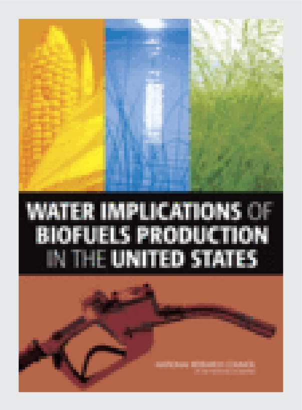

Water Implications of Biofuels Production in the United States

DETAILS

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WATER IMPLICATIONS OF BIOFUELS PRODUCTION IN THE UNITED STATES

Committee on Water Implications of Biofuels
Production in the United States

Water Science and Technology Board

Division on Earth and Life Studies

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Acknowledgments

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.

This project was sponsored by the McKnight Foundation, Energy Foundation, National Science Foundation, National Research Council (NRC) Day Fund, and U.S. Environmental Protection Agency.

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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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

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[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.

1

About Biomass, Biofuels, and Water

In the United States as of 2006, about 85 percent of the total energy consumed and about 97 percent of the energy for transportation came from fossil fuels such as oil, natural gas, and coal (http://www.eia.doe.gov). Fossil fuels are nonrenewable, and almost all estimates of domestic oil production indicate that the country has already used more than remains untapped. The United States imports well over 60 percent of the oil it consumes, and this percentage has been increasing.

Because of a strong national interest in greater energy independence, biofuels—fuels derived from biological materials, or biomass—have become important liquid fuels for transportation and are likely to remain so for the foreseeable future. Potential sources of biomass are plentiful. They include field crops such as soy and corn; 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 streams such as sewage sludge or solid waste.

Table 1-1 shows U.S. production of biofuels in 2006. In the United States, ethanol is derived mainly from corn kernels and biodiesel is derived mainly from soybeans, although other crops can serve to produce these biofuels. Approximately 4.9 billion gallons of ethanol were produced in the United States, which represents 3.6 percent of annual gasoline demand on a volume basis and 2.4 percent on an energy basis (U.S. CRS, 2007). Ethanol is blended in gasoline at levels of up to 10 percent for use in conventional vehicles and, less commonly, as high as 85 percent for use in "flexible fuel vehicles." Because biofuels recycle carbon (by removing carbon dioxide from the atmosphere during photosynthesis and storing the carbon in plant structures) rather than release stored subsurface carbon as fossil fuels do, they also have the potential to produce lower net greenhouse gas emissions.

TABLE 1-1 U.S. Production of Biofuels from Various Feedstocks in 2006

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

SOURCE: U.S. CRS (2007).

The new technology on the horizon is the production of "cellulosic ethanol" from the fibrous material from a variety of plants such as corn stalks and wheat straw, native grasses, and forest trimmings. Cellulosic ethanol production currently exists only at pilot and commercial demonstration-scales, because the technologies for breaking down the fibers into fuel on a commercial scale are still being developed and may be five or more years in the future. A 2005 joint study of the U.S. Department of Energy and the U.S. Department of Agriculture concludes that the United States could produce 60 billion gallons of ethanol by 2030 through a combination of grain and cellulosic feedstocks, enough to replace 30% of projected U.S. gasoline demand (USDA/DOE, 2005).

WATER AND BIOFUEL CROPS

Biofuels production will alter both what types of crops are grown and where they are grown and may increase overall agricultural production. The effects of these changes in the agricultural mix of crops on water are complex, difficult to monitor, and will vary greatly by region. In general, crops that require less irrigation, less fertilizer and pesticides, and provide better year-round erosion protection will likely produce fewer negative water impacts.

Understanding water quantity impacts is dependent on understanding the agricultural water cycle depicted in Figure 1-1. Crops can be either rainfed or irrigated (see Figure 1-2). Irrigation water can come from groundwater or surface water, and groundwater can be withdrawn from either a surficial aquifer (connected directly to the surface) or a confined aquifer (overlain by a low permeability layer, or aquitard, such as clay). Some of

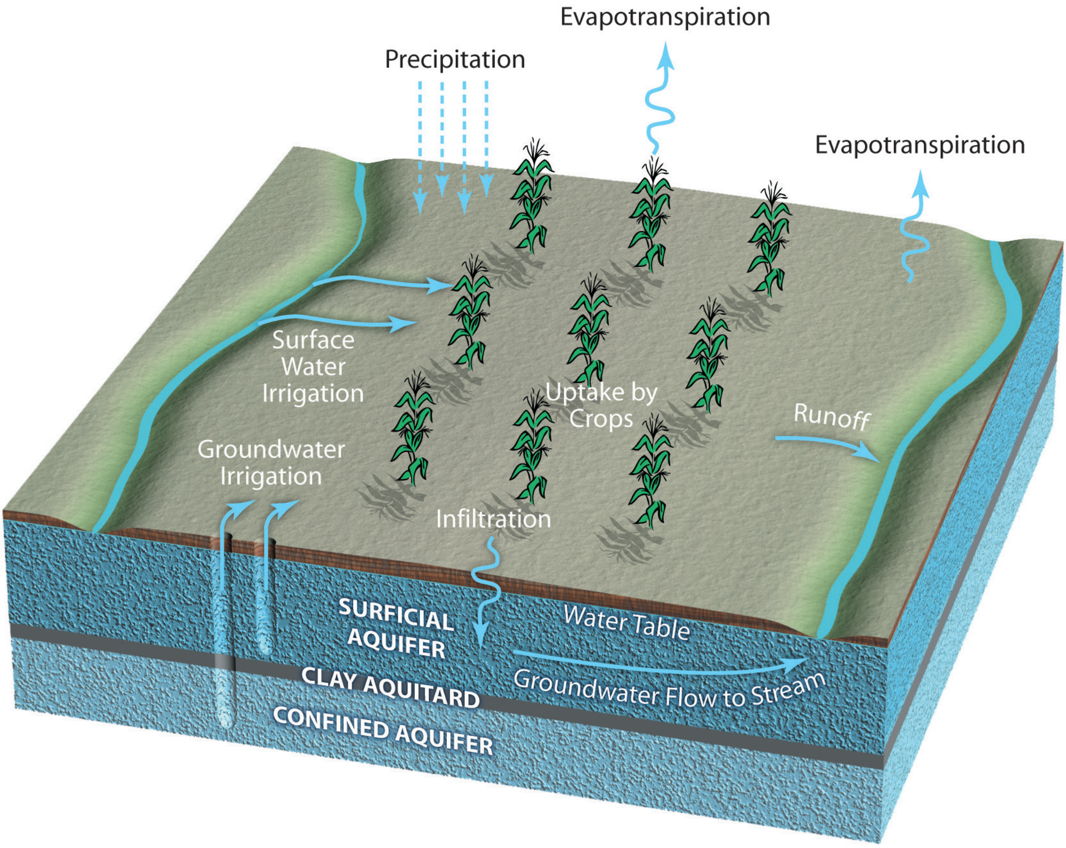

FIGURE 1-1 The agricultural water cycle. Inputs to a crop include rainfall and irrigation from surface water and groundwater. Some water is "consumed" (that is, incorporated in the crop or evapotranspired), some returns to surface waterbodies for human or ecological use downstream, and some infiltrates into the ground. Copyright by the International Mapping Associates.

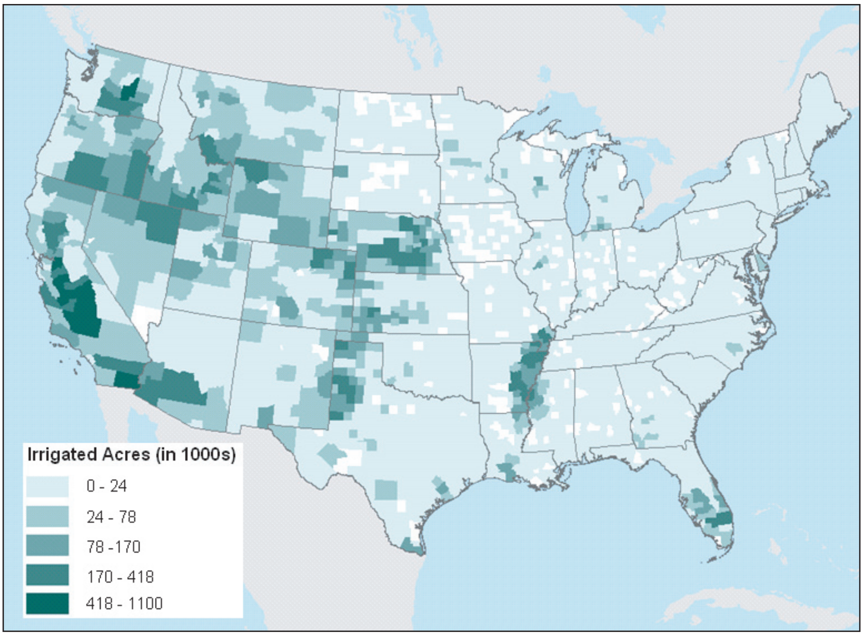

FIGURE 1-2 Irrigated land in the United States. Note that most of this is located in the more arid regions of the country.
SOURCE: N. Gollehon, USDA ERS, written commun., July 12, 2007. Based on data from U.S. Department of Agriculture (USDA) Economic Research Service (ERS) Census of Agriculture.

the applied water is incorporated into the crop, but most of it leaves the fields as (1) evaporation from the soil and transpiration from plants (called evapotranspiration or ET), (2) runoff to rivers and streams (sometimes called "return flow"), and (3) infiltration to the surficial aquifer. The water that is incorporated into the crops or lost to evapotranspiration is referred to as "consumptive use," because it cannot be reused for another purpose in the immediate vicinity.

Rates of ET vary greatly by the type of crop. During a growing season, a leaf will transpire many times more water than its own weight. An acre of corn gives off about 3,000-4,000 gallons of water each day while a large oak tree can transpire 40,000 gallons per year (USGS, 2007). Grasses that might be in cellulosic production have a slightly higher ET rate than corn, but a considerably lower ET rate than trees.

For most crops, it is standard agricultural practice to apply fertilizers such as nitrogen (N) and phosphorus (P), as well as herbicides, fungicides, insecticides, and other pesticides. Nitrogen in forms such as nitrate (NO_3) is highly soluble, and along with some pesticides infiltrates downwards toward the water table. Surface runoff and infiltration to groundwater both have significant impacts on water quality. Nutrient pollution causes excess algae to grow, decompose, and consume the oxygen in water, creating areas where fish cannot survive such as "dead zones" in the Gulf of Mexico and the Chesapeake Bay. The amount of fertilizers applied varies greatly with the type of crop. However, there are many management practices that can improve the efficiency of fertilizer application and how they are used by plants.

Water quality is also impaired by sediments that result from soil erosion associated with agriculture. It has been estimated that cropland erosion accounts for about half of the sediment that reaches the nation's waterways each year (USDA, 1993). Sediments impair water quality and also carry pollutants including excess nutrients and pesticides. 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.

Surface cover is crucial in reducing sediment in runoff and limiting soil erosion. Farmers can employ a number of conservation tillage techniques that leave some portion of crop residues on the soil surface. In "no-till" systems, as the name implies, crops are simply planted into the previous year's crop residues. An additional consideration for corn is that its residues called corn stover—the stalks and cobs left in the field after the grain has been harvested—can be converted into biofuels. However, leaving the corn stover on the fields can greatly reduce soil erosion.

WATER AND BIOREFINERIES

Ethanol is made by converting the starch in corn to sugars and then converting those sugars into ethanol, similar to the process used in a brewery. As with other industrial processes, biorefineries use water in the conversion processes and to heat things up and cool things down.

To produce ethanol, feedstock such as corn, wheat, barley, or other grain is ground to the consistency of coarse flour, mixed with water and enzymes, and cooked at high temperature to break down the starch polymers into glucose (sugar) molecules. The liquefied mash and yeast are put into tanks where the sugar is fermented into ethanol and carbon dioxide.

The fermented mash, called beer, is put in a distillation system that separates the ethanol from the water and leftover solids, called stillage, which are processed and sold for use in other industries. A dehydration system removes the remaining water, leaving nearly pure ethanol. Consumptive use of water includes steam lost through the cooling towers and water evaporated in drying the stillage.

Converting cellulose to ethanol involves breaking the long chains of cellulose molecules into glucose and other sugars, and fermenting those sugars into ethanol. In nature, these processes are performed by a variety of organisms, such as the bacteria in the stomachs of cows, which use enzymes (cellulases) to break down cellulose into sugars. Other microbes, primarily yeasts, then ferment the sugars into alcohol. The first step in this process is not yet possible on a commercial scale.

Ethanol distilling plants have various waste streams. First, salts build up in cooling towers and boilers due to evaporation and scaling, and must be periodically discharged ("blowdown"). Second, the technologies used to make the pure water needed for various parts of the process result in a brine effluent. Under the National Pollutant Discharge Elimination System (NPDES), permits are required from the states to discharge this effluent.

PROJECTED FUTURE GROWTH OF ETHANOL PRODUCTION

Recent increases in oil prices, which reflect a narrowing gap between oil supply capacity and oil demand, combined with subsidy policies have led to a dramatic expansion in corn ethanol production and high interest in further expansion over the next decade. Expansion of ethanol production to meet President Bush's call for 35 billion gallons annually by 2017 will drive increased corn production until marketable future alternatives are developed.

Even with the addition of cellulosic crops, corn will likely comprise a significant portion of biofuel crops. Figure 1-3 illustrates one possible scenario of crop production based on ethanol from cellulose becoming commercially available by 2015. The assumption is that agricultural commodity programs remain as of 2006, the current cropland base stays within 434 million acres, and yield increases in food and feed crops is sufficient to meet domestic demand, but there is a decline in U.S. exports of such crops.

Figure 1-4 shows the projected geography of production of cellulosic material in dry tons by the year 2030. It illustrates that although the types of crops may change, they will be mainly in areas that are already agriculture intensive. The trend in water use may show a decline, depending on whether

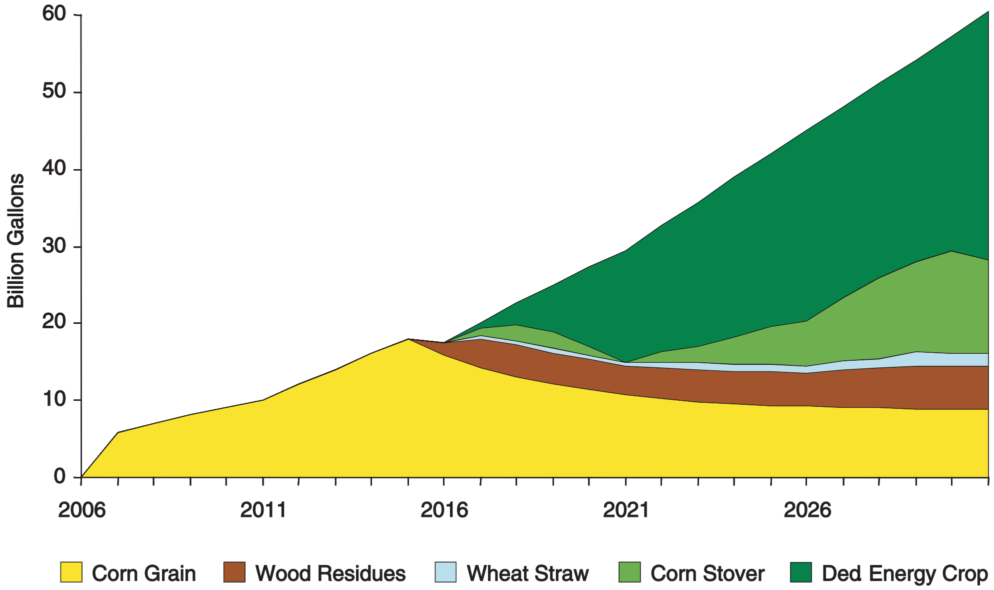

FIGURE 1-3 Projection of ethanol production by feedstock assuming cellulose-to-ethanol production begins in 2015. Dedicated energy crops refer to those grown solely for energy production.
SOURCE: Reprinted, with permission, from D. Ugarte, University of Tennessee, written commun., July 12, 2007.

the biomass crops use more or less water than those that were replaced (see Chapter 2). The water quality impacts will depend on the character of the land utilized and the extent to which the crops require nutrients and pesticides.

A perennial crop of cellulosic biomass such as switchgrass would hold soil and nutrients in place and require lower fertilizer and pesticide inputs, thus reducing water quality impacts. There are, however, large uncertainties surrounding the production of cellulosic ethanol. The expected cellulosic crops have very little, if any, 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.

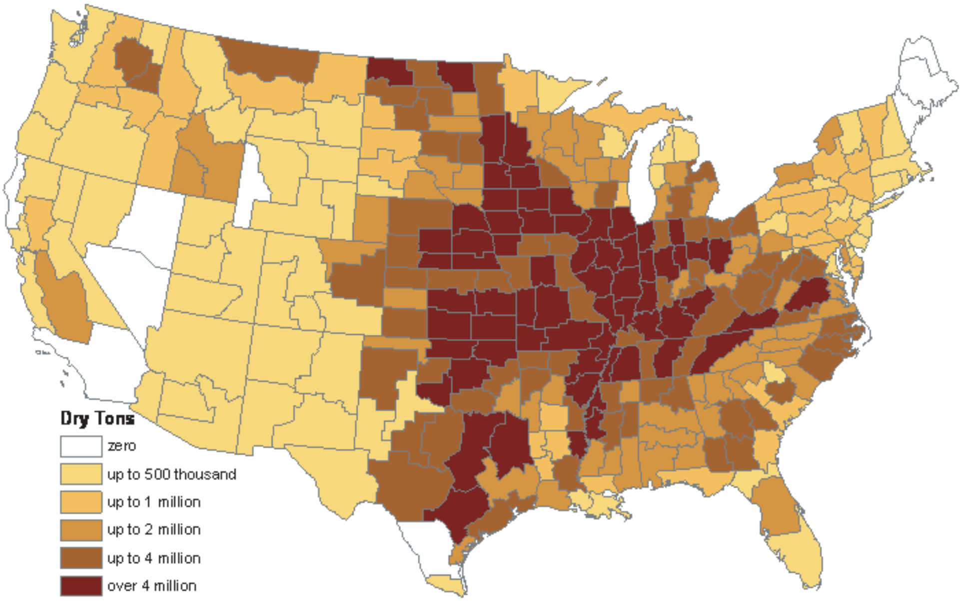

FIGURE 1-4 Distribution of the production of cellulosic materials in dry tons by the year 2030.
SOURCE: Reprinted, with permission, from D. Ugarte, University of Tennessee, written commun., July 12, 2007.

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2

Crop Water Availability and Use

As noted in Chapter 1, ethanol production from corn kernels has become an established industry and is projected to grow even further in the near future. While much of this increase will occur at the expense of soybeans, other sources of land for increased corn production will likely include cropland used as pasture, reduced fallow, acreage from expiring conservation programs, and shifts from other crops such as cotton (USDA, 2007). In the longer term, the likely expansion of cellulosic biofuel production has the potential to further increase the demand for water resources in many parts of the United States. Biofuels expansion beyond current irrigated agriculture, especially in dry western areas, has the potential to greatly increase pressure on water resources in some areas.

The water resource is already stressed in many agricultural areas. 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. Colorado River reservoirs are at their lowest levels in about 40 years. And overirrigation in areas such as the San Joaquin Valley of California has led to salinization of the soils. This should be kept in mind when utilizing today's water use as a baseline for comparison of future water-availability scenarios.

WILL THERE BE ENOUGH WATER TO GROW CROPS FOR THE PROJECTED BIOFUELS DEMAND?

In the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the national-aggregate view of water use. However, growing crops for biofuel production is likely to have significant regional and local impacts. Shifting land from an existing crop (or non-crop plant species) to a crop used in biofuel production has the potential to change irrigation water use, and thus the local water availability. Conversion to the

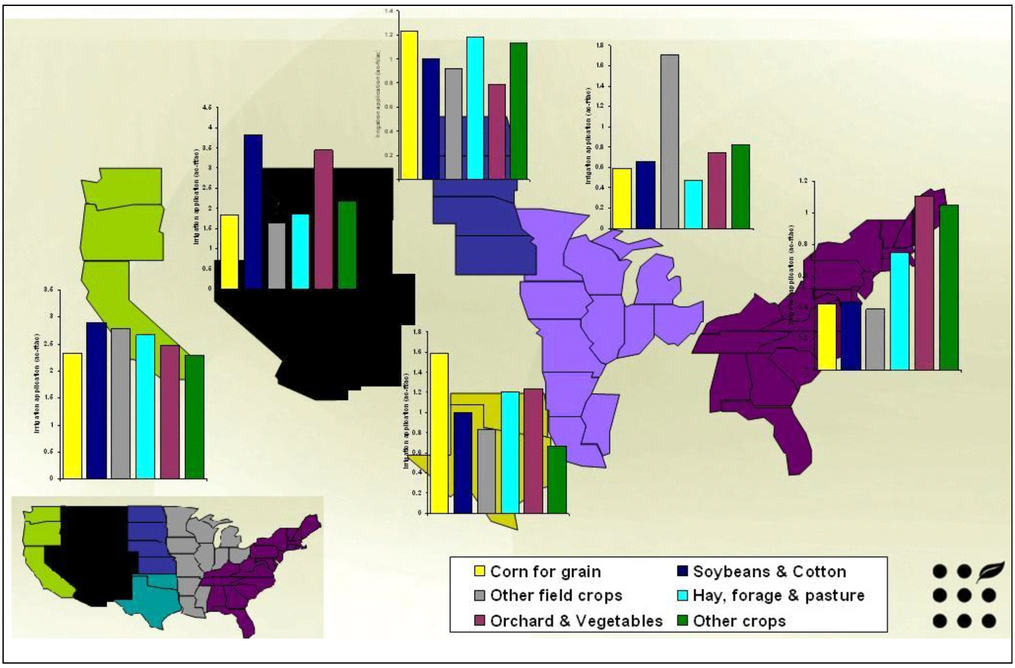

FIGURE 2-1 Regional irrigation water application for various crops for six regions of the United States. Irrigation application is normalized by area, and is in feet.
SOURCE: N. Gollehon, U.S. Department of Agriculture (USDA) Economic Research Service (ERS), written commun., July 12, 2007. Based on data from USDA Census of Agriculture.

different type of biomass will result in increased water use in some cases, in other cases a decrease.

As an example, in much of the country, the crop substitution is from soy to corn. The regional effects of this can be seen in Figure 2-1. Corn generally uses less water than soybeans and cotton in the Pacific and Mountain regions. 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. Changes in agricultural water use would generally parallel these trends. Another example is in Northern Texas, where annual evapotranspiration (ET) rates per year for alfalfa, corn, cotton, and sorghum are estimated to be about 1,600, 760, 640, and 580 mm (63, 30, 25, and 23 inches), respectively. Therefore, regional water loss to ET will likely decrease if alfalfa acreage is converted to corn, but increase if cotton or sorghum is converted (R. Allen, Univ. of Idaho, written commun., July 12, 2007. Data from Durwood et al. [1960]).

Given the regional differences in rainfall and groundwater storage, the feasibility and sustainability of biofuel crop production as a function of water availability may vary significantly by region. Figure 2-2 shows the state-by-state water requirement of irrigated corn in the continental United States. It demonstrates that the amount of rainfall and other hydroclimate conditions in a given area causes significant (10-fold) variations in the water requirement for the same crop. Clearly there will be geographic limits on certain kinds of biofuels feedstock simply based on their water require-

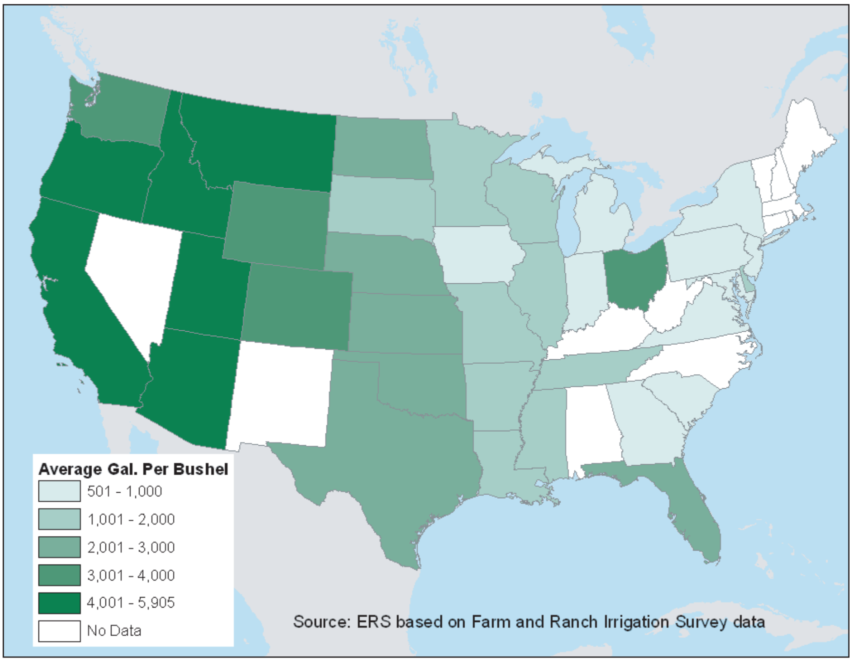

FIGURE 2-2 State-by-state water requirements in 2003 of irrigated corn (gallons of irrigation water per bushel).
SOURCE: N. Gollehon, USDA ERS, written commun., July 12, 2007. Based on data from 2003 Farm and Ranch Irrigation Survey (USDA, 2003).

ments. While the preceding discussion focuses on the conversion of one crop type to another, this may simply reflect the earliest phase of biofuels expansion. It seems likely that biofuels will push into a number of other regions, including regions that currently support little agriculture. Biofuels expansion beyond current irrigated agriculture, or even current agriculture in general, especially into dry western areas, has the potential to dramatically affect water use in such areas. The actual impact would be crop specific, and would be especially great where irrigation is introduced to an area that previously did not employ it.

There are other local or region-specific factors to address in considering substitution of a crop designed for biofuel production for another crop. The value of the crops relative to their water demand needs to be considered. Water rights can often be bought and sold if the value of the crop is sufficiently high. Competing demands for water are another local phenomenon, and the feasibility and sustainability of water diversions for biomass irrigation will vary depending on the region. The timing of the water demand of the replacement crop may also be critical. Water is often plentiful in one season but scarce in another.

HOW WILL BIOMASS PRODUCTION INTERACT WITH THE OVERALL WATER RESOURCE?

While the agricultural water cycle was summarized in Figure 1-1, agriculture is only one of many uses of water in a large basin. Water is also used for drinking water and cooling thermoelectric plants, in addition to nonconsumptive uses such as hydropower, fish habitat, and recreation. Conflicts are common: for example, agriculture competes with endangered species in the Klamath River basin of Oregon and California (NRC, 2004), and with urban and other water uses in the Apalachicola-Chattahoochee-Flint (ACF) River Basin in Georgia, Alabama, and Florida. It is important to weigh withdrawal and use of water for crop production against those competing uses, especially since much of the water applied to fields is lost to evapotranspiration. Therefore, the question of how much water is used in biofuel production has societal as well as scientific dimensions.

Figure 1-1 makes it clear that crop water may originate from one source, such as rain or groundwater, and be discharged to another, such as surface water. Precipitation, groundwater, and surface water sources—and groundwater and surface water discharges—are not only viewed differently in water law and policy, but also have different consequences for long-term sustainable use of the resource base. Since groundwater accounts for almost all of the long-term storage of water on the continents, extracting groundwater for irrigation that is subsequently discharged to streams may decrease the water available for future users of the aquifer.

Some of the applied irrigation water from any source runs off immediately into nearby streams, canals, and lakes. This addition to streamflow and water depth in turn may have positive or negative impacts on the ecosystems in and around these waterbodies, in terms of biodiversity, wildlife habitat, and wetlands loss or creation. It may also affect the potential for flooding or water shortages downstream. The fraction of the applied water that seeps into the shallow groundwater system (Figure 1-1) recharges aquifers for other users and in time provides additional base flow to streams. Thus, changes in one part of the agricultural water cycle (e.g., evapotranspiration or runoff) due to conversion of one type of vegetation or management practice to another will have inevitable impacts—for better or for worse—on the groundwater resource base and streamflow.

At a macroscale, the high prices of energy driving the increased production of biofuels will likely affect water availability and use. For example, Schoengold and Zilberman (2007) show that higher energy prices can lead to increased groundwater pricing, resulting in adoption of modern irrigation technologies and improved pumps. Conveyance costs related to surface waters will also increase with an increase in energy costs. These changes may lead to water conservation that may counter the expansion of water use associated with higher prices for crops.

WILL THE WATER REQUIREMENTS OF BIOFUELS CROPS IN THE FUTURE BE DIFFERENT?

The introduction of new feedstocks—including cellulosic, corn, and other crops optimized for fuel production—is expected as biofuel production increases. However, there are fundamental knowledge gaps that preclude making reliable assessments of the water impacts of these future crops. While a large body of information exists for water requirements and ET of the nation's traditional crops grown in their traditional regions, this is not true for non-native species that may be planted in new areas. The same challenge will exist for genetically modified crops that, for example, may be optimized for such things as energy production and water-use efficiency.

Water data is also less available for some of the proposed cellulosic feedstock—for example, native grasses on marginal lands—than for widespread and common crops such as corn, soy, sorghum, and others. Neither the current ET 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 cellulosic biofuel production gets underway. Thus, there are many uncertainties in estimating quantities such as consumptive water use of the biofuel feedstock of the future.

There are additional aspects of crop production for biofuel that may not be fully anticipated using the frameworks existing for food crops. For example, biofuel crops may be irrigated with wastewater that is biologically and chemically unsuitable for use with food crops. In other cases, crops such as safflower may be grown using irrigation water of moderate salinity, in effect increasing the available water supply. Overall, there may be opportunities for integrated domestic-agricultural-industrial water, energy, and materials exchange systems that are efficient and beneficial in terms of environmental and ecosystem services. Design and assessment of such systems reinforces the need for assessment tools and understanding that includes the full life-cycle of current and future agroecosystems.

HOW MIGHT CLIMATE CHANGE AFFECT THIS PICTURE?

Climate change predictions tend to indicate possible wetter and warmer conditions across the major agricultural regions of the continental United States. This is projected to increase aggregate yields of rain-fed agriculture by 5-20 percent, but with important variability among regions. Warming in the western mountains is projected to lead to decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources (IPCC, 2007). These changes are due to enrichment of the global atmosphere with the greenhouse gases from burning fossil fuels. The net surface water impact of wetter and warmer conditions depends on the land use and seasonally varying factors. Changing climate within the horizon of conversion to biofuels adds an element of uncertainty and warrants extra caution in making assessments.

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3

Water Quality

Throughout the nation, standard agricultural practices for most crops involve the application of fertilizers such as nitrogen (N) and phosphorus (P) along with herbicides, fungicides, insecticides, and other pesticides. The amount of a fertilizer nutrient that is captured in a crop, and the amount of pesticide that remains in the soil, depend on the crop, the amount, timing, and method of application, the methods of soil cultivation (see next chapter), and other variables. A certain amount inevitably moves offsite by various pathways. Nitrogen in forms such as nitrate (NO_3) is highly soluble, and along with some pesticides infiltrates downwards toward the water table (Figure 1-1). From there it can migrate to drinking water wells, or slowly find its way to rivers and streams. Another pathway is surface runoff, which transports N and P to streams either in solution or attached to eroding soil particles. A third pathway is wind erosion (or volatilization to the atmosphere in the case of nitrogen) followed by atmospheric transport and deposition over a broad area downwind. Surface runoff and infiltration to groundwater both have significant impacts on water quality, as is discussed below.

HOW MIGHT INCREASED BIOMASS PRODUCTION AFFECT THE WATER QUALITY OF OUR RIVERS?

Biomass feedstocks such as corn grain, soybeans, and mixed-species grassland biomass differ in current or proposed application rates of fertilizers and of pesticides. Of these three potential feedstocks, the greatest application rates of both fertilizer and pesticides per hectare are for corn (Figure 3-1). Phosphorus application rates are somewhat lower for soybeans than for corn. Nitrogen application rates are much lower for soybeans than for corn because soybeans, which are legumes, fix their own nitrogen from the atmosphere. Pesticide application rates for soybean are about half those for

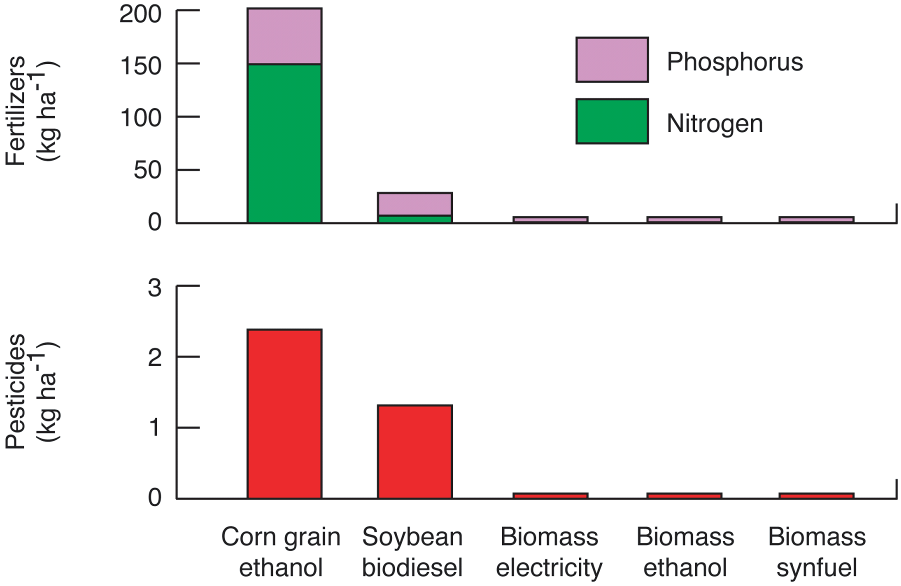

FIGURE 3-1 Comparison of fertilizer (top) and pesticide (bottom) application rates for corn, soybean, and low-input high-diversity (LIHD; "biomass" in the figure) mixtures of native grassland perennials. Fertilizer and pesticide application rates are U.S. averages.
SOURCE: Tilman et al. (2006). Reprinted, with permission, from American Association for the Advancement of Science. © 2006 by the American Association for the Advancement in Science.

corn. The native grasses compare highly favorably to corn and soy for both fertilizers and pesticides, with order-of-magnitude lower application rates.

The impacts of these differences in inputs can be visualized nationally by comparing N inputs (such as fertilizer and manure) and the concentrations of nitrate in stream water (Figure 3-2, top). There are similar patterns for stream concentrations of atrazine, a major herbicide used in corn cultivation (Figure 3-2, bottom), although the environmental effects of pesticides in current use are difficult to decipher. Both of these maps show that regionally the highest stream concentrations occur where the rates of application are highest, and that these rates are highest in the U.S. "Corn Belt." These stream flows of nitrate mainly represent application to corn, which is already the major source of total N loading to the Mississippi River.

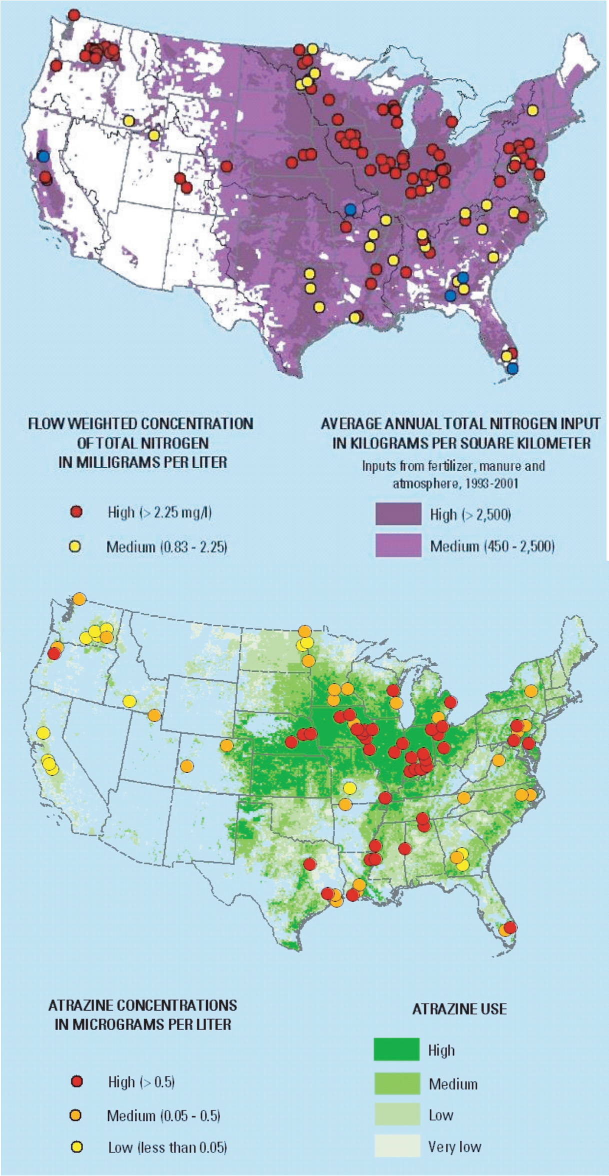

FIGURE 3-2 (top) N fertilization rates and stream concentrations of nitrate. (bottom) Atrazine application rates and stream concentrations of atrazine.
FIGURE SOURCE: J. Ward, U.S. Geological Survey, personal commun., July 12, 2007. DATA SOURCES: stream N, Mueller and Spahr (2007); N inputs, Ruddy et al. (2006); stream atrazine and atrazine inputs, Gilliom et al. (2006).

Increased sediment runoff is the most important environmental effect in many regions, such as the upper Mississippi River (UMRBA, 2004). High sedimentation rates increase the cost of often-mandatory dredging for transportation and recreation. They also have consequences for ecosystems and sport fishermen; many of the backwater areas along major streams, which are important in the lifecycles of fish and their prey, are slowly filling in with sediment.

One of the most likely causes of increased erosion in the near term may be the withdrawal of lands from the U.S. Department of Agriculture's (USDA) voluntary Conservation Reserve Program (CRP; see Chapter 6), as well as expansion of biomass production on non-CRP marginal land, due to increases in food and energy prices. The CRP makes annual rental payments to farmers to convert environmentally sensitive or highly erodible acreage to native grasses, wildlife plantings, trees, filter strips, and riparian buffers. It also provides cost-share assistance for up to 50 percent of the costs in establishing approved conservation practices. In exchange, participants enroll in CRP contracts for 10 to 15 years. High rates of withdrawal from the program in favor of growing biomass will have the effect of converting lands that may be helping to ameliorate water pollution into lands that are additional sources of water pollution. In the longer term, the use of crop residues such as corn stover either as feedstock for cellulosic ethanol or as fuel for conventional biorefineries has the potential to greatly increase erosion, as described in the next chapter.

WHAT MAY BE THE IMPACTS OF BIOMASS PRODUCTION ON THE NATION'S COASTAL AND OFFSHORE WATERS?

The effects of biomass production on the nation's coastal and offshore waters may be considerable. Nitrogen in the Mississippi River system is known to be the major cause of an oxygen-starved "dead zone" in the Gulf of Mexico (Figure 3-3), which in 2007 was the third largest ever mapped (http://www.gulfhypoxia.net). The condition known as hypoxia (low dissolved oxygen) occurs because elevated N (and, to a lesser extent, P) loading into the Gulf leads to algal blooms over a large area. Upon the death of these algae, they fall to the bottom and their decomposition consumes nearly all of the oxygen in the bottom water. This is lethal for most fish and other species that live there.

The Chesapeake Bay and other coastal waterbodies also experience the same phenomenon. Over the last 40 years, the volume of the Chesapeake Bay's dead zone has more than tripled, and in many summers comprises

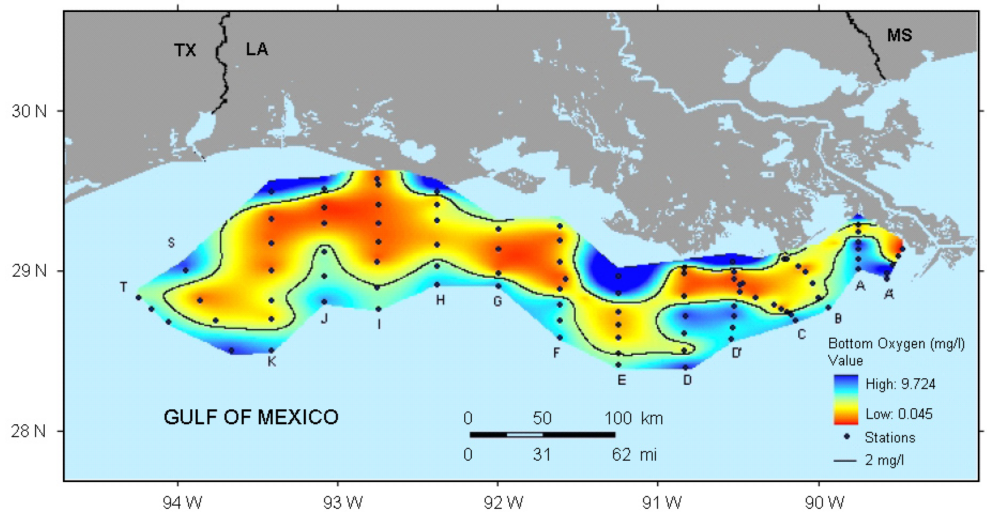

FIGURE 3-3 Dissolved oxygen contours (in milligrams per liter) in the Gulf of Mexico, July 21-28, 2007.
SOURCE: Slightly modified from http://www.gulfhypoxia.net/shelfwide07/PressRelease07.pdf. Reprinted, with permission, from N. Rabalais, Louisiana Universities Marine Consortium.

almost a quarter of the water in the mainstem Bay (Chesapeake Bay Foundation, 2006).

All else being equal, the conversion of other crops or non-crop plants to corn will likely lead to much higher application rates of nitrogen (Figure 3-1). Given the correlation of nitrogen application rates to stream concentrations of total nitrogen, and of the latter to the increase in hypoxia in the nation's waterbodies, the potential for additional corn-based ethanol production to increase the extent of these hypoxic regions is considerable. Since the dead zone in the Gulf of Mexico is already on the order of 10,000 square kilometers, the economic stakes are high.

WHAT ARE SOME LIKELY EFFECTS ON GROUNDWATER QUALITY?

Groundwater quality is directly impacted by the high levels of nitrate and nitrite—the products of nitrogen fertilizers—that leach into the groundwater from corn fields. Independent of the form of fertilizer N applied to

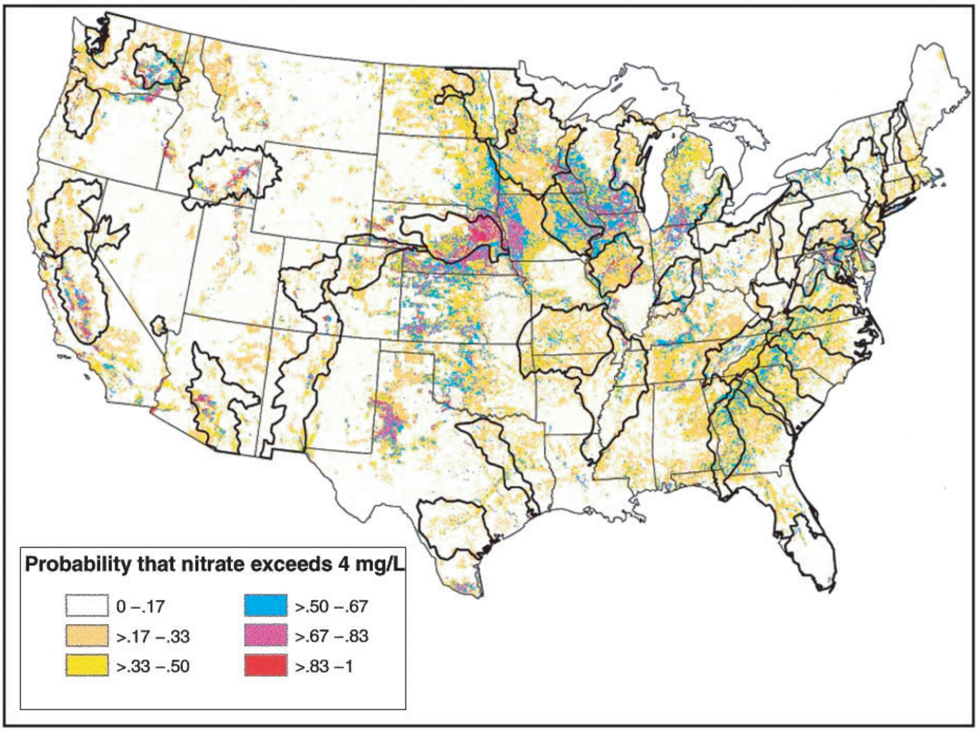

FIGURE 3-4 Probability that nitrate exceeds 4 milligrams per liter in shallow groundwaters of the United States, based on a logistic regression model.
SOURCE: Reprinted, with permission, from Nolan et al. (2002). © 2002 by The American Chemical Society.

agricultural fields, soil microorganisms convert much of the excess fertilizer N into nitrate, which, under anaerobic conditions in the soil or the groundwater, is converted into nitrite. U.S. Environmental Protection Agency (EPA) water quality standards classify wells that have nitrate+nitrite levels greater than 10 milligrams per liter as impaired and recommend that water be treated to remove the nitrate and nitrite before consumption. Failure to do so can have significant health impacts, including causing "blue baby syndrome" in infants, when ingested nitrite binds with hemoglobin thus preventing oxygen transport.

Nolan et al. (2002) demonstrate convincingly that the probability of nitrate contamination of shallow groundwater correlates strongly with increased N fertilizer loading, as well as with well-drained surficial soils over unconsolidated sand and gravels along with various other factors. This is shown visually in Figure 3-4. The probability of encountering N levels above 4 milligrams per liter is greatest in the High Plains, which is characterized by both high N fertilizer loading and well-drained soils overlying unconsolidated, coarse-grained deposits.

Some pesticides may also leach to groundwater. In a national study, pesticides were detected in 61 percent of shallow wells sampled in agricultural areas (Gilliom et al., 2006). However, in only 1 percent of these cases did any pesticide occur at concentrations greater than water quality benchmarks for human health. As with nitrate, pesticide contamination in groundwater is correlated with moderate to high application rates where soils are permeable and drainage practices do not divert recharge to surface waters, such as in parts of Iowa, Minnesota, Wisconsin, and Pennsylvania (Gilliom et al., 2006). It is reasonable to believe that groundwater quality issues associated with increased biofuels production may also be focused in these areas, and in others identified in Figure 3-4.

Groundwater contamination problems take longer to develop and longer to fix than surface water problems. However, over time the proportion of affected wells would increase if a common practice of year-to-year rotation of corn to soybeans to corn to soybeans, etc., were replaced by continuous corn or by corn grown with a higher frequency than half of the years. The area of the nation subject to having elevated groundwater nitrate and nitrite levels would also increase if corn were grown in new areas.

HOW CAN ENVIRONMENTAL EFFECTS OF DIFFERENT BIOMASS TYPES BE COMPARED?

There are many possible metrics, but an index that builds on the work shown in Figure 3-1 is inputs of fertilizers and pesticides *per unit of the net energy gain* captured in a biofuel. To estimate this first requires calculation of a biofuel's net energy balance (NEB), that is, the energy content of the biofuel divided by the total fossil energy used throughout the full lifecycle of the production of the feedstock, its conversion to biofuel, and transport. U.S. corn ethanol is most commonly estimated to have a NEB of 1.25 to 1.3, that is, to return about 25-30 percent more energy, as ethanol, than the total fossil energy used throughout its production lifecycle (Farrell et al., 2006; Hill et al., 2006; Wang et al., 1997; Shapouri et al., 2004). The NEB estimated for U.S. soybean biodiesel is about 1.8 to 2.0, or about a 100

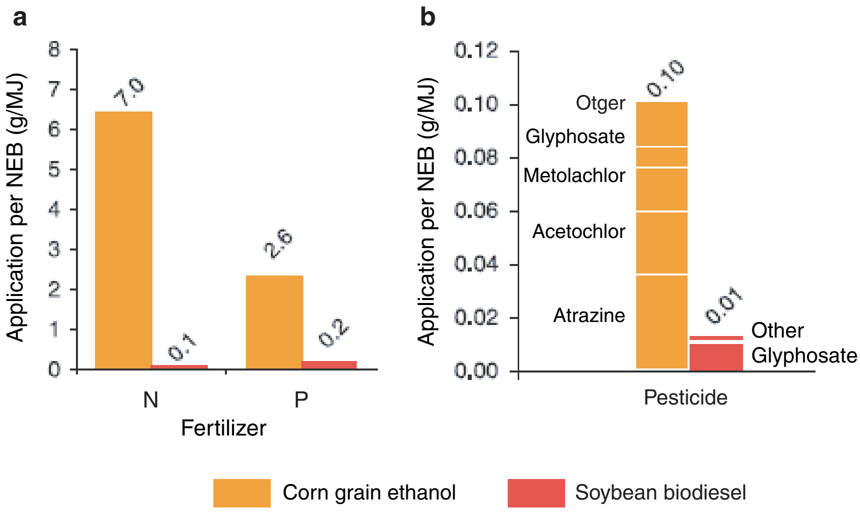

FIGURE 3-5 Environmental effects from the complete production and combustion life cycles of corn grain ethanol and soybean biodiesel. The figure shows the application of both (a) fertilizers and (b) pesticides, per unit of net energy gained from biofuel production.
SOURCE: Hill et al. (2006).

percent net energy gain (Hill et al., 2006; Sheehan et al., 1998). Switchgrass ethanol via fermentation is projected to be much higher—between 4 and 15 (Farrell et al., 2006). Similarly high are the estimates for (a) cellulosic ethanol and (b) synthetic gasoline and diesel from certain mixtures of perennial prairie grasses, forbs, and legumes (NEB=5.5 and 8.1, respectively; Tilman et al., 2006).

Per unit of energy gained, corn ethanol and soybean biodiesel have dramatically different impacts on water quality (Hill et al., 2006). When fertilizer and pesticide application rates (Figure 3-1) are scaled relative to the NEB values of these two biofuels, they are seen to differ dramatically (Figure 3-5). 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 per NEB differs similarly. Low-input high-diversity prairie biomass and other native species would also compare favorably relative to corn using this metric.

This is just one possible metric of biofuels' impact on water quality.

Other measures might incorporate land requirements per unit of biofuel, soil erosion, or impacts of the associated biorefinery (Chapter 5).

The large recent increases in U.S. corn acreage have already led to increased rates of N and P loading into surface and groundwaters. If projected future increases in use of corn for ethanol production do occur, the increase in harm to water quality could be considerable.

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4

Agricultural Practices and Technologies to Reduce Water Impacts

The challenges of water use and water quality presented in the earlier chapters raise the question, "What are the promising new agricultural practices being developed that might help cut water use and minimize pollution associated with the production of biomass?" In fact, there are many such practices and technologies that, if used, can significantly reduce the impact of agricultural activities on water resources. It is important to acknowledge that many technologies have already been developed and applied to various crops, with corn being the best example. The challenge will be to modify them for cellulosic feedstocks.

WHAT ARE THE AVAILABLE PRACTICES AND TECHNOLOGIES?

Irrigation Techniques

Efficient application of irrigation water is one the most important ways to mitigate any effects that increased biofuels production may have on water resources. There are several irrigation techniques that reduce the amount of water applied per unit of biomass produced, thus improving irrigation efficiency regardless of crop type. For example, subsurface drip irrigation systems minimize the amount of water lost due to evaporation and runoff by being buried directly beneath the crop and applying water directly to the root zone, thus keeping the soil surface dry (Payero et al., 2005). Real-time soil moisture and weather monitoring—the former through microwave remote sensing—are emerging technologies that can potentially help improve the scheduling of irrigation. Rainfall harvesting, efficient irrigation water transport, and use of reclaimed water can also lead to more efficient agricultural water use. These techniques would be effective for both corn and cellulosic ethanol crops.

The overall effect of improved irrigation techniques on the regional water budget will vary on a case-by-case basis. For example, if application efficiencies lead to less water being withdrawn from an aquifer, this would leave more water in long-term groundwater storage for future use. On the other hand, if lower water withdrawals from a stream only serve to make additional water available for junior water rights holders, the net effect on the regional water budget might be negligible.

Soil Erosion Prevention

As pointed out in the previous chapter, soil erosion can impair the water quality of streams and rivers and also contribute to nutrient pollution. Surface cover, especially in conjunction with conservation buffers, is crucial in reducing sediment in runoff and limiting soil erosion (Figure 4-1). Farmers can employ a number of conservation tillage techniques that leave some portion of crop residues on the soil surface. In “no-till” systems, as the name implies, crops are simply planted into the previous year’s crop residues. In “strip-till” systems, less than full-width tillage is conducted, leaving a relatively high amount of crop residue between rows. For corn, the stalks and cobs left in the field after the grain has been harvested—called the corn stover—can potentially be converted to cellulosic biofuel, but leaving them on the fields can greatly reduce soil erosion.

The effects of crop residue management on soil erosion can be represented by the “cover-management factor” (C) in the U.S. Department of Agriculture’s Revised Universal Soil Loss Equation. Because soil loss varies directly with C, a lower value corresponds to lower erosion estimates. In Table 4-1, the C-factor is estimated to be 0.02 for perennial grass, 0.04 for continuous corn when 100 percent of the corn stover is left in the field, and 0.55 for continuous corn when 95 percent of the residue is removed. Thus, from the standpoint of water quality with regard to erosion, sediment, N loss, P loss, and pesticide loss, it is clear that perennial grasses or polyculture (a form of agriculture in which one raises multiple species of crops at the same time and place) would have a great advantage over continuous corn, especially if most of the stover is removed.

Overall, conservation tillage appears to have had a positive effect on erosion. 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 U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, overall annual cropland erosion fell from 3.06 billion tons in 1982 to about 1.75

FIGURE 4-1 Terraces, conservation tillage, and conservation buffers, Woodbury County, northwest Iowa.
SOURCE: Photo by Lynn Betts, USDA Natural Resources Conservation Service. http://photogallery.nrcs.usda.gov/.

TABLE 4-1 Effect of Cropping System on Cover-Management Factor C of the Revised Universal Soil Loss Equation

Cropping System	C
Perennial grass or polyculture	.02
Continuous Corn Grain only removed	.04
Continuous Corn—75% residue removed	.16
Continuous Corn—95% residue removed	.55

NOTES: C-Factor is used to reflect the effect of cropping and management practices on erosion rates.

SOURCE: R. Cruse, Iowa State University, personal commun., July 12, 2007. Results calculated using the integrated crop and livestock production and biomass planning tool I-FARM, available online at http://i-farmtools.org.

billion tons in 2003, a reduction of over 40 percent (http://www.nrcs.usda.gov/TECHNICAL/NRI/). The data presented in Table 4-1 suggest that stover removal might best be combined with some kind of soil conservation practice.

Nutrient Pollution Reduction

There are various nutrient management techniques that can reduce the amounts of N and P in stream runoff and groundwater. One technique is using enhanced efficiency fertilizers that match nitrogen fertilizer applications to the nitrogen uptake patterns of various crops. Another is injecting the fertilizer below the soil surface, which will result in reduced runoff and volatilization. Controlled release fertilizers have water-insoluble coatings that prevent water-soluble nitrogen from dissolving. These techniques increase the efficiency of the way nutrients are supplied to and are taken up by the plant, regardless of the corp.

Precision Agriculture Tools

Precision Agriculture (PA) can be defined as "an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment" (U.S. House of Representatives H.R.2534). The approach can be used to manage feedstock production inputs on a site-specific basis such as land preparation for planting, seed, fertilizers and nutrients, and pest control. PA has the potential to reduce waste, increase profits, and maintain environmental quality.

PA is actually a return toward pre-industrial revolution site-specific agriculture while retaining the economies of scale of large operations. As such, it accounts for spatial variability in a field on a micro scale. This variability can include soil pH, soil moisture, soil depth, soil type, soil texture, topography, pest populations, nutrient levels, organic matter content, expected yield, etc. Key tools that have catalyzed the development of PA include Global Positioning Systems (GPS), Geographic Information Systems (GIS), yield monitoring and mapping, real-time in-situ soil testing, crop scouting, remote sensing of crop and soil status, real-time weather information, map-based variable-rate technology (VRT), and sensor-based VRT.

One PA technology is the Low-Energy Precision-Application Irrigation System (LEPA), an example of which can be seen below in Figure 4-2. The

FIGURE 4-1 Low-Energy Precision-Application Irrigation System.
SOURCE: USDA/ERS (2004).

LEPA differs from other types of low-pressure nozzles and heads in several ways. Generally, it operates at lower pressures and has higher irrigation-water application and distribution efficiencies, which result in lower net water loss and energy use (Fipps and New, 1991). This system can also be set up to apply fertilizers and pesticides.

Another promising technology involves using spectral radiometers that analyze crop color (Scharf et al., 2001). These can be mounted directly on fertilizer applicators and used to control variable-rate nitrogen applications. Systems that utilize sensors to assess color and health of crop plants, as well as variable-rate nutrient applications based on soil management zones and aerial photography, should find success with multiple types of feedstocks. Perennial feedstocks such as switchgrass or other native grasses would be in the field longer and thus should provide a greater opportunity to apply PA technologies. However, the application of technologies for efficient production of cellulosic biofuel will be determined by the economics of the specific production system.

HOW CAN BIOTECHNOLOGY CONTRIBUTE?

Biotechnology innovations can be important in at least three areas. The first and obvious one is in improving biomass feedstock development through molecular biology/genetic engineering as well as traditional crossing and selection of plants. This has long been done with a focus on optimization for food, but now there is a need to broaden the focus to optimizing for biofuels production. Currently, major companies are screening their corn germplasm for ethanol production efficiency (i.e., gallons of ethanol per bushel of corn), and work is progressing to transfer identified traits into commercial varieties (Mark Alley, Virginia Tech, personal commun., July 20, 2007).

By optimizing for fuel as opposed to food, researchers can create biomass feedstocks that have a higher nitrogen-use efficiency, increased drought and water-logging tolerance, and improved root distribution characteristics—technologies that can be applied to both corn and cellulosic feedstocks. It should be noted that corn has a head start in this area in the form of a 15-year history of biotechnological development while even the basic tools of biotechnology for cellulosic crops remain in their infancy. An example of this can be seen in the rate of yield gain, in which corn yields increased at a rate of about 2.5 bushels per acre per year during this 15-year period (Troyer, 2006).

Second, this new molecular genetics knowledge can be incorporated into weather-sensitive crop models that can help design crop varieties to match climate conditions, as well as determine optimal management of crops in specific climate conditions, either in the present or in the future. Biotechnology innovations that will increase the water-use efficiency of both food and biofuel crops will be of great value, as the introduction of biofuels will in some regions lead to an increased demand for water that will also increase the value of drought-tolerant varieties of crops.

Finally, biotechnology research and development can be important in improving lignocellulosic, microbial, and bioconversion as well as thermochemical conversion technologies. Although the cost of cellulolytic enzymes, which are used to break down these forms of biomass into biofuels, has decreased in recent years, sugar release from biomass still remains an expensive and slow step, perhaps the most critical in the overall process. Intensive research and development has produced a reduction in the cost of such enzymes by a factor of 10 to 30, down to 20 to 30 cents per gallon of ethanol produced. Although this decrease in price is an important advance, it is estimated that the enzyme cost will have to be further reduced to a level comparable to that of current approaches that produce ethanol from the starch in corn kernels at a cost of 3 to 4 cents per gallon of ethanol (Stephanopoulos, 2007).

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5

Water Issues of Biofuel Production Plants

In addition to the water required to grow crops, biofuel facilities require significant process water. As noted earlier, existing U.S. biofuel facilities consist primarily of ethanol production from corn kernels and minor biodiesel from soybeans, and at the pilot or demonstration-scale, additional ethanol is planned from cellulosic crops such as switchgrass.

HOW MUCH WATER DO BIOREFINERIES USE?

A useful measure of performance from a water-efficiency standpoint is the net energy yield per unit of water withdrawn or consumed. Consumptive use of water is largely due to evaporation losses from cooling towers and evaporators during the distillation of ethanol following fermentation. Consumptive use of water is difficult to directly measure because it depends on relative humidity, wind speed, and temperature in addition to the process configuration. However, water permits are generally required from state authorities to withdraw well water or surface water for industrial use, and this water is more or less continually metered. For that reason, this report considers water withdrawals as the measure of water use. This includes both consumptive and non-consumptive use, but as biorefineries increasingly incorporate water recycling, the difference between consumptive and total water use is decreasing. The water needs of each type of production system are discussed in the text below.

Corn Ethanol

Ethanol produced from corn kernels totaled 4.5 billion gallons in 2006. Production is growing rapidly in the United States and is expected to reach 6 billion gallons this year, but it still provides only a small fraction of total U.S. liquid transportation fuels. A typical process schematic and unit operations of an ethanol plant are shown in Figure 5-1. Pure water is required for the slurry operation with whole corn, followed by liquefaction to liberate sugars from starch via hydrolysis. This is followed by fermentation and distillation operations.

Current estimates of the consumptive water use from these facilities are in the range of 4 gallons of water per gallon of ethanol produced (gal/gal) (Pate et al., 2007). For perspective, consumptive water use in petroleum refining is about 1.5 gal/gal (Pate et al., 2007). Overall water use in biorefineries may be as high as 7 gal/gal, but this number has been consistently decreasing over time and as of 2005 was only slightly over 4 gal/gal in 2005 (Phillips et al., 2007). Thus for a 100 million gallon per year plant, a little over 400 million gallons of water per year would be withdrawn from aquifers or surface water sources (1.1 million gallons per day). The overall water balance for a typical bioethanol plant using corn is shown in Figure

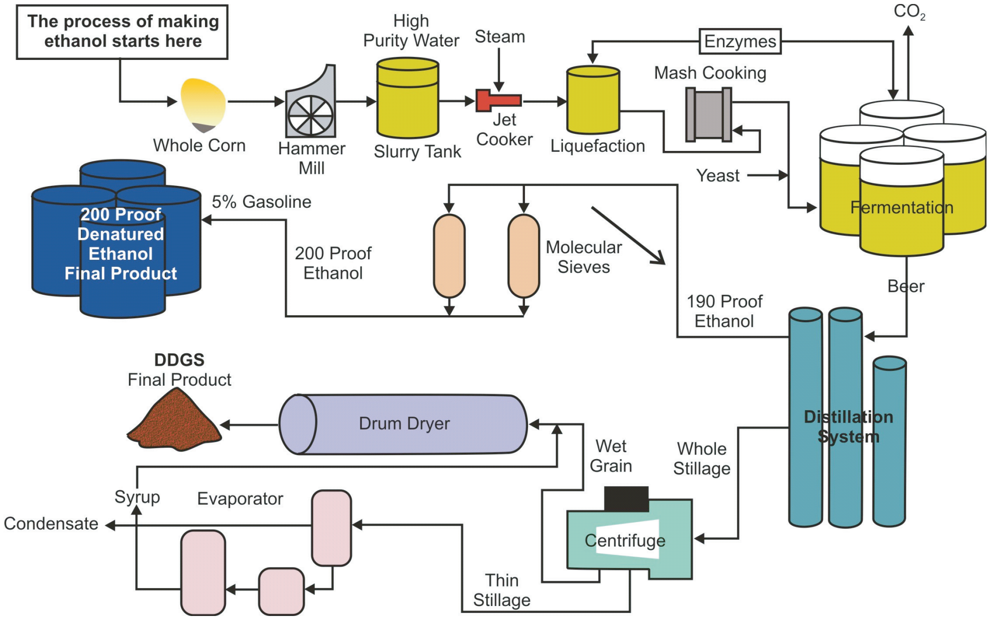

FIGURE 5-1 Process schematic and unit operations of ethanol production facility from whole corn kernels. DDGS is "dry distillers grains with solubles."
SOURCE: Parkin et al. (2007).

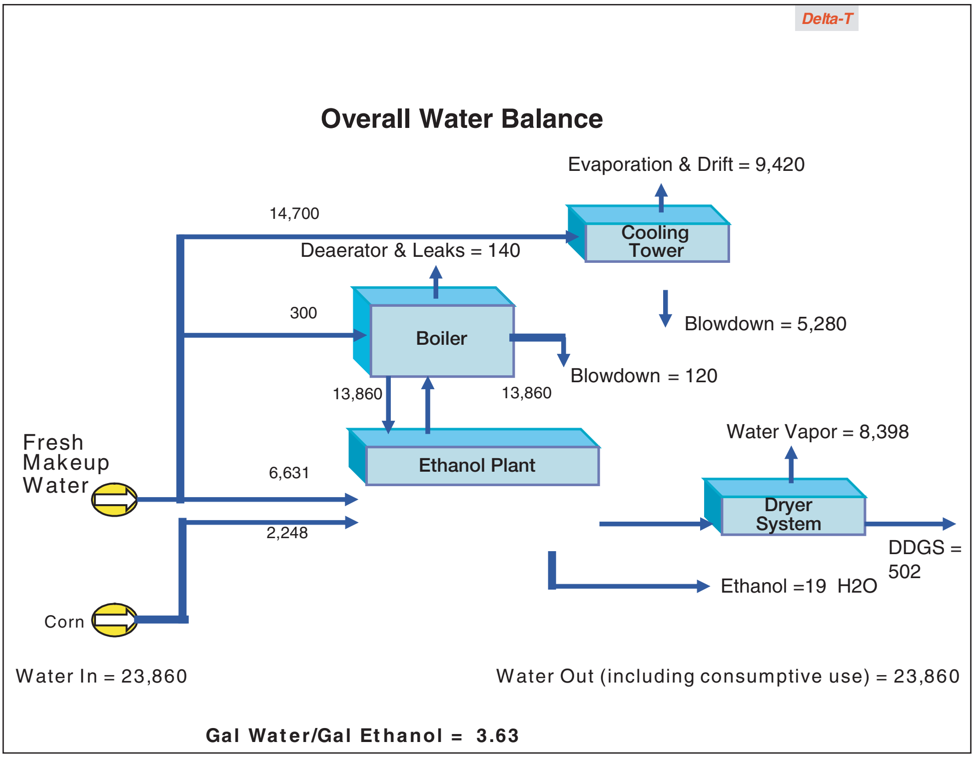

FIGURE 5-2 The overall water balance of a typical 50 million gallon per year corn-based Dry Mill ethanol production facility. All figures are in gallons per hour.
SOURCE: Reprinted, with permission, from Courtesy of Delta-T Corp.

5-2. Ethanol could also be produced from crops other than corn. Potatoes, sugar cane, sugar beets, or sweet sorghum could be used as a source of starch or sugar for fermentation, and these would alter the water requirements somewhat.

Sugar Fermentation of Cellulosic Ethanol

Producing ethanol from cellulosic materials such as grasses, crop residues, and wood requires a different process than for corn because they are not rich in starch or sugar. Rather, they are primarily made up of larger or more complex molecules such as cellulose, hemicellulose, and lignin, which must be converted to starch prior to processing. Additional enzymes are required to break down these substances in cellulosic-ethanol production, and the biochemical pathways used by microbes in the guts of ruminants such as cattle, and in wood-boring insects like termites, are also being studied. Conventional wisdom is that a technology breakthrough is required for this process to become commercialized, and it may be five or more years in the future. Only demonstration- and pilot-scale plants are currently operating for cellulosic-ethanol production.

The total water requirements for ethanol from cellulose are thought to be large—about 9.5 gal/gal (M. Holtzapple, Texas A&M, personal commun., July 12, 2007), but this likely will decline as efficiency increases with experience at cellulosic-ethanol plants. Consumptive use is projected to be about 2 to 6 gal/gal (Pate et al., 2007).

Thermochemical Conversion

Thermochemical conversion of cellulosic materials could be the next generation of biofuel plants. The process begins with gasification of biomass. Various catalysts are used to obtain a wide variety of potential products including synthesis gas, hydrogen, methane, or mixed alcohols (including ethanol) for fuel. DuPont Chemical has invested heavily in the alcohol, biobutanol, as a potentially important transportation fuel.

Biofuels are normally produced from homogeneous feedstocks, i.e., single-food crops like corn kernels, sugar beets, sugar cane, potatoes, canola, sunflower, and soybeans. But thermochemical conversion would allow the use of mixtures of feedstocks. In this technology, polycultures such as mixtures of native prairie plants could be used as a feedstock for transportation fuels (Tilman et al., 2006). This is attractive, because the use of prairie polycultures may have a distinct advantage in terms of lower soil loss, less nutrient applications and runoff, and especially improvement in wildlife habitat (Chapter 3).

The thermochemical conversion process holds the promise of much better energy yields and possibly lower water use. However, such technology is available today only at a demonstration scale; the infrastructure of automobile manufacturing and fuel delivery might need to be revamped to enable the use of biofuels from thermochemical conversion. Phillips et al. (2007) developed a design that would require about 2 gal/gal; this would be about half that required for corn ethanol plants (see above). Pate et al. (2007) estimate of 2 to 6 gal/gal consumptive use is lumped for several processing methods. Some of the water savings in Phillips et al.'s (2007) design is through improvements in cooling tower and boiler feed operations. Some of these efficiencies may be applicable to corn ethanol plants as well.

Biodiesel

Biodiesel, which in the United States is produced primarily from soybeans, comprises several percent of the nation's total biofuel production. Methanol and caustic (sodium hydroxide) are used in the production of biodiesel. Glycerin is a major co-product that has a low market value currently, in large part due to biodiesel production. Because of this, it is sometimes viewed as a major waste product, but greater commercial uses for glycerol could make biodiesel production more profitable. Biodiesel itself burns much cleaner than petrochemical diesel and enjoys considerable advantage in terms of lower air pollution.

Biodiesel refining requires much less water per unit of energy produced than bioethanol. Overall, consumptive use is about 1 gallon of fresh water per gallon of biodiesel and overall water use may be up to 3 gal/gal (Pate et al., 2007). Still lower usage may be possible in the future with new technologies, which include the possibility of using recycled waste water with various degrees of treatment.

HOW DOES BIOREFINERY WATER USE COMPARE TO THE AMOUNT NEEDED TO GROW ITS FEEDSTOCK?

Water withdrawals by biofuel production plants are similar to those of many other industries. They should be considered in the context of the total water cycle for the watershed or aquifer unit that is being utilized. Thus, biofuel plants can present local (or regional) problems depending upon where they are located. Even within the same state, the conditions can vary greatly; for example, aquifers in the northeastern part of Iowa tend to be quite productive, whereas those in the south have a much more limited yield.

Siting of some ethanol plants is occurring where the water resource is already under duress. Figure 5-3 shows, for example, that many bioethanol plants that each require 0.1-1.0 million gallons per day are located on the High Plains aquifer. This aquifer is currently being pumped at a rate of more than 1.5 billion gallons per day for agriculture, municipalities, industry, and private citizens. Thus, 15 million gallons per day for bioethanol would represent only 1 percent of total withdrawals. But it is an incremental withdrawal from an already unsustainable resource. Current water withdrawals are much greater than the aquifer's recharge rate (about 0.02 to 0.05 foot per year in

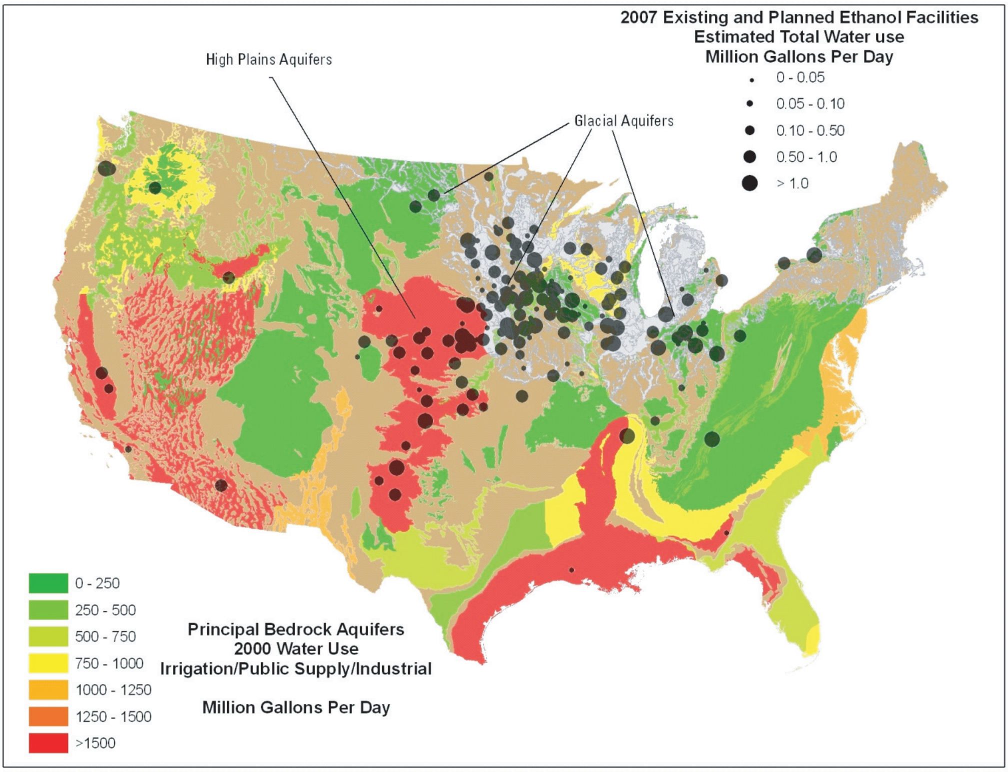

FIGURE 5-3 Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000.
SOURCE: Janice Ward, U.S. Geological Survey, personal commun., July 12, 2007.

south-central Nebraska; McMahon et al., 2007), resulting in up to a 190-foot decline in the water table over the past 50 years. It is equivalent to "mining" the water resource, and the loss of the resource is essentially irreversible.

The situation is also of concern in some locations in the Midwest, which draw water from confined units like the Silurian-Devonian and the Cambrian-Ordovician aquifers. Counties west of Chicago, for example, have drawn down the Cambrian-Ordovician aquifer by more than 800 feet of water head since 1850. In southwestern Minnesota, a proposed 100 million gallon per year ethanol plant was turned down by the local water system, which could not supply the 350 million gallons of water per year (~1 million gallons per day) that would be needed by the plant. By comparison, per capita water use from public water supply nationally is about 180 gallons per person per day (Table 5, Hutson et al., 2004), so this is the equivalent to the water supply for a town of about 5,000 people.

Compared to the water incorporated in the feedstock, water use for the biorefineries is quite small. For example, in neighboring Nebraska about 2,100 gallons of irrigation water were applied per bushel of corn in 2003 (Noel Gollehon, U.S. Department of Agriculture Economic Research Service, personal commun., July 12, 2007). Assuming the common figure of about 2.7 gallons of ethanol from one bushel of corn, 2,100 gallons of water/bushel × 1 bushel/2.7 gallons of ethanol = about 780 gallons of water per gallon of ethanol. This is about 200 times larger than the approximately 4 gal/gal given above for a corn ethanol biorefinery. This indicates that biorefineries themselves generate local, but often intense, water supply challenges, while irrigated agriculture can generate regional-scale problems. If, however, the agriculture is rainfed, water for the biorefinery may be the primary source of groundwater or surface water extraction in the area.

WHAT WATER QUALITY ISSUES ARE ASSOCIATED WITH BIOREFINERIES?

Ethanol plants have various waste streams. First, salts build up in cooling towers and boilers due to evaporation and scaling, and must be periodically discharged ("blowdown"). Second, the technologies used to make the pure water needed for various parts of the process (e.g., reverse osmosis [RO], ion exchange, iron removal; not shown in Figure 5-1) result in a brine effluent. Under the National Pollutant Discharge Elimination System (NPDES) permits are required from the states to discharge this effluent. These permits often cover total dissolved solids (TDS), acidity, iron, residual chlorine, and total suspended solids. Table 5-1 gives chemical characteristics of waste water from the RO operation and from the cooling tower blowdown for two plants in Iowa. Some violations of NPDES permits have been reported in Iowa and Minnesota from ethanol facilities, primarily for TDS.

Wastewater, potentially high in biochemical oxygen demand (BOD, the oxygen used when organic matter is decomposed by microbes), emanates from the processing of by-products such as thin stillage, wet distillers' grains, and dry distillers' grains with solubles (DDGS). Discharge of high-BOD water to rivers and lakes is problematical because decomposition can consume all of the dissolved oxygen, suffocating aquatic animals. DDGS is a valuable by-product that is rich in protein and especially good feed for animals such

TABLE 5-1 Water Quality of Waste Streams from Two Existing Ethanol Facilities in Iowa

Siouxland Ethanol Facility (Sioux Center, Iowa)		Little Sioux Ethanol Facility Simulated Blowdown		
Constituent[a]	Raw GW	Big Sioux RO Reject Water	Surface Water	Tower Eff.
TDS	2,113	7,288	703	3,240[b]
Ca^{2+}	305	1,033	129	638
Mg^{2+}	138	458	58	185
K^{+}	0	0	2	33
Na^{+}	148	485	20	297
Cl^{-}	23	131	35	27
SO$_4^{2-}$	1,420	4,716	107	2,265

[a] Concentrations in milligrams per liter.

[b] Concentration in milligrams per liter as $CaCO_3$.

SOURCE: Parkin et al. (2007).

as dairy cattle, steers, and sheep. Co-location of animal feeding operations with bioethanol production facilities could capture better efficiency in the overall operation compared to transporting the DDGS long distances to animals as is sometimes done.

Cellulosic-ethanol plants would have similar water requirements and brine discharges as the current operating corn ethanol plants. There are two additional steps required in converting lignin and cellulose into starch, and these operations could produce wastewater streams that are high BOD and would require on-site treatment or treatment at publicly-owned treatment works (POTWs).

Biodiesel has the potential to produce waste water discharges of high BOD, grease, and oils. Wastewater is normally transported to the local POTWs or treated on-site. If treated on-site, it is regulated by the U.S. Environmental Protection Agency as a bulk organic chemical production facility. Like ethanol plants, biodiesel plants also have waste streams from cooling tower blowdowns and water treatment reject streams.

One final potential water quality impact of biofuels would occur well "downstream" in a commercial sense. The increasing production of new mixtures of alcohol and gasoline, such as the 85:15 ratio known as E85, may create new challenges for groundwater in association with fuel spills. These spills might occur around gas stations, or from tanker truck or railcar accidents. While there is an extensive body of knowledge concerning the behavior of contaminants such as benzene in common gasoline spills, a mixture of 85 percent ethanol could alter this behavior considerably. While ethanol is completely soluble in water and rapidly biodegraded under most conditions, the presence of high ethanol concentrations enhances dissolution of more toxic gasoline compounds. In addition, rapid biodegradation of ethanol may inhibit the biodegradation of these compounds, which might then migrate farther off-site (Rice and Depue, 2001).

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Photo by Brett Hampton, Agricultural Research Service, U.S. Department of Agriculture

6

Policy Options

Subsidies for corn ethanol production coincident with low corn prices and high oil prices have driven the dramatic expansion of corn ethanol production over the last several years. The nation's subsidy policies have been motivated by the desire to improve energy security and to provide support for farmers as a matter of farm policy. 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.

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

WHAT FACTORS HAVE SHAPED THE CURRENT POLICY CONTEXT?

Several circumstances have favored the development of ethanol as a biofuel over the past 30 years. Following the oil crisis of the mid-1970s, Congress implemented a subsidy to encourage ethanol fuel additives in gasoline that has ranged from $0.40-0.60 per gallon of ethanol produced. This allowed a small ethanol fuels industry to develop in the United States that was profitable, even when the price of oil was low at $30-40 per barrel. Later, ethanol was shown to reduce carbon monoxide emissions in motor vehicles. Ethanol derived from corn kernels was a logical starting point to replace imported petroleum and, in addition, it provided another market for farmers' products in the United States.

Following Hurricane Katrina in 2005, the price of oil quickly rose to more than $50 per barrel and since then has been well above that price. This caused a "gold rush" of interest in ethanol production because corn prices were low and gasoline prices were high. Ethanol from corn was already a proven technology, so farmers, cooperatives, and large grain companies quickly responded to the strong market signal. Production capacity increased dramatically to more than 6 billion gallons in 2007. Still today, this represents only 3.5 percent of U.S. transportation fuel.

Congress and the Executive Branch have encouraged even greater production through the Energy Act of 2005, continuation of the ethanol subsidy at the current rate of $0.51 per gallon, and by direct payments to farmers for corn and soybeans through the Farm Bill. The Department of Energy (DOE) has projected that 30 percent of U.S. transportation fuel could be provided by biofuels, ethanol, and biodiesel from all feedstocks by 2030.

There will likely be adjustments brought about by international trade. The use of corn, soybeans, and sugar for liquid fuels is going to be affected by international production and demand for these commodities. International trade in ethanol or biodiesel will affect production of these in the United States to some extent, but the trade volumes initially will be modest at best. In the case of low-value, high-volume crops for cellulosic conversion, these are unlikely to be traded because transportation costs become limiting.

Biofuels will be an important component of the nation's energy portfolio for at least the next several decades (Doering, 2005). 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. Irrigation of crops creates consumptive use of water in areas where aquifers are being depleted and/or surface water quality is impaired. Policies designed to conserve water and prevent the unsustainable withdrawal of water from depleted aquifers could be formulated.

From a water quality perspective, it is vitally important to pursue policies that prevent an increase in total loadings of nutrient and sediments to waters. 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 (see Chapter 3). 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.

It should be noted that current agricultural production is not an appropriate benchmark against which to set environmental standards. As noted early, in many regions, water resources have already been stressed. Water quality has not improved markedly in key waterbodies like the lower Mississippi River and Chesapeake Bay. Gains made in erosion control through various conservation programs are being offset by substitution to corn crops that are more prone to water erosion. Although water quality improvement efforts in some areas have held nutrient levels steady, there has been little progress in improving water quality in key watersheds or in further reducing erosion to meet water quality and soil maintenance targets.

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. These 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.

HOW CAN POLICY REDUCE IMPACTS OF BIOFUEL PRODUCTION ON WATER QUALITY?

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. 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 soils that do not hold nutrients can increase both loads of nutrients and sediments.

Alternative Subsidies

Policymakers have options to alter the current subsidy structures to make funds available to ameliorate impacts of ethanol or feedstock production on water use and quality. For example, one option to consider is a variable subsidy for ethanol that would reduce public expenditures when ethanol production is profitable on a market basis. Money paid to producers would be reduced as ethanol becomes profitable and then increased as ethanol production costs exceed ethanol prices. Such a policy would likely have prevented the financial distress in the ethanol industry in the late 1990s when oil prices were low and corn prices high.

The subsidy money saved when ethanol is profitable could be redirected to efforts to reduce water impacts and/or other policy goals. To meet goals regarding overall water use, for example, performance incentives could be developed to encourage producers to increase water recycling in ethanol plants and farmers to adopt improved irrigation technology.

Policies to Encourage Biofuels Produced from Cellulosic Alternatives

Given the likelihood that cellulosic biofuels often will have less impact on water quality per unit of energy gained, it seems prudent to encourage the transition from corn ethanol to the next generation of biofuels. One of the issues within the current system is that investors will continue to prefer corn ethanol over cellulose because cellulose is riskier (W. Tyner, personal commun., July 12, 2007). This transition will be dependent on the development of cost-effective technology, and a policy bridge will likely be needed as well.

The extent and intensity of water quality problems from biofuels will be partially driven by the conditions under which the cellulosic biofuels industry develops. For the foreseeable future, this industry is likely to be driven by subsidies in addition to favorable petroleum and biomass feedstock prices. The current ethanol subsidy of $0.51 per gallon has raised profitability levels allowing rapid payback to ethanol producers irrespective of whether they have increased processing efficiency. In one scenario, with oil at $60 a barrel, an ethanol plant could pay $4.82 per bushel for corn and still achieve a 12 percent return on equity (Tyner, 2007).

Looking forward to cellulosic-ethanol production, there may be creative alternatives to a simple subsidy per gallon produced. If taxpayer money can be spent on subsidies, it can also be

used to provide incentives to encourage both the technology and the production of product and feedstock to meet public objectives. 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.

Policies to Encourage Best Agricultural Practices

Policies to maximize nutrient-use efficiency could help reduce nutrient pollution reaching such water bodies as the Mississippi River and the Chesapeake Bay. About $4 billion is spent annually for voluntary conservation programs and incentives that require farmers to engage in conservation activities to reduce soil erosion. The largest of these in terms of expenditures is the Conservation Reserve Program (CRP), which is administered by the U.S. Department of Agriculture's Farm Service Agency. The program initially focused on retirement of highly erosive and other environmentally sensitive land from crop production, but the scope of the CRP has been steadily expanded (SWCS, 2003).

The Natural Resources Conservation Service's (NRCS) Environmental Quality Incentives Program (EQIP), which has the largest number of participants and acres under contract, provides financial and technical assistance to farmers and ranchers to implement nutrient management and other practices to improve water quality and reduce erosion. The Conservation Security Program (CSP), introduced with the 2002 Farm Bill, is a stewardship program that complements the CRP and EQIP programs. CSP provides incentives to farmers specifically for improved nutrient management as part of an overall farm plan for reducing the environmental impact of the farming operation.

At the watershed or river basin level, some areas produce greater sediment and nutrient loadings than other areas. One option to increase the effectiveness of conservation programs is to target areas that would yield the greatest environmental benefits. The 2002 Farm Bill reduced the opportunity to target, but the Administration's proposed 2007 Bill partially restores targeting.

The U.S. Environmental Protection Agency and some states have adopted a strategy of issuing water quality permits—a concept originally applied to reduce pollutant emissions to the atmosphere. Every polluting entity is allowed to discharge pollutants up to a predetermined limit. Entities that discharge less than their allocated limits generate credits that they can sell (EPA, 2006).

Cross-compliance regulations issued in 1985 stipulate that a farmer would forego commodity price supports and other program subsidies if conservation practices were not followed on highly erosive lands, if grasslands were plowed, or if wetlands were drained, but the regulations have become less restrictive since they were introduced in 1985. Cross-compliance and other more stringent approaches may be necessary to achieve improvements in water quality (GAO, 2003). However, when commodity prices are high and price supports are less essential, a loss of subsidies may not be sufficient motivation for compliance; financial accountability for poor practices may be needed.

Because most nutrient pollution comes from non-point sources, it is relatively free of regulatory control. The possibility of increased nutrient pollution could encourage a more directed institutional approach to non-point source pollution by states or the federal government—something like a Total Maximum Daily Load (TMDL) regulation for a multi-state region or large river system. TMDLs are calculations of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. A paucity of data and difficulty in assigning responsibility for non-point source pollution raise technical and political challenges. Use of the best available science can help make TMDL programs more equitable and effective (NRC, 2001).

Although cellulosic crops in general hold soil better than corn, they can also pose problems of nutrient leaching and erosion. The imminent expansion of biomass production raises the urgency of this concern.

Implications of Biorefineries

Process water for corn ethanol production raises both quantity and quality concerns. However, both the impacts and the regulatory opportunity for mitigation are likely to be at the local or state level. With the rapid expansion of ethanol production, some local communities and governments have not anticipated withdrawal levels or discharge volumes and have suffered the resulting water draw-downs and water treatment requirements. Mitigation will require effective withdrawal rules and enforcement and/or enhancement of existing state/federal rules on point discharge.

WHAT METRICS CAN BE USED TO INFORM POLICY DECISIONS?

Many different metrics can be used to assess real-world consequences of different crop choices. For example, measuring greenhouse gas emissions per unit of energy produced can be a useful metric when attempting to capture some of the environmental consequences of biofuels production. Or, measuring petroleum displacement per unit of energy produced can be useful when assessing strategies that are driven by a policy leading to greater energy independence for the United States. The choice of metric is important because different feedstocks will be ranked differently and will have varying strengths and weaknesses depending on the choice of metric.

One possible metric to compare the impact of biofuels on water quality, as discussed in Chapter 3, is to compare crops based on inputs of fertilizers and pesticides *per unit of the net energy gain* captured in a biofuel. Similar metrics could be developed for water quantity; water application rates or consumptive water use could be used depending on the kinds of impacts being measured. Other measures might incorporate land requirements per unit of biofuel, soil erosion, or impacts of the associated biorefinery.

Regulations and voluntary programs have been the traditional policy approach to ameliorating the negative impacts of agricultural production, and the degree to which such practices have been applied has often been the measure of success. Because biofuels could become a dominant driver of agricultural production across the landscape—affecting crop choice, land use, and production practices—it may be appropriate to respond to this change with measures of success that relate specifically to the new driver. For example, feedstocks could be chosen using metrics of energy output per unit of water quality impact and water use, and more performance measures that directly monitor impacts of biofuels production on water resources could be applied.

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Appendix A

Agenda for the Colloquium on Water Implications of Biofuels Production in the United States

JULY 12, 2007

The National Academy of Sciences Building
Lecture Room
2100 C St. N.W.
Washington, D.C.

7:30–8:30	Breakfast available in the Great Hall	
8:30–8:45	Break	
8:45–9:00	Welcome and brief introductions	Jerry Schnoor (U. of Iowa) Steve Parker (WSTB)
9:00–9:15	Introductory remarks—setting the context	Otto Doering (Purdue)

Topic #1: **How much additional water, if any, might be required to grow different kinds of biomass? Is there going to be "enough" water to produce as much biofuel as we want where we want it?**

9:15–10:15

9:15	Initial presentation	Noel Gollehon (USDA/ERS)
9:35	Discussants	Rick Allen, (U. Idaho–Kimberly); Steve Kaffka, (UC–Davis)
9:55	Open discussion	Dara Entekhabi (MIT)

Topic #2: **What are the possible, or likely, water quality effects associated with increases in growing different kinds of biomass?**

10:15–11:15

10:15	Initial presentation	Rick Cruse (Iowa State)
10:35	Discussants	Janice Ward (USGS); Liz Marshall (WRI)
10:55	Open discussion	David Tilman (University of Minnesota)

11:15–11:30 Break

Topic #3: **What will be the water requirements of the production plants themselves, and what water quality problems may be associated with them?**

11:30–12:30

11:30	Initial presentation	Mark Holtzapple (Texas A&M)
11:50	Discussants	Dennis Keeney (IATP); Fran Kremer (EPA/ORD)
12:10	Open discussion	Ted Hullar (Cornell)

12:30–1:30 Lunch

Topic #4: **What are new and promising agricultural practices and technologies that might help us out by cutting water use or minimizing pollution?**

1:30–2:30

1:30	Initial presentation	Wendy Graham (University of Florida)
1:50	Discussants	Richard Nelson (Kansas State University) Mark Alley (Va. Tech)
2:10	Open discussion	Ed Hiler (Texas A&M)

Topic #5: **What policy, regulatory, and legal changes might help moderate any water use conflicts and mitigate any water quality issues?**

2:30–3:30		
2:30	Initial presentation	Daniel de la Torre Ugarte (University of Tennessee)
2:50	Discussants	Wally Tyner (Purdue); Craig Cox (Soil and Water Conservation Soc.)
3:10	Open discussion	Otto Doering (Purdue)
3:30–3:45	Break	
3:45–4:45	Guided discussion—“Key Themes”	Jerry Schnoor (U. of Iowa)
4:45 p.m.	Adjourn	

Appendix B

Water Science and Technology Board

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ANITA A. HALL, Senior Program Associate
DOROTHY K. WEIR, Research Associate
MICHAEL J. STOEVER, Senior Program Assistant

Appendix C

Biographical Sketches for Committee on Water Implications of Biofuels Production in the United States

Jerald L. Schnoor (NAE), *Chair,* is the Allen S. Henry Chair Professor in Engineering, Professor in Civil & Environmental Engineering; Professor in Occupational and Environmental Health, the College of Public Health; and Co-Director of the Center for Global and Regional Environmental Research at the University of Iowa. Dr. Schnoor is a member of the National Academy of Engineering and a registered professional engineer. His research interests are in mathematical modeling of water quality, phytoremediation, and global change. He has research projects on the design of environmental observatories, carbon sequestration to mitigate global warming, phytoremediation of hazardous wastes, and exposure risk assessment modeling. Dr. Schnoor is also the Editor-in-Chief of the journal Environmental Science and Technology, Co-editor of the John Wiley Series of Texts and Monographs in Environmental Science & Technology, and a member of the U.S. EPA Science Advisory Board. He received his B.S. in chemical engineering from Iowa State University, his M.S. in environmental health engineering from the University of Texas and Ph.D. in civil engineering from the University of Texas.

Otto C. Doering is a professor in the Department of Agricultural Economics at Purdue University. He is a public policy specialist and has served the U.S. Department of Agriculture (USDA) working on the 1977 and 1990 Farm Bills. In 1997, he was the principal advisor to USDA's Natural Resources Conservation Service for implementing the 1996 Farm Bill. In 1999, he was team leader for the economic analysis of the White House's National Hypoxia Assessment looking at the dead zone in the Gulf of Mexico. His recent publications include a book on the 1996 Farm Bill and a book on the effects of climate change and variability on agricultural production systems. Recent publications of his focus on economic linkages driving the response to nitrogen over-enrichment, the rationale for U.S. agricultural policy, and integrating biomass energy into existing energy systems. Dr. Doering received his M.S. degree in economics from the London School of Economics and his Ph.D. degree from Cornell University.

Dara Entekhabi is a professor in the Department of Civil and Environmental Engineering and the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology. His research interests are in the basic understanding of coupled surface, subsurface, and atmospheric hydrologic systems that may form the bases for enhanced hydrologic predictability. More specifically, his current research is in land-atmosphere interactions, remote sensing, physical hydrology, operational hydrology, hydrometeorology, groundwater-surface water interaction, and hillslope hydrology. He received his B.A. and M.A. degrees from Clark University and his Ph.D. degree in civil engineering from the Massachusetts Institute of Technology. He was founding chair of the WSTB's committee on hydrologic science, a current member of the WSTB, and recently a member of the committee reviewing the National Weather Service Advanced Hydrologic Prediction Service.

Edward A. Hiler (NAE) is the Ellison Chair in International Floriculture at Texas A&M University. He is a member of the National Academy of Engineering. His research interests are in the areas of soil and water conservation engineering, small watershed hydrology, irrigation and drainage engineering, and soil-plant-water-atmosphere relations as related to irrigation management. Other interests have included alternate energy sources, with particular emphasis on biomass energy, and the associated biochemical and microbiological energy conversion processes. He received his B.S., M.S., and Ph.D. degrees in agricultural engineering from The Ohio State University.

Theodore L. Hullar, professor at Cornell University, is currently on leave. He was director of Higher Education Programs for The Atlantic Philanthropies (USA) Inc. Dr. Hullar was director of the Cornell University Center for the Environment. He served as chancellor at the University of California-Davis and professor of environmental toxicology. Dr. Hullar has served as deputy commissioner of the New York Environmental Conservation Commission and as research director at the Cornell University Agricultural Research Station. His research interests include biochemistry, environmental toxicology, agriculture, and environmental policy. Dr. Hullar received his B.S. and Ph.D. degrees from the University of Minnesota.

G. David Tilman (NAS) is Regents Professor and director of the Cedar Creek Natural History Area at the University of Minnesota. He received his Ph.D. in 1976 from the University of Michigan. He is a member of the National Academy of Sciences. He is one of the world's leading ecologists, blending theoretical and experimental work seamlessly. His classic research created the benchmark model for determining how different organisms within an ecosystem compete for resources, and his field experiments and theoretical insights have helped to alert scientists to the fact that the reduction in the number of plant and animal species on the planet has a profound effect on the way the earth's ecosystems function. He has been a member of numerous NRC studies and was a member of the *Proceedings of the National Academy of Sciences* Editorial Board and the Board on Environmental Studies and Toxicology.

Appendix D

Biographical Sketches for Speakers and Discussants, NRC Colloquium on the Water Implications of Biofuels Production in the United States

Richard G. Allen is a professor of Water Resources Engineering at the University of Idaho. He has 30 years' experience in irrigation water requirements, irrigation hydrology, and general water resources systems. His current research is focused on satellite-based remote sensing of evapotranspiration from large areas. He has served on research and training missions to more than 20 countries.

Mark M. Alley is the W. G. Wysor Professor of Agriculture at Virginia Tech. He has responsibilities for research, teaching, and extension in the areas of soil fertility and crop management. Mark teaches the senior course in soil fertility and management and the graduate soil-plant relationships course. Research and extension efforts focus on efficient use of fertilizers and other plant nutrient sources in agronomic and forage crops. He is a fellow of the American Society of Agronomy and the Soil Science Society of America, and is incoming president-elect of the American Society of Agronomy.

Craig A. Cox has devoted his working life to natural resource conservation beginning in 1977 when he joined the Minnesota Department of Natural Resources as a field biologist. Since that time he has served as senior staff officer with the Board on Agriculture of the National Academy of Sciences; professional staff member of the Senate Committee on Agriculture, Nutrition and Forestry; special assistant to the Chief of the U.S. Department of Agriculture's (USDA) Natural Resource Conservation Service; and briefly as acting deputy undersecretary for Natural Resources and Environment at USDA. He is currently executive director of the Soil and Water Conservation

Society—a professional society dedicated to promoting the art and science of natural resource conservation.

Richard M. Cruse is a professor of Agronomy at Iowa State University and director of the Iowa Water Center, focusing research activities on managing soil and water resources. He received his B.S. from Iowa State University and his M.S. and Ph.D. from the University of Minnesota. He currently serves on the National Advisory Council for Environmental Policy and Technology in the Energy Work Group. He is a fellow of the Soil Science Society of America and the American Society of Agronomy.

Noel R. Gollehon is an agricultural economist with the Economic Research Service, USDA. His research has examined water quantity and quality issues in agriculture, including national/regional irrigation water use and confined livestock waste. He has led award-winning research teams and is frequently called on as a water-use expert for USDA and other government agencies. With a Ph.D. in agricultural economics from the University of Nebraska, he has been with the Economic Research Service for 20 years in various research and administrative positions. His training for this presentation began years ago moving sprinkler pipe on the farm in Eastern New Mexico.

Wendy D. Graham is the Carl S. Swisher Eminent Scholar in Water Resources in the Department of Agricultural and Biological Engineering at the University of Florida and director of the University of Florida Water Institute. She graduated from the University of Florida with a B.S. in environmental engineering. Her Ph.D. is in civil engineering from the Massachusetts Institute of Technology. She conducts research in the areas of coupled hydrologic-water quality-ecosystem modeling; water resources evaluation and remediation; evaluation of impacts of agricultural production on surface and groundwater quality; and stochastic modeling and data assimilation.

Mark T. Holtzapple is a professor of chemical engineering at Texas A&M University, where he has been teaching for 21 years. He received his Ph.D. from the University of Pennsylvania. His research interests are very broad and include the following: biomass conversion, seawater desalination, engines, air conditioning, jet ejectors, waste processing, and feed production.

Stephen R. Kaffka is director of the Long Term Research on Agricultural Systems Project, part of the Agricultural Sustainability Institute at the University of California-Davis. As director he leads the development of current and new projects focusing on sustainable agriculture at the University's Russell Ranch site. Additionally, he works on sugar and oilseed crops and on the reuse of saline drainage water for crop, forage, and livestock production in salt-affected areas of the San Joaquin Valley. He is co-chair of the new University of California work group on bioenergy feedstock production, and a member of the UC-Davis Bioenergy Research Group and the California Biomass Collaborative.

Dennis R. Keeney is emeritus professor of Agronomy and former director of the Leopold Center for Sustainable Agriculture, Iowa State University. He is currently senior fellow, Institute for Agriculture and Trade Policy in Minneapolis, MN, and the Department of Soil, Water and Climate, University of Minnesota, St. Paul. He is also active with the Iowa Environmental Council and the Center for a Livable Future, Johns Hopkins University, Thomas Jefferson Agriculture Institute, and Food and Water Watch.

Fran V. Kremer is a senior science advisor for the Land Remediation and Pollution Control Division of the National Risk Management Research Laboratory at the U.S. Environmental Protection Agency. Dr. Kremer has conducted research on underground storage systems with regards to the fate and transport of methyl *tert*-butyl ether (MTBE) in groundwater and the development and evaluation of passive and active low-cost biological treatment systems. She is also initiating research on the fate and transport of ethanol in groundwater and the impact of ethanol upon the hydrocarbon fraction in a gasoline spill, as well as developing biotreatment approaches for remediation of petroleum and non-petroleum oil spills in estuarine and fresh water environments.

Elizabeth Marshall is a senior economist/associate at the World Resources Institute. Her expertise is in agriculture and food; climate change, energy, and transportation; and people and ecosystems. Her work includes the assessment of the impact of biofuel production on the environment and agricultural structure, and how policy influences feedstock production, technology change, and the environment.

Richard G. Nelson is director and department head, Engineering Extension Programs, Kansas State University. He has over 13 years' experience in biomass research, performing a number of biomass resource assessments at a county, regional, state, and national basis for agricultural crop residues and herbaceous energy crops. His research focuses on environmental and sustainability aspects of biomass resource production and collection including impacts of residue removal on soil erosion and on water quality at a watershed level. Dr. Nelson received his Ph.D. in engineering from Oklahoma State University.

Daniel G. de La Torre Ugarte is associate director of the University of Tennessee's Agricultural Policy Analysis Center, conducting integrated economic, environmental, and policy analysis. His analysis was used by Congress to establish the pilot program for production and use of biomass on Conservation Reserve Program acres and he has provided expert advice to the USDA chief economist, the Department of Energy (DOE) Office of Power Technologies, the Senate Agricultural Committee, and numerous public and private initiatives regarding the economic impacts of energy crop production on the agricultural sector. Dr. Ugarte received his Ph.D. in agricultural economics from Oklahoma State University.

Wallace E. Tyner is a professor of agricultural economics at Purdue University. His research interests are in the area of energy, agricultural, and natural resource policy analysis and structural and sectoral adjustment in developing economies. His work in energy economics has encompassed oil, natural gas, coal, oil shale, biomass, ethanol from agricultural sources, and solar energy. His recent energy work has focused on renewable energy policy issues. Most of his recent international work has focused on agricultural trade and policy issues in developing economies, particularly in the Middle East, North Africa, and West Africa.

Janice R. Ward is a senior hydrologist with the U.S. Geological Survey (USGS), Office of Water Quality. She has worked on national water quality issues over the past 12 years, including special emphasis on the environmental effects of agriculture on water resources and national water quality programs and policies of the USGS. She currently serves on a number of interagency groups: USDA's Conservation Effects Assessment Project (CEAP) Steering Committee, Outreach Team for the National Learning Center for Animal Agricultural Water Quality Issues, Coordinating Committee for the Mississippi River Basin and Gulf of Mexico Watershed Nutrient Task Force, and the U.S. Environmental Protection Agency's Agricultural Issues Forum.