricity displaces coal or natural gas at a power station. The lignin does give off carbon dioxide when burned, but growing new corn or switchgrass consumes gases. Optimists, including scientists at Iogen, foresee adapting their process to progressively lower-value feedstock, including converting the cellulose in paper such as that used in this magazine (after you have finished reading it).

Problems remain, though. Chief among them is taming one of the natural processes that break down cellulose; the sugars locked in the fiber cannot be distilled into ethanol until they are liberated from the lignin. Bacteria or fungi must produce enzymes to do the job. Those bacteria live in inconvenient locations, such as the underbrush of a distant jungle or the gut of a termite, and they turn out to be harder to domesticate than yeast was. Convincing them to multiply inside the unfamiliar confines of a 2,000-gallon stainless-steel tank is tricky, as is controlling their activity in the industrial-scale quantities needed to sustain conversion to ethanol inside such a space.

Several companies have made their proprietary processes work, but it does not appear that any has done so with enough consistency to persuade lenders. Although they have not been explicit about their technical problems, at a seminar at the House of Representatives last September companies complained that they could not convince a design firm to guarantee to a bank that the finished plant would work.

Certain organisms being tried may improve the odds. Iogen, whose process exploits a fungus from Guam that company scientists refer to as "jungle rot," has tinkered with the organism's DNA so it produces more of the needed enzyme. Other investigators are using enzymes made by mushrooms. Last fall Honda said it might have found a new bug for the job. Agrivida in Cambridge, Mass., is trying to bioengineer corn that contains enzymes that make it break down more readily to ethanol.

Nevertheless, U.S. Energy Secretary Samuel Bodman said at a September roundtable with reporters that the technology might be commercially viable within five years. More companies should be lured in part by generous government incentives, even though no one seems quite ready to build on a commercial scale.

In the meantime, relying on ethanol from corn is an unsustainable strategy: agriculture will never be able to supply nearly enough crop, converting it does not combat global warming, and socially it can be seen as taking food off people's plates. Backers defend corn ethanol as a bridge technology to cellulose ethanol, but for the moment it is a bridge to nowhere. SA

If companies can spawn enzymes in sufficient amounts, cellulose ethanol could extensively displace gasoline.

MORE TO EXPLORE

Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts Are Negative. David Pimentel in *Natural Resources Research,* Vol. 12, No. 2, pages 127–134; June 2003.
Available at **www.ethanol-gec.org/netenergy/neypimentel.pdf**

Updated Energy and Greenhouse Gas Emissions: Results of Fuel Ethanol. Michael Wang in the 15th International Symposium on Alcohol Fuels, September 26–28, 2005.
Available at **www.transportation.anl.gov/pdfs/TA/354.pdf**

Plan B 2.0: Rescuing a Planet under Stress and a Civilization in Trouble. Expanded and updated edition. Lester R. Brown. W. W. Norton, 2006.

25 × '25 Vision on renewable energy: **www.25x25.org/**