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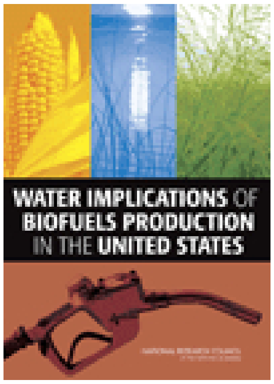

Water Implications of Biofuels Production in the United States

Committee on Water Implications of Biofuels Production in the United States, National Research Council

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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. To help illuminate these issues, the National Research Council held a colloquium on July 12, 2007 in Washington, DC. This report, based in part on discussions at the colloquium, concludes that if projected future increases in use of corn for ethanol production do occur, the increase in harm to water quality could be considerable from the increases in fertilizer use, pesticide use, and soil erosion associated with growing crops such as corn. Water supply problems could also develop, both from the water needed to grow biofuels crops and water used at ethanol processing plants, especially in regions where water supplies are already overdrawn. The production of "cellulosic ethanol," derived from fibrous material such as wheat straw, native grasses, and forest trimmings is expected to have less water quality impact but cannot yet be produced on a commerical scale. To move toward a goal of reducing water impacts of biofuels, a policy bridge will likely be needed to encourage growth of new technologies, best agricultural practies, and the development of traditional and cellulosic crops that require less water and fertilizer and are optimized for fuel production.

Summary

Because of a strong U.S. national interest in greater energy independence, biofuels have become important liquid transportation fuels and are likely to remain so for the foreseeable future. Currently, the main biofuel in the United States is ethanol derived from corn kernels, with a very small fraction made from sorghum. Biodiesel from soybeans also comprises a small fraction of U.S. biofuels. Ethanol from "cellulosic" plant sources (such as corn stalks and wheat straw, native grasses, and forest trimmings) is expected to begin commercially within the next decade.

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. President Bush has called for production of 35 billion gallons[1] of ethanol annually by 2017, which, if achieved, would comprise about 15 percent of U.S. liquid transportation fuels. This goal is almost certain to result in a major increase in corn production, at least until marketable future alternatives are developed.

Among the possible challenges to biofuel development that may not have received appropriate attention are its effects on water and related land resources. The central questions are how water use and water quality are expected to change as the U.S. agricultural portfolio shifts to include more energy crops and as overall agricultural production potentially increases. Such questions need to be considered within the context of U.S. policy and also the expected advances in technology and agricultural practices that could help reduce water impacts.

To help illuminate these issues, the Water Science and Technology Board (WSTB) of the National Research Council held a colloquium on "Water Implications of Biofuels Production in the United States" in Washington, D.C., on July 12, 2007, which was attended by more than 130 people from

[1] 1 gallon is equal to 3.79 liters.

BOX S-1
Statement of Task

The Water Science and Technology Board will conduct a colloquium and produce a short consensus report (and a "derivative" dissemination product in the form of a brochure) that airs and addresses key water quality, water quantity, and related land resources implications of biofuel production in the United States. The following issues will be addressed:

1. How much water and land might be required to grow different kinds of biomass in different regions? Where is water availability likely to be a limiting factor?
2. What are the possible, or likely, water quality effects associated with increases in production of different kinds of biomass?
3. What promising agricultural practices and technologies might help reduce water use or minimize water pollution associated with biomass production?
4. What are the water requirements of existing and proposed production plants, and what water quality problems may be associated with them?
5. What policy, regulatory, and legal changes might help address some of these water-use and water quality issues?

federal and state government, non-governmental organizations, academia, and industry. WSTB established a committee to organize and host the colloquium and to develop this report (see Box S-1). This report draws some conclusions about the water implications of biofuels productions based on discussions at the colloquium, written submissions of participants, the peer-reviewed literature, and the best professional judgments of the committee.

KEY ISSUES REGARDING WATER RESOURCES

Water is an increasingly precious resource used for many purposes including drinking and other municipal uses, hydropower, cooling thermoelectric plants, manufacturing, recreation, habitat for fish and wildlife, and agriculture. The ways in which a shift to growing more energy crops will affect the availability and quality of water is a complex issue that is difficult to monitor and will vary greatly by region.

In some areas of the country, water resources already are 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. Deterioration in water quality may further reduce available supplies. Increased biofuels production adds pressure to the water management challenges the nation already faces.

Crop Water Availability and Use

Some of the water needed to grow biofuel crops will come from rainfall, but the rest will come from irrigation from groundwater or surface water sources. The primary concern with regard to water availability is how much irrigation will be required—either new or reallocated—that might compete with water used for other purposes. Irrigation accounts for the majority of the nation's "consumptive use" of water—that is the water lost through evaporation and through plant leaves that does not become available for reuse.

The question of whether more or less water will be applied to biofuel crops depends on what crop is being substituted and where it is being grown. For example, in much of the country, the crop substitution to produce biofuel will be from soybeans to corn. Corn generally uses less water than soybeans and cotton in the Pacific and Mountain regions, but the reverse is true in the Northern and Southern Plains, and the crops use about the same amount of water in the North Central and Eastern regions.

There are many uncertainties in estimating consumptive water use of the biofuel feedstocks of the future. Water data are less available for some of the proposed cellulosic feedstocks—for example, native grasses on marginal lands—than for widespread and common crops such as corn, soybeans, sorghum, and others. Neither the current consumptive water use of the marginal lands nor the potential water demand of the native grasses is well known. Further, while irrigation of native grass today would be unusual, this could easily change as production of cellulosic ethanol gets underway.

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.

Water Quality Impacts

Fertilizers applied to increase agriculture yields can result in excess nutrients (nitrogen [N] and to a lesser extent, phosphorous [P]) flowing into waterways via surface runoff and infiltration to groundwater. Nutrient pollution can have significant impacts on water quality. Excess nitrogen in the Mississippi River system is known to be a major cause of the oxygen-starved "dead zone" in the Gulf of Mexico, in which many forms of marine life cannot survive. The Chesapeake Bay and other coastal waterbodies also suffer from hypoxia (low dissolved oxygen levels) caused by nutrient pollution. Over the past 40 years, the volume of the Chesapeake Bay's hypoxic zone has more than tripled. Many inland lakes also are oxygen starved, more typically due to excess levels of phosphorous.

Corn, soybeans, and other biomass feedstocks differ in current or proposed rates of application of fertilizers and pesticides. One metric that can be used to compare water quality impacts of various crops are the inputs of fertilizers and pesticides *per unit of the net energy gain* captured in a biofuel. Of the potential feedstocks, the greatest application rates of both fertilizer and pesticides per hectare are for corn. Per unit of energy gained, biodiesel requires just 2 percent of the N and 8 percent of the P needed for corn ethanol. Pesticide use differs similarly. Low-input, high-diversity prairie biomass and other native species would also compare favorably relative to corn using this metric.

Another concern with regard to water quality is soil erosion from the tillage of crops. Soil erosion moves both sediments and agricultural pollutants into waterways. There are various farming methods that can help reduce soil erosion. However, if biofuel production increases overall agricultural production, especially on marginal lands that are more prone to soil erosion, erosion problems could increase. An exception would be native grasses such as switchgrass, which can reduce erosion on marginal lands.

All else being equal, the conversion of other crops or non-crop plants to corn will likely lead to much higher application rates of N, which could increase the severity of the nutrient pollution in the Gulf of Mexico and other waterways. However, it should be noted that recent advances in biotechnology have increased grain yields of corn per unit of applied N and P.

Reducing Water Impacts through Agricultural Practices

There are many agricultural practices and technologies that, if employed, can increase yield while reducing the impact of crops on water resources. Many of these technologies have already been developed and applied to various crops, especially corn, and they could be applied to cellulosic feedstocks. Technologies include a variety of water-conserving irrigation techniques, soil erosion prevention techniques, fertilizer efficiency techniques, and precision agriculture tools that take into account site-specific soil pH (acidity, alkalinity), soil moisture, soil depth, and other measures. Best Management Practices (BMPs) are a set of established methods that can be employed to reduce the negative environmental impacts of farming.

Such practices can make a large, positive environmental impact. For example, in 1985, incentives were put in place to encourage adoption of conservation tillage practices. According to data from the National Resources Inventory (NRI), maintained by the Natural Resources Conservation Service, overall annual cropland erosion fell from 3.06 billion tons in 1982 to about 1.75 billion tons in 2003, a reduction of over 40 percent (http://www.nrcs.usda.gov/TECHNICAL/NRI/).

In addition, biotechnologies are being pursued that optimize grain production when the grain is used for biofuel. These technologies could help reduce water impacts by significantly increasing the plants' efficiency in using nitrogen, drought and water-logging tolerance, and other desirable characteristics.

Water Impacts of Biorefineries

All biofuel facilities require process water to convert biomass to fuel. Water used in the biorefining process is modest in absolute terms compared to the water applied and consumed in growing the plants used to produce ethanol. However, because this water use is concentrated into a smaller area, its effects can be substantial locally. A biorefinery that produces 100 million gallons of ethanol per year would use the equivalent of the water supply for a town of about 5,000 people.

Consumptive use of water in biorefineries is largely due to evaporation losses from cooling towers and evaporators during the distillation of ethanol following fermentation. However, consumptive use of water is declining as ethanol producers increasingly incorporate water recycling and develop new methods of converting feedstocks to fuels that increase energy yields while reducing water use.

Chapter 5 discusses the various waste streams from ethanol plants, which are controlled through various state discharge permitting systems.

Key Policy Considerations

Subsidy policies for corn ethanol production coupled with low corn prices and high oil prices have driven the dramatic expansion of corn ethanol production over the past several years. These policies have been largely motivated to improve energy security and provide a clean-burning additive for gasoline. As biofuel production expands, and particularly as new cellulosic alternatives are developed, there is a real opportunity to shape policies to also meet objectives related to water use and quality impacts.

As total biofuels production expands to meet national goals, the long-term sustainability of the groundwater and surface water resources used for biofuel feedstocks and production facilities will be key issues to consider. From a water quality perspective, it is vitally important to pursue policies that prevent an increase in total loadings of nutrients, pesticides, and sediments to waterways. It may even be possible to design policies in such a way to reduce loadings across the agricultural sector, for example, those that support the production of feedstocks with lower inputs of nutrients.

Cellulosic feedstocks, which have a lower expected impact on water quality in most cases (with the exception of the excessive removal of corn stover from fields without conservation tillage), could be an important alternative to pursue, keeping in mind that there are many uncertainties regarding the large-scale production of these crops. There may be creative alternatives to a simple subsidy per gallon produced that could help protect water quality. Performance subsidies could be designed to be paid when specific objectives such as energy-conversion efficiency and reducing the environmental impacts of feedstock production—especially water quality—are met.

Biofuels production is developing within the context of shifting options and goals related to U.S. energy production. There are several factors to be considered with regard to biofuels production that are outside the scope of this report but warrant consideration. Those factors include: energy return on energy invested including consideration of production of pesticides and fertilizer, running farm machinery and irrigating, harvesting and transporting the crop; the overall "carbon footprint" of biofuels from when the seed is planted to when the fuel is produced; and the "food vs. fuel" concern with the possibility that increased economic incentives could prompt farmers worldwide to grow crops for biofuel production instead of food production.

CONCLUSIONS

Currently, biofuels are a marginal additional stress on water supplies at the regional to local scale. However, significant acceleration of biofuels production could cause much greater water quantity problems depending on where the crops are grown. Growing biofuel crops in areas requiring additional irrigation water from already depleted aquifers is a major concern.

The growth of biofuels in the United States has probably already affected water quality because of the large amount of N and P required to produce corn. The extent of Gulf hypoxia in 2007 is among the three largest mapped to date, and the amount of N applied to the land is also at or near its highest level. If not addressed through policy and technology development, this effect could accelerate as biofuels expand to 15 percent of domestic usage to meet President Bush's 2017 goal, or to 30 percent of domestic fuel usage as proposed by President Bush as the ultimate goal.

If projected future increases in the use of corn for ethanol production do occur, the increase in harm to water quality could be considerable. Expansion of corn on marginal lands or soils that do not hold nutrients can increase loads of both nutrients and sediments. To avoid deleterious effects, future expansions of biofuels may need to look to perennial crops, like switchgrass, poplars/willows, or prairie polyculture, which will hold the soil and nutrients in place.

To move toward a goal of reducing water impacts of biofuels, a policy bridge will likely be needed to encourage development of new technologies that support cellulosic fuel production and develop both traditional and cellulosic feedstocks that require less water and fertilizer and are optimized for fuel production. Policies that better support agricultural best practices could help maintain or even reduce water quality impacts. Policies which conserve water and prevent the unsustainable withdrawal of water from depleted aquifers could also be formulated.

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Production in the United States

Water Science and Technology Board

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JERALD L. SCHNOOR, *Chair*, University of Iowa, Iowa City
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G. DAVID TILMAN, University of Minnesota, St. Paul

NRC Staff

WILLIAM S. LOGAN, Study Director
NANCY HUDDLESTON, Senior Communications Officer
MICHAEL J. STOEVER, Senior Program Assistant

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This report is the result of a process in which many people and organizations participated. The matter of biofuel development and implications to water resources was raised as an emerging issue of significant concern by the Water Science and Technology Board (WSTB) in 2006. Members of the board (Appendix B), working with WSTB staff and prospective sponsors, determined the approach to address this issue, crafted the task statement, identified candidates for the steering committee, and provided other general oversight. The steering committee (see listing in front matter and biographies in Appendix C) organized and hosted the colloquium and wrote this report. Fifteen individuals gave much time to prepare and make presentations and discussions (see colloquium agenda in Appendix A and biographical sketches in Appendix D) at the colloquium, thus providing a rich basis for deliberations at the colloquium itself by the 130 individuals present (too numerous to list) and by the steering committee following the event as it deliberated its way to consensus on the content of this report.

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Mary Jo Baedecker, U.S. Geological Survey (emeritus); Paul Bertsch, Savannah River Ecology Lab; Christopher Field, Carnegie Institution of Washington; David Fischhoff, Monsanto Company; Leonard Shabman, Resources for the Future, Inc.; H. Eugene Stanley, Boston University; and David Zilberman, University of California, Berkeley.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by George M. Hornberger, University of Virginia. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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