THE NATIONAL ACADEMIES
REPORT IN BRIEF

October 2007

Water Implications of Biofuels Production in the United States

National interests in greater energy independence, concurrent with favorable market forces, have driven increased production of corn-based ethanol in the United States and research into the next generation of biofuels. The trend is changing the national agricultural landscape and has raised concerns about potential impacts on the nation's water resources. This report examines some of the key issues and identifies opportunities for shaping policies that help to protect water resources.

Biofuels—fuels derived from biological materials—are likely to play a key role in America's energy future. In 2007, President Bush called for U.S. production of ethanol to reach 35 billion gallons per year by 2017, which would displace 15 percent of the nation's projected annual gasoline use. By 2030, the administration aims to increase that production to 60 billion gallons per year. Recent increases in oil prices in conjunction with subsidy policies have led to a dramatic expansion in corn ethanol production and high interest in further expansion over the next decade.

Increased use of biofuels offers many benefits, such as a decreased reliance on foreign oil, but it also presents some challenges. Among the challenges that may not have received appropriate attention are the effects of biofuel development on water and related land resources. Growing and processing biofuel crops to meet America's energy needs will alter how the nation's water resources are used. However, the water implications of biofuels production are complex, difficult to monitor, and will vary greatly by region.

To help illuminate these issues, the National Research Council held a colloquium on July 12, 2007 in Washington, DC to facilitate discussion among representatives from federal and state government, non-governmental organizations, academia, and industry. This report examines the water implications of biofuels

production based on discussions at the colloquium, written submissions of participants, the peer-reviewed literature, and the best professional judgments of the committee.

Types of Biofuels

Currently, the main biofuel in the United States is ethanol derived from corn kernels. Corn-based ethanol is made by converting the starch in corn to sugars and then converting those sugars into ethanol. Ethanol derived from sorghum and biodiesel derived from soybeans each currently make up a very small fraction of U.S. biofuels. Other potential sources of materials for use in biofuels include field crops such as soy; short-rotation woody crops such as poplar and willow; animal fats, vegetable oils, and recycled greases; perennial grasses, such as switchgrass; agricultural and forestry residues such as manure and cellulosic waste; aquatic products such as algae and seaweed; and municipal waste such as sewage sludge or solid waste. Different biofuel sources have

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences • National Academy of Engineering • Institute of Medicine • National Research Council

unique implications for water resources.

One of the most promising new biofuels on the horizon is "cellulosic ethanol," derived from fibrous material such as corn stalks and wheat straw, native grasses, and forest trimmings. Because of technological limitations, cellulosic ethanol can currently be produced only at pilot and commercial demonstration-scales; however, production of cellulosic ethanol is expected to begin commercially within the next decade.

Implications for Water Supply

Water is an increasingly precious resource used for many critical purposes; in some areas of the country, water resources are already significantly stressed. For example, large portions of the Ogallala (or High Plains) aquifer, which extends from west Texas up into South Dakota and Wyoming, show water table declines of over 100 feet. Increased biofuels production will likely add pressure to the water management challenges the nation already faces as biofuels drive changing agricultural practices, increased corn production, and growth in the number of biorefineries.

Water Use for Irrigation

Whether or not biofuel crops will require more or less water will depend on what crop is being substituted and where it is being grown. Corn generally uses less water than soybeans in the Pacific and Mountain regions, but the reverse is true in the Northern and Southern Plains. Therefore, farmers switching from soybeans to corn will need more water in some regions and less water in others As this example demonstrates, there are many uncertainties in estimating the overall net impacts of biofuel crops on our water resources.

Another important consideration is how biofuel production might drive the expansion of agriculture into regions that currently support little agriculture. Expansion of agricultural lands, especially into dry western areas, has the potential to dramatically affect water use.

The report concludes that in the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the national-aggregate view of water use. However, there are likely to be significant regional and local impacts where water resources are already stressed. Depending on what crops are grown, where the crops are grown, and whether there is an increase in overall agricultural production, significant acceleration of biofuels production could cause much greater water quantity problems than are currently experienced.

Water Use for Biorefineries

All biofuel facilities require water to convert biological materials into fuel. The amount of water used in the biorefining process is modest compared to the water used for growing the plants used to produce ethanol; however, because water use in biorefineries is concentrated into a smaller area, its effects can be substantial locally. A biorefinery that produces 100 million gallons of ethanol per year, for example, would use the equivalent of the water supply for a town of about 5,000 people. Ethanol producers are increasingly incorporating water recycling and use-reduction measures in order to maximize energy yields while reducing water use.

Implications for Water Quality

Shifting agricultural practices to incorporate more biofuel crops will impact water quality as well as water quantity. Converting pastures or woodlands into cornfields, for example, may exacerbate problems associated with fertilizer runoff and soil erosion.

Fertilizer Runoff and Nutrient Pollution

For most crops, it is standard agricultural practice to apply fertilizers such as nitrogen and phosphorus, as well as pesticides, which include herbicides and insecticides. However, these chemicals can wash into bodies of water and affect water quality. For example, excess nitrogen washing into the Mississippi River is known to be a cause of the oxygen-starved "dead zone" in the Gulf of Mexico, in which marine life cannot survive.

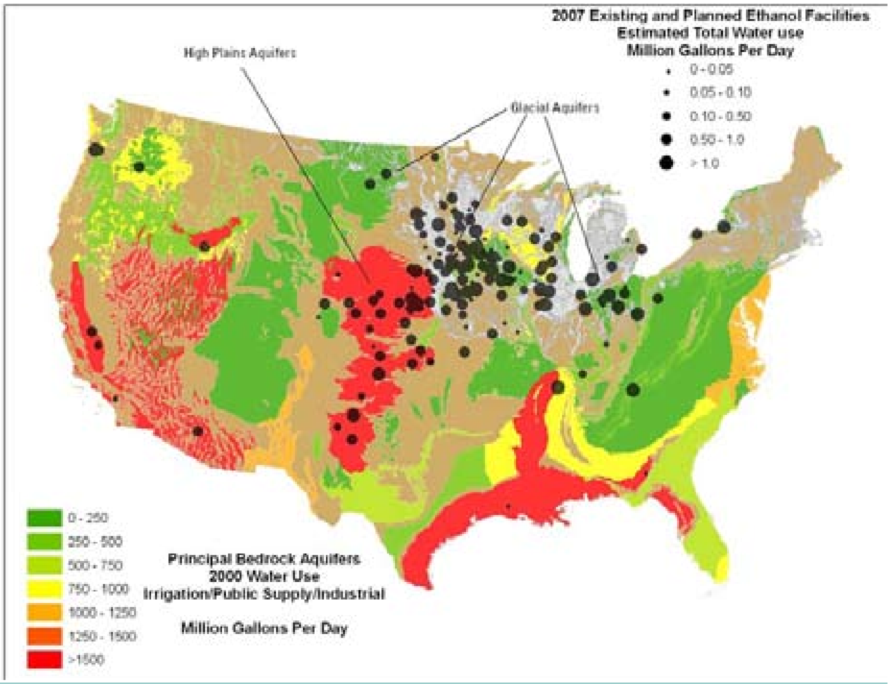
Different crops require different amounts of fertilizers. One metric that can be used to compare water quality impacts of various crops are the inputs

Fuel	Feedstock	U.S. Production in 2006
Ethanol	Corn	4.9 billion gallons
	Sorghum	< 100 million gallons
	Cane sugar	No production (600 million gallons imported)
	Cellulose	No production (one demonstration plant in Canada)
Biodiesel	Soybean oil	Approximately 90 million gallons
	Other vegetable oils	< 10 million gallons
	Recycled grease	<10 million gallons
	Cellulose	No production

(Left) 2006 U.S. production of different types of biofuels. SOURCE U.S. Congressional Research Service.

of fertilizers and pesticides *per unit of the net energy gain* captured in a biofuel. Of the potential biofuel crops, the greatest application rates of both fertilizer and pesticides per hectare are for corn. Per unit of energy gained, biodiesel requires a small fraction of the nitrogen and phosphorous used for corn-based ethanol. All else being equal, converting other crops or non-crop plants to corn will likely lead to much higher application rates of nitrogen.

However, there are many management practices that can improve the efficiency of fertilizer application and how they are used by plants. For example, recent advances in biotechnology have increased yields of corn per unit of applied nitrogen and phosphorous.



Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000. SOURCE: Janice Ward, U.S. Geological Survey.

Soil Erosion and Sedimentation

Sedimentation occurs when soil erodes from land and washes down into surface water bodies. Sediments impair water quality and also carry agricultural and other pollutants. The amount of sediment eroding from agricultural areas is directly related to land use—the more intensive the use, the greater the erosion. For example, more sediment erodes from row crop fields such as corn than from pastures or woodlands.

One of the most likely causes of increased erosion in the near term may be withdrawal of lands from the U.S. Department of Agriculture's voluntary Conservation Reserve Program due to an increase in overall agricultural production. The program pays farmers to convert environmentally sensitive or highly erodible acreage to native grasses, wildlife plantings, trees, filter strips, and riparian buffers and provides cost-share assistance for conservation practices.

Producing biofuels from perennial crops that hold soil and nutrients in place and require lower fertilizer and pesticide inputs, like switchgrass, poplars, willows, or prairie polyculture, is another option for reducing the deleterious effects of biofuel crops. There are, however, large uncertainties surrounding the production of cellulosic ethanol from such crops: such crops have very little history of use in large-scale cultivation. Therefore, even basic information such as water or nitrogen inputs needed, herbicide use, impact on soil erosion, and even overall yields is preliminary.

Reducing Water Impacts through Agricultural Practices

There are many agricultural practices and technologies that can simultaneously increase crop yields while reducing impacts on water resources. These technologies include a variety of water-conserving irrigation techniques, erosion prevention techniques, fertilizer efficiency techniques, and precision agriculture tools that take into account site-specific soil pH, moisture, and other measures. Such practices can have a large, positive environmental impact.

Surface cover is crucial in reducing sediment in runoff and limiting soil erosion. Farmers can employ a number of techniques that leave some portion of crop residues on the soil surface, helping to reduce erosion. In "no-till" systems, as the name implies, crops are simply planted into the previous year's crop residues. One of the issues for corn is what to do with the stalks and cobs left in the field after the grain has been harvested—called the corn stover. This material could potentially be converted to cellulosic biofuel, but leaving corn stover on the fields can greatly reduce soil erosion.

Key Policy Considerations

The water implications of biofuels production are complex, difficult to monitor, and will vary greatly by region. In general, however, crops that require less irrigation, less fertilizer and pesticides, and provide better erosion protection will likely produce fewer negative water impacts. Therefore, policy decisions that encourage such measures can have a significant positive impact on the protection of water resources as the demand for biofuels expands.

This report describes factors that shape the current policy context and raises some important considerations for future policy; however, it does not evaluate specific policy options or make any recommendations about policies to be implemented.

Current Policy Framework

The dramatic expansion of corn ethanol production over the past several years has largely been driven by subsidy policies for corn ethanol production coupled with low corn prices and high oil prices. These policies have been targeted to improving energy security and providing a clean-burning additive for gasoline. Staying the current policy path would likely result in the continued trend of expansion of corn-based ethanol production, driven by the economics of input costs and ethanol prices supplemented by the subsidy.

Future Policy Options

As biofuel production expands and technology advances, there is a real opportunity to shape policies to also meet objectives related to water use and quality impacts. To move toward a goal of reducing water impacts of biofuels, a policy bridge will likely be needed to encourage growth of new technologies that develop both traditional and cellulosic crops requiring less water and fertilizer and are optimized for fuel production.

Policy options that could help protect water resources include:

- *Alternative subsidies to reduce impacts of biofuels production on water use and quality.* To meet goals regarding overall water use, for example, performance incentives could be developed that encourage producers to increase water recycling in ethanol plants and farmers to adopt improved irrigation technology.
- *Policies to encourage best agricultural practices.* Several existing programs provide incentives to farmers specifically for improved nutrient management, for example. In addition, about $4 billion is spent annually on incentives for farmers to engage in practices to reduce soil erosion. Greater implementation of agricultural best practices could help maintain or even reduce water quality impacts.
- *Policies to encourage biofuels produced from cellulosic alternatives.* It is likely that cellulosic biofuels will have less impact on water quality per unit of energy gained; therefore, it would be prudent to encourage the transition from corn ethanol to the next generation of biofuels. The extent and intensity of water quality problems from biofuels will be partially driven by the conditions under which the cellulosic biofuels industry develops.

If projected future increases in use of corn for ethanol production do occur, the increase in harm to water quality could be considerable. In addition, expansion of corn production on fragile soils or can increase loads of both nutrients and sediments.It is vitally important to pursue policies that prevent an increase in total loadings of nutrients, pesticides, and sediments to waterways. From a water quantity perspective, measures to conserve water and prevent the unsustainable withdrawal of water from depleted aquifers could be critical.

Committee on Water Implications of Biofuels Production in the United States: Jerald L. Schnoor, *(Chair)*, University of Iowa, Iowa City; **Otto C. Doering III**, Purdue University; **Dara Entekhabi**, Massachusetts Institute of Technology; **Edward A. Hiler**, Texas A&M University; **Theodore L. Hullar**, Cornell University; **G. David Tilman**, University of Minnesota, St. Paul; **William S. Logan** *(Study Director)* and **Nancy Huddleston** *(Communications Officer)*, National Research Council.

This report brief was prepared by the National Research Council based on the committee's report. For more information or copies, contact the Water Science and Technology Board at (202) 334-3422 or visit http://nationalacademies.org/wstb. Copies of *Water Implications of Biofuels Production in the United States* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu. Support for the study was provided by the McKnight Foundation, Energy Foundation, National Science Foundation, U.S. Environmental Protection Agency, and the National Research Council Day Fund.