Thirsty fuel. Corn ethanol is expected to require trillions of liters of additional water by 2015.

GREEN ENERGY

Another Biofuels Drawback: The Demand for Irrigation

New U.S. mandates are prompting farmers to plant more corn in areas of the country that require irrigation. The move could trigger water shortages and water-quality problems

At first blush, it's easy to make the case for biofuels. By converting crops into ethanol or biodiesel, farmers can reduce demand for imported oil, lower national dependence on authoritarian governments in the Middle East, and potentially cut greenhouse gas emissions.

But dig a little deeper, and the story gets more complicated. Biofuels promise energy and climate gains, but in some cases, those improvements wouldn't be dramatic. And they come with some significant downsides, such as the potential for increasing the price of corn and other food staples. Now, a series of recent studies is underscoring another risk: A widespread shift toward biofuels could pinch water supplies and worsen water pollution. In short, an increased reliance on biofuel trades an oil problem for a water problem.

"It really means a greater potential for agricultural pollution of the waterways, eutrophication of the Gulf Coast, and a significant increase in water use, which may produce localized shortages," says Pedro Alvarez, an environmental engineer at Rice University in Houston, Texas. But just how severe such shortages could become remains unclear. They could be mitigated, some researchers suggest, by steady improvements in crop yields and an increasing reliance on nonfood feedstocks for making ethanol.

In 2007, the perceived benefits of biofuels helped spur the U.S. Congress to pass the Energy Independence and Security Act (EISA), which mandated a nearly fivefold increase in U.S. ethanol production, to 117 billion liters, by 2022. Of this amount, nearly half is slated to come from corn ethanol by 2015. Most of the rest will be added from cellulosic ethanol, which is made from agricultural wastes and other feedstocks. Biodiesel and other "advanced biofuels" will eventually chip in about 10%. Although cellulosic ethanol and other advanced biofuels aren't yet cheap enough to compete with corn ethanol, their prices are expected to decline over the next several years.

WATER REQUIREMENTS FOR ENERGY PRODUCTION (Liters per megawatt hour)

Petroleum Extraction	10-40
Oil Refining	80-150
Oil shale surface retort	170-681
NGCC* power plant, closed loop cooling	230-30,300
Coal integrated gasification combined-cycle	~900
Nuclear power plant, closed loop cooling	~950
Geothermal power plant, closed loop tower	1900-4200
Enhanced oil recovery	~7600
NGCC*, open loop cooling	28,400-75,700
Nuclear power plant, open loop cooling	94,600-227,100
Corn ethanol irrigation	2,270,000-8,670,000
Soybean biodiesel irrigation	13,900,000-27,900,000

*Natural Gas Combined Cycle

Growing all those feedstocks will be a stretch, especially for irrigated lands. Meeting the 2015 mandate alone would require 44% of the corn produced in the United States in 2007. That's in addition to existing food and feed corn needs, assuming no change in demand or prices. According to a report in January by May Wu and colleagues at Argonne National Laboratory in Illinois, 98 liters of irrigation water are required on average to produce a liter of corn ethanol. (Estimates range between 10 and 324 liters of water per liter of ethanol, depending on where the corn is grown.) Together, the need for more corn and the mandates for biofuels could increase water demand by some 5.5 trillion liters a year.

Making matters worse, other U.S. energy sectors are growing and increasing their demand for water. Another recent report from Argonne by Deborah Elcock, an energy and environmental policy analyst, for example, found that water consumption for energy production in the United States will jump two-thirds between 2005 and 2030—from about 6 billion gallons of water per day to roughly 10 bgd—driven primarily by population growth. About half of that increase will go toward growing biofuels. According to Elcock's analysis, which is scheduled to be published in the *Journal of the American Water Resources Association*, the impact from the increase in biofuels is likely to fall almost entirely on the Corn Belt states ranging from the Dakotas, Nebraska, and Kansas eastward to Ohio.

A separate analysis by Charlotte de Fraiture and colleagues at the International Water Management Institute in Colombo, Sri Lanka, underscores the scale of the change. De Fraiture and her colleagues looked at how the expected increase in biofuels would affect countries around the world. They found that the proportion of irri-

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THE PROMISE OF DROUGHT-TOLERANT CORN

The biofuels drive is just one of several factors, along with worldwide population growth and rising incomes, that's increasing the demand for corn and other crops. According to a report this year by the Food and Policy Research Institute at Iowa State University, Ames, demand for grains—primarily corn—is expected to grow over the next decade by about 15%, or roughly 200 million metric tons per year. That will put additional stress on global supplies of fresh water, 70% of which already goes to agriculture.

Growers have traditionally responded to increasing demand by boosting crop yields, bringing more land under cultivation, or both. But now seed companies are closing in on a third option: creating seed varieties able to tolerate drought. According to Winwei Xu, a plant geneticist with a joint appointment at Texas Tech University and Texas A&M's Texas AgriLife Research in Lubbock, such drought-resistant varieties could be particularly useful in reducing water demand in areas dependent on declining groundwater reserves. "The use of drought-tolerant and high-yield corn hybrids is key for sustainable corn production under limited irrigation," Xu says.

In traditional corn varieties, even a short drought at the wrong time can spell disaster. Corn seeds are properly pollinated if the pollen emerges from the plants at the same time as the corn silks, which capture the pollen and carry it down to individual corn kernels. But if a dry spell comes just as the plants are flowering, the silks may be delayed—drastically reducing the number of fertilized kernels. Drought that comes a little later, as corn grains are beginning to fatten, can also sharply limit growth.

Hearty stalk. Monsanto's engineered corn (*right*) resisted drought better than conventional corn plants in a trial.

Researchers at Monsanto say they have found a way to blunt some of these effects. Earlier this year, they announced that in field trials, newly engineered corn varieties were largely able to maintain yields under drought-like conditions. The Monsanto corn was engineered to express a cold shock protein from the bacterium *Bacillus subtilis*. According to Mark Lawson, who heads corn stress and yields research at Monsanto in St. Louis, Missouri, the protein helps the plant manage stress and continue growing. In early field trials, the extra gene helped boost plant yields by 6% to 10%. Monsanto has applied for regulatory approval of this variety, which should be available beginning in 2012 if all goes well, says Lawson, who adds that the company is also working on a second-generation drought-tolerant corn. DuPont's Pioneer Hi-Bred and other agribusiness companies are also gearing up to release drought-resistant corn.

Whether these new varieties can actually lower water use remains to be seen. Lawson says the goal of first-generation drought-tolerant corn is just to maintain yields during extended dry periods. But Michael Ottman, a crop scientist at the University of Arizona, Tucson, notes that farmers don't like dancing on the edge. For regions such as Nebraska that typically supplement rainwater with irrigation water, Ottman doubts that farmers will cut back on irrigation: "Most irrigation farmers don't want to stress their crops and reduce their yield. So it's hard to imagine they will use less water unless the irrigation district limits it." As a result, even if drought-tolerant corn helps prevent crop losses, it may not actually reduce water use.

–R.F.S.

gation water used to grow biofuels was expected to rise from about 2% to roughly 4% worldwide by 2030. But in the United States, the proportion of irrigation water going to biofuels is expected to skyrocket from about 3% in 2005 to 20% in 2030.

So what's the likely impact from this potential increased water use? That depends on where you are, Wu and others say. "Overall, I think there will be some shortages of water introduced by the EISA mandates," Alvarez says. The potential for shortages is greatest in the western plains states, where average rainfall isn't sufficient to grow corn and biofuel production is increasing, Wu reports. The demands could be particularly challenging for siting biofuel processing facilities. A typical facility might produce 100 million gallons of ethanol a year and use as much water as a town of 5000 people would. Although that amount of water isn't a lot on a national scale, "this can strain local resources," Wu says. "Water is like politics," adds Michael Ottman, a crop scientist at the University of Arizona, Tucson. "It's local that counts."

Another local impact that could hit hard is eutrophication in the Gulf of Mexico, caused by runoff of nitrogen fertilizers into the Mississippi River. Marine ecologists already see the runoff as a primary culprit in the vast "dead zone" that starves the northern Gulf waters of oxygen, killing everything from crabs to shrimp. A report by Michael Griffin of Carnegie Mellon University in Pittsburgh, Pennsylvania, and colleagues in the 15 October issue of *Environmental Science and Technology* found that even if all the future increase in biofuels were to come from cellulosic feedstocks, the amount of nitrogen pollution in the Gulf of Mexico would continue to rise. That stark forecast illustrates how difficult this environmental problem will be to reverse.

Experts see a few points of light in the gloom, however. Ottman notes that as biofuel production increases, other agricultural water needs may decline. In fact, even as the amount of U.S. land devoted to irrigating corn has grown in recent years, the total amount of irrigated land dropped from 2000 to 2007, as farmers took some land out of production and shifted away from some irrigation-intensive crops such as cotton.

Other factors may curb future water demands. Monsanto and other seed companies, for example, are engineering novel drought-tolerant corn strains that maintain their yields through extended dry spells (see sidebar). And even with current strains, the amount of water needed to grow and process corn ethanol has been dropping in recent years, thanks to increased yields and improvements in processing technology, according to Wu. The amount of water required to produce a liter of ethanol dropped from 112 to 98 liters between 1998 and 2006, Wu reports. The upshot, Wu, Ottman, and others say, is that better methods will partly offset the increased irrigation demands for biofuels.

The potential impact of cellulosic biofuels remains unclear. Many cellulosics will essentially be neutral from a water perspective, says Martha Schlicher, who heads biofuels development at Monsanto. Corn husks, for example, are a byproduct that can be harvested without additional demand for water. And processing switchgrass grown in rain-fed areas requires only between 2 and 10 liters of water per liter of ethanol, according to Wu's report. But Alvarez and others note that as the market develops for cellulosic feedstocks, farmers will have an incentive to begin irrigating switchgrass and other cellulosic ethanol crops to maximize their yields. That could further obscure what has already become a murky case for the advantage of biofuels.

–ROBERT F. SERVICE

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