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Report to the Chairman, Committee on Science and Technology, House of Representatives

November 2009

ENERGY-WATER NEXUS

Many Uncertainties Remain about National and Regional Effects of Increased Biofuel Production on Water Resources

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Highlights

Highlights of GAO-10-116, a report to Chairman, Committee on Science and Technology, House of Representatives

Why GAO Did This Study

In response to concerns about the nation's energy dependence on imported oil, climate change, and other issues, the federal government has encouraged the use of biofuels. Water plays a crucial role in all stages of biofuel production—from cultivation of feedstock through its conversion into biofuel. As demand for water from various sectors increases and places additional stress on already constrained supplies, the effects of expanded biofuel production may need to be considered.

To understand these potential effects, GAO was asked to examine (1) the known water resource effects of biofuel production in the United States; (2) agricultural conservation practices and technological innovations that could address these effects and any barriers to their adoption; and (3) key research needs regarding the effects of water resources on biofuel production. To address these issues, GAO reviewed scientific studies, interviewed experts and federal and state officials, and selected five states to study their programs and plans related to biofuel production.

GAO is not making any recommendations in this report. A draft of this report was provided to the Departments of Agriculture (USDA), Energy (DOE), and the Interior (DOI); and the Environmental Protection Agency (EPA). USDA, DOE, and DOI concurred with the report and, in addition to EPA, provided technical comments, which were incorporated as appropriate.

View GAO-10-116 or key components.
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November 2009

ENERGY-WATER NEXUS

Many Uncertainties Remain about National and Regional Effects of Increased Biofuel Production on Water Resources

What GAO Found

The extent to which increased biofuels production will affect the nation's water resources depends on the type of feedstock selected and how and where it is grown. For example, to the extent that this increase is met from the cultivation of conventional feedstocks, such as corn, it could have greater water resource impacts than if the increase is met by next generation feedstocks, such as perennial grasses and woody biomass, according to experts and officials. This is because corn is a relatively resource-intensive crop, and in certain parts of the country requires considerable irrigated water as well as fertilizer and pesticide application. However, experts and officials noted that next generation feedstocks have not yet been grown on a commercial scale and therefore their actual effects on water resources are not fully known at this time. Water is also used in the process of converting feedstocks to biofuels, and while the efficiency of biorefineries producing corn ethanol has increased over time, the amount of water required for converting next generation feedstocks into biofuels is still not well known. Finally, experts generally agree that it will be important to take into account the regional variability of water resources when choosing which feedstocks to grow and how and where to expand their production in the United States.

The use of certain agricultural practices, alternative water sources, and technological innovations can mitigate the effects of biofuels production on water resources, but there are some barriers to their widespread adoption. According to experts and officials, agricultural conservation practices can reduce water use and nutrient runoff, but they are often costly to implement. Similarly, alternative water sources, such as brackish water, may be viable for some aspects of the biofuel conversion process and can help reduce biorefineries' reliance on freshwater. However, the high cost of retrofitting plants to use these water sources may be a barrier, according to experts and officials. Finally, innovations—such as dry cooling systems and thermochemical processes—have the potential to reduce the amount of water used by biorefineries, but many of these innovations are currently not economically feasible or remain untested at the commercial scale.

Many of the experts GAO spoke with identified several areas where additional research is needed. These needs fall into two broad areas: (1) feedstock cultivation and biofuel conversion and (2) data on water resources. For example, some experts noted the need for further research into improved crop varieties, which could help reduce water and fertilizer needs. In addition, several experts identified research that would aid in developing next generation feedstocks. For example, several experts said research is needed on how to increase cultivation of algae for biofuel to a commercial scale and how to control for potential water quality problems. In addition, several experts said research is needed on how to optimize conversion technologies to help ensure water efficiency. Finally, some experts said that better data on water resources in local aquifers and surface water bodies would aid in decisions about where to cultivate feedstocks and locate biorefineries.

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Abbreviations

CRP	Conservation Reserve Program
NPDES	National Pollutant Discharge Elimination System
DOE	Department of Energy
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
RFS	Renewable Fuel Standard
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UST	underground storage tank

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United States Government Accountability Office
Washington, DC 20548

November 30, 2009

The Honorable Bart Gordon
Chairman
Committee on Science and Technology
House of Representatives

Dear Mr. Chairman:

In recent years, the federal government has increasingly encouraged the use of biofuels and other alternatives to petroleum in response to concerns over U.S. dependence on imported oil, climate change, and other issues. The United States is the largest user of petroleum in the world, consuming 19.4 million barrels per day in 2008, over half of which is imported. Biofuels, such as ethanol and biodiesel, can be produced domestically and are derived from renewable sources, such as corn, sugar cane, and soybeans. The Energy Independence and Security Act of 2007 (EISA) expanded the Renewable Fuel Standard (RFS) by requiring that U.S. transportation fuel contain 9 billion gallons of renewable fuels in 2008 and increasing this amount annually to 36 billion gallons in 2022.[1] Currently, the vast majority of domestic biofuel production is ethanol derived from corn starch, which EISA defines as a "conventional" feedstock. However, in 2022, the RFS's 36-billion-gallon total requires that at least 16 billion gallons be derived from "cellulosic" materials, such as stalks, stems, branches, and leaves. These cellulosic materials, along with newer feedstocks, such as algae, are often referred to as "next generation" feedstocks, and the fuels produced from them are often referred to as "advanced" biofuels.[2]

[1]Pub. L. No. 110-140, § 201 (2007). The act authorizes the Administrator of the Environmental Protection Agency (EPA), in consultation with the Secretaries of Agriculture and Energy, to waive the RFS levels established in the act, by petition or on the Administrator's own motion, if meeting the required level would severely harm the economy or environment of a state, a region, or the United States or there is an inadequate domestic supply. Throughout this report, the RFS levels established in the act are referred to as requirements, even though these levels could be waived by the EPA Administrator.

[2]For additional information on the effects of biofuel production, see GAO, *Biofuels: Potential Effects and Challenges of Required Increases in Production and Use*, GAO-09-446 (Washington, D.C.: Aug. 25, 2009).

Although freshwater flows abundantly in many of the nation's lakes, rivers, and streams, water is a dwindling resource in many parts of the country and is not always available when and where it is needed or in the amount desired because of competing demands on water supplies, climatic changes contributing to drought conditions in parts of the country, and population growth. Foremost among these competing demands is irrigation, which accounts for 40 percent of the nation's freshwater withdrawals.[3] Water is crucial to many stages of the biofuel life cycle and is needed for the growth of the feedstock as well as for fermentation, distillation, and cooling during the process of converting the feedstock into biofuel. As biofuel production increases, questions have emerged about the effects that increased production could have on the nation's water resources.

To understand the potential effects of increased biofuel production on water resources, you asked us to describe (1) the known water resource effects of increased biofuel production in the United States; (2) the agricultural conservation practices and technological innovations that exist or are being developed to address these effects, and any barriers that may prevent the adoption of these practices and technologies; and (3) key research needs regarding the effects of biofuel production on water resources.

To address all of these objectives, we conducted a systematic analysis of relevant articles from scientific journals and key federal and state government publications. In addition, in consultation with the National Academy of Sciences, we identified and interviewed recognized experts who have published peer-reviewed research analyzing the water supply requirements of one or more biofuel feedstocks and the implications of increased biofuel production on water resources. These experts included research scientists in such fields as environmental science, agronomy, soil science, hydrogeology, ecology, and engineering. Furthermore, we studied five states in greater depth—Georgia, Iowa, Minnesota, Nebraska, and Texas—to gain an understanding of the programs and plans they have or are developing to address increased biofuel production. We selected these states based on several criteria, including ethanol and biodiesel

[3]Other major sources of freshwater withdrawals in the United States are thermoelectric (39 percent), public water supply (13 percent), and industrial (5 percent) uses. The remaining withdrawals consist of mining (1 percent), domestic (1 percent), aquaculture (1 percent), and livestock (1 percent) uses. S. Hutson et al., "Estimated Use of Water in the United States in 2000," Circular 1268, U.S. Geological Survey (2004).

production, feedstock cultivation type, reliance on irrigation, geographic diversity, and varying approaches to water resource management and law. For each of the states, we analyzed documentation from and conducted interviews with a wide range of stakeholders to gain the views of diverse organizations covering all stages of biofuel production. These groups included relevant state agencies, including those responsible for oversight of agriculture, environmental quality, and water and soil resources; federal agency officials with responsibility for a particular state or region, such as officials from the U.S. Geological Survey (USGS), the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service, and the Environmental Protection Agency (EPA); university researchers; industry representatives; and relevant nongovernmental organizations, such as environmental groups, state-level corn growers' associations, and ethanol producer associations.

We also interviewed senior officials, scientists, economists, researchers, and other federal officials from USDA, the Departments of Defense and Energy (DOE), EPA, the National Aeronautics and Space Administration, the Department of Commerce's National Oceanic and Atmospheric Administration, the National Science Foundation, and USGS about effects on water supply and water quality during biofuel production. We also interviewed representatives of nongovernmental organizations, such as the Renewable Fuels Association, the Biotechnology Industry Organization, the Pacific Institute, and the Fertilizer Institute. A more detailed description of our scope and methodology is presented in appendix I. We conducted our work from January 2009 to November 2009 in accordance with all sections of GAO's Quality Assurance Framework that are relevant to our objectives. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our stated objectives and to discuss any limitations in our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for any findings and conclusions in this product.

Background

Biofuels, such as ethanol and biodiesel, are an alternative to petroleum-based transportation fuels and are produced in the United States from a variety of renewable sources such as corn, sugar cane, and soybeans. Ethanol, the most common U.S. biofuel, is mainly used as a gasoline additive in blends of about 10 percent ethanol and 90 percent gasoline, known as E10, which is available in most states. A relatively small volume is also blended at a higher level called E85—a blend of 85 percent ethanol and 15 percent gasoline—which can only be used in specially designed vehicles, known as flexible fuel vehicles. Biodiesel is a renewable alternative fuel produced from a range of plant oils, animal fats, and recycled cooking oils. Pure biodiesel or biodiesel blended with petroleum diesel—generally in a blend of 20 percent biodiesel and 80 percent diesel—can be used to fuel diesel vehicles.

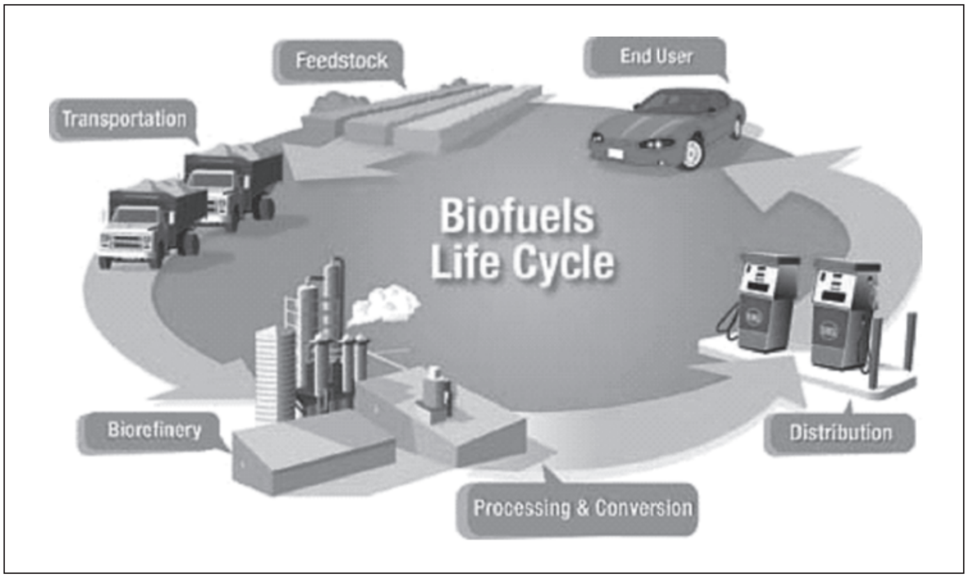
The federal government has promoted biofuels as an alternative to petroleum-based fuels since the 1970s, and production of ethanol from corn starch reached 9 billion gallons in 2008. The Energy Policy Act of 2005 originally created an RFS that generally required U.S. transportation fuel to contain 4 billion gallons of renewable fuels in 2006 and 7.5 billion gallons in 2012.[4] EISA expanded the RFS by requiring that U.S. transportation fuel contain 9 billion gallons of renewable fuels in 2008 and increasing this amount annually to 36 billion gallons in 2022.[5] Moreover, the 36-billion-gallon total must include at least 21 billion gallons of advanced biofuels, defined as renewable fuels other than ethanol derived from corn starch that meet certain criteria; only 15 billion of the 36 billion gallons of renewable fuels can come from conventional biofuels. In addition, at least 16 billion gallons of the 21-billion-gallon advanced biofuels requirement must be made from cellulosic feedstocks, such as perennial grasses, crop residue, and woody biomass. Unlike corn starch, most of the energy in plant and tree biomass is locked away in complex cellulose and hemicellulose molecules, and technologies to produce biofuels economically from this type of feedstock are still being developed. Some cellulosic biorefineries are piloting the use of biochemical processes, in which microbes and enzymes break down these complex plant molecules to produce ethanol, while others are piloting the use of thermochemical processes, which use heat and chemical catalysts to convert plant material into a liquid that more closely resembles petroleum.

There are a number of steps in the biofuels life cycle, from cultivation of the feedstock through distribution to the end user at the fuel pump (see fig. 1).

[4]The RFS applies to transportation fuel sold or introduced into commerce in the 48 contiguous states. However, the Administrator of EPA is authorized, upon a petition from Alaska or Hawaii, to allow the RFS to apply in that state. On June 22, 2007, Hawaii petitioned EPA to opt into the RFS, and the Administrator approved that request. For the purposes of this report, statements that the RFS applies to U.S. transportation fuel refer to the 48 contiguous states and Hawaii.

[5]Pub. L. No. 110-140, § 201 (2007).

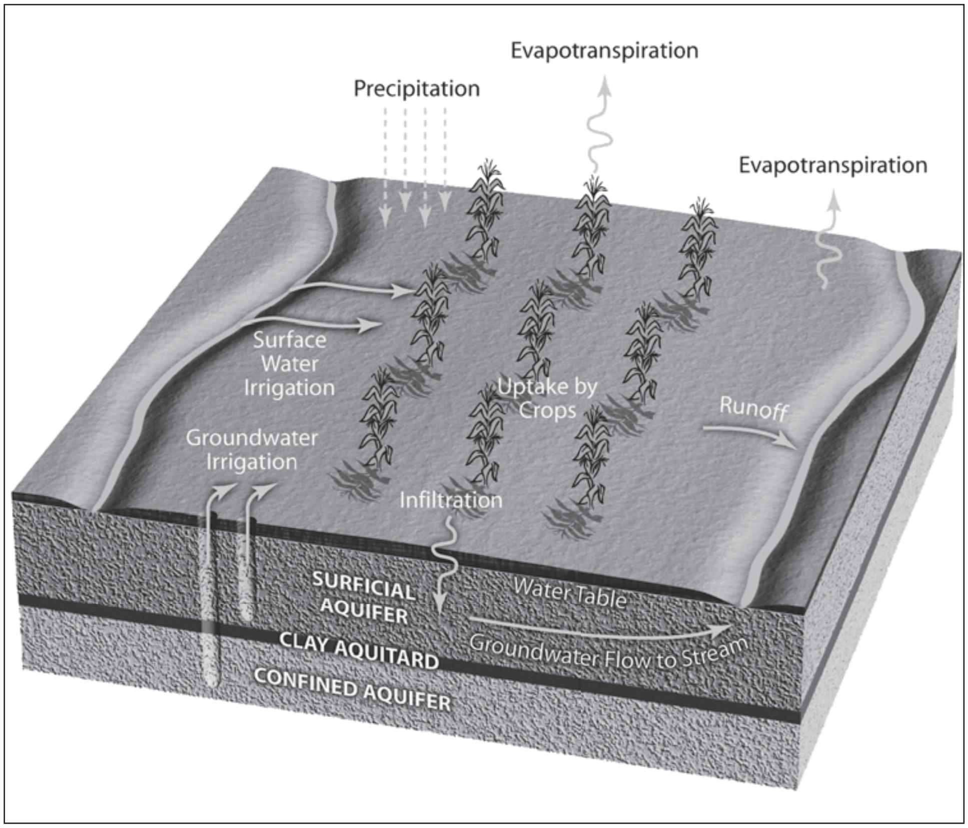
Figure 1: Biofuels Life Cycle



Source: DOE.

Water plays a critical role in many aspects of this life cycle. On the cultivation side, water is needed to grow the feedstock. Crops can be either rainfed, with all water requirements provided by natural precipitation and soil moisture, or irrigated, with at least some portion of water requirements met through applied water from surface or groundwater sources. Figure 2 shows the various water inputs (sources of water) and outputs (water losses) that are part of the agricultural water cycle.

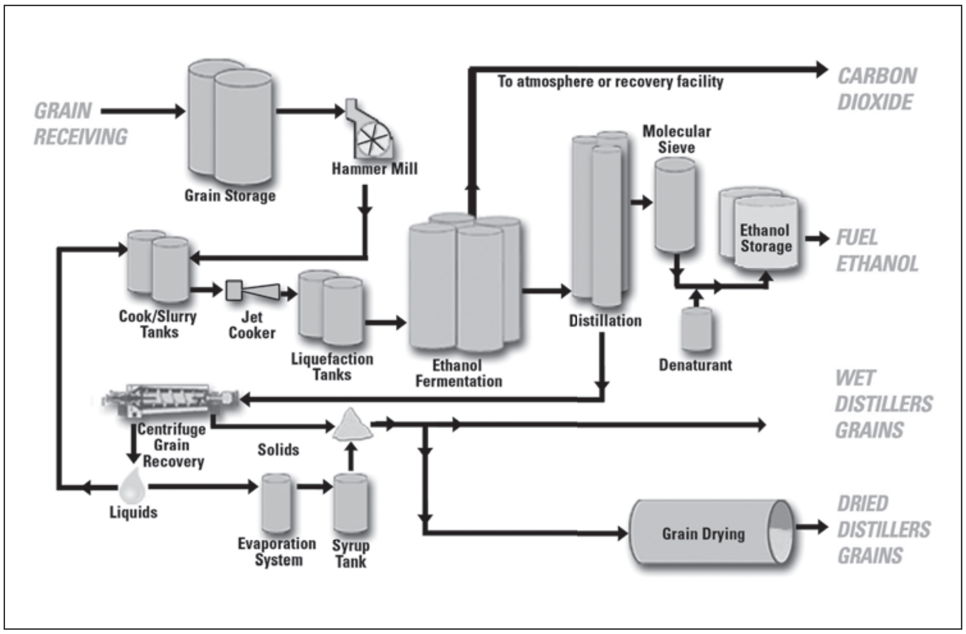
Figure 2: Agricultural Water Cycle



Source: © 2008 International Mapping.

Water is also important for conversion of feedstocks into biofuels. In particular, water is used for heating and cooling as well as for processing. For example, during the processing of corn-based ethanol, corn is converted to ethanol through fermentation using one of two standard processes, dry milling or wet milling. The main difference is the initial treatment of the corn kernel. In the dry-mill process, the kernel is first ground into flour meal and processed without separating the components of the corn kernel. The meal is then slurried with water to form a mash, and enzymes are added to convert the starch in the mash to a fermentable sugar. The sugar is then fermented and distilled to produce ethanol. In the wet-mill process, the corn kernel is steeped in a mixture of water and sulfurous acid that helps separate the kernel into starch, germ, and fiber components. The starch that remains after this separation can then be fermented and distilled into fuel ethanol. Traditional dry-mill ethanol plants cost less to construct and operate than wet-mill plants, but yield fewer marketable co-products. Dry-mill plants produce distiller's grains (that can be used as cattle feed) and carbon dioxide (that can be used to carbonate soft drinks) as co-products, while wet-mill plants produce many more co-products, including corn oil, carbon dioxide, corn gluten meal, and corn gluten feed. The majority of ethanol biorefineries in the United States are dry-mill facilities. Figure 3 depicts the conversion process for a typical dry-mill biorefinery.

Figure 3: Diagram of Conversion Process for a Typical Corn-Based Ethanol Biorefinery



Source: © 2007 ICM, Inc.

Each Stage of Biofuel Production Affects Water Resources, but the Extent Depends on the Feedstock and Region

The extent to which increased biofuel production will affect the nation's water resources will depend on which feedstocks are selected for production and which areas of the country they are produced in. Specifically, increases in corn cultivation in areas that are highly dependent on irrigated water could have greater impacts on water availability than if the corn is cultivated in areas that primarily produce rainfed crops. In addition, most experts believe that greater corn production, regardless of where it is produced, may cause greater impairments to water quality than other feedstocks, because corn production generally relies on greater chemical inputs and the related chemical runoff will impact water bodies. In contrast, many experts expect next generation feedstocks to require less water and provide some water quality benefits, but even with these feedstocks the effects on water resources will largely depend on which feedstock is selected, and where and how these feedstocks are grown. Similarly, the conversion of feedstocks into biofuels may also affect water supply and water quality, but these effects also vary by feedstock chosen and type of biofuel produced. Many experts agree that as the agriculture and biofuel production industries make decisions about which feedstocks to grow and where to locate or expand conversion facilities, it will be important for them to consider regional differences and potential impacts on water resources.

Water Supply and Water Quality Effects of Increased Corn Cultivation

Many experts and officials told us that corn cultivation requires substantial quantities of water, although the amount used depends on where the crop is grown and how much irrigation water is used. The primary corn production regions are in the upper and lower Midwest and include 12 states classified as USDA farm production Regions 5, 6, and 7. Together, these regions accounted for 89 percent of corn production in 2007 and 2008, and 95 percent of ethanol production in the United States in 2007. Corn cultivation in these three regions averages anywhere from 7 to 321 gallons of irrigation water for every gallon of ethanol produced, as shown in table 1.[6] However, the impact of corn cultivation on water supplies in these regions varies considerably. For example, in USDA Region 7, which comprises North Dakota, South Dakota, Kansas, and Nebraska, the production of one bushel of corn consumes an average of 865 gallons of freshwater from irrigation. In contrast, in USDA Regions 5 and 6, which comprise Iowa, Illinois, Indiana, Ohio, Missouri, Minnesota, Wisconsin, and Michigan, corn is mostly rainfed and only requires on average 19 to 38 gallons of supplemental irrigation water per bushel.[7]

[6] Wu, M., M. Mintz, M. Wang, and S. Arora. "Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory (Argonne, Ill., January 2009.)

[7] According to the National Corn Growers Association, across the United States the acres of corn irrigated represent 21 percent of the total irrigated crop area. The volume of water used in corn irrigation represents 7 percent of all irrigation water.

Table 1: Average Water Consumed in Corn Ethanol Production in Primary Producing Regions in the United States, in Gallons of Water/Gallon of Ethanol Produced

Type of water consumed	USDA Region 5 (Iowa, Indiana, Illinois, Ohio, Missouri)	USDA Region 6 (Minnesota, Wisconsin, Michigan)	USDA Region 7 (North Dakota, South Dakota, Nebraska, Kansas)
Cultivation			
Corn irrigation, groundwater	6.7	10.7	281.2
Corn irrigation, surface water	0.4	3.2	39.4
Total irrigated water	**7.1**	**13.9**	**320.6**
Conversion - Corn ethanol	3.0	3.0	3.0
Total water consumption	**10.0**	**16.8**	**323.6**

Source: Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, "Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline," Center for Transportation Research, Energy Systems Division, Argonne Laboratory, January 2009

Note: The numbers may not add up due to rounding. The Argonne National Laboratory study estimated the water consumed in corn ethanol production in each of the major ethanol producing regions considering water consumed in both corn cultivation and conversion processing steps. Estimates were based on average consumption of 3.0 gallons of water per gallon of corn ethanol produced in a corn dry mill, average consumptive use of irrigation water for corn in major corn producing regions, and dry-mill yield of 2.7 gallons of ethanol per bushel. In evaluating corn cultivation, the water consumed is based on total amount of irrigation water used for corn production and total corn production for each region, and does not include precipitation. In addition, the calculation assumes that 30 percent of water recharges local surface and groundwater, and the remaining 70 percent of the water is consumed by evapotranspiration (water lost through evaporation from the soil and plants) and other factors.

The effects of increased corn production for ethanol on water supplies are likely to be greatest in water-constrained regions of the United States where corn is grown using irrigation. For example, some of the largest increases in corn acres (1.1 million acres) are projected to occur in the Northern Plains region, which is already a water constrained region. Parts of this region draw heavily from the Ogallala Aquifer, where water withdrawals are already greater than the natural recharge rate from precipitation. A 2009 USGS report found water levels in the aquifer had dropped more than 150 feet in parts of southwest Kansas and the Texas Panhandle, where crop irrigation is intense and recharge to the aquifer is minimal.[8] In 2000, about 97 percent of the water withdrawn from the aquifer was used for irrigation, according to USGS.[9]

[8]McGuire, V.L., "Water-level changes in the High Plains aquifer, predevelopment to 2007, 2005-2006, and 2006-2007," USGS SIR 2009-5019 (2009).

[9]Maupin, M.A., and Barber, N.L., "Estimated withdrawals from principal aquifers in the United States," USGS Circular 1279 (2000).

Many officials told us that an increase in corn cultivation using current agricultural practices will also impair water quality as a result of the runoff of fertilizer into lakes and streams. This will happen because corn requires high applications of fertilizers relative to soybeans and other potential biofuel feedstocks, such as perennial grasses.[10] For example, in Iowa, the expansion of biofuel production has already led to an increasing amount of land dedicated to corn and other row crops, resulting in surface water impacts, including nutrient runoff and increased bacteria counts as well as leaching of nitrogen and phosphorus into groundwater, according to a state official. Fertilizer runoff containing nitrogen and phosphorus can lead to overenrichment and excessive growth of algae in surface waters. In some waters, such enrichment has resulted in harmful algal blooms, decreased water clarity, and reduced oxygen in the water, which impair aquatic life.[11] In marine waters, this excessive algal growth has created "dead zones," which cannot support fish or any other organism that needs oxygen to survive.[12] The number of reported dead zones around the world has increased since the 1960s to more than 400.[13] Many of them are along the Gulf of Mexico and the Atlantic Coast, areas that receive drainage from agricultural and urban landscapes, including a large portion of the Corn Belt, where many of the existing and planned ethanol production facilities are located. A 2007 USGS model estimated that 52 percent of the nitrogen and 25 percent of the phosphorus entering the Gulf system are from corn and soybean cultivation in the Mississippi River basin.[14]

Increased corn production will also increase the use of pesticides—including insecticides and herbicides—which also have the potential to

[10]Increased corn cultivation could also result in soil erosion, which reduces fertility by reducing nutrient-rich topsoil. It also contributes to sedimentation, which fills channels in deep areas of waterbodies, affecting aquatic life and recreation. Sediment can also carry contaminants, such as fertilizers and pesticides.

[11]The algae themselves do not reduce oxygen; instead, when the algae die, bacteria deplete oxygen as the algae decompose.

[12]Dried distiller's grain, a byproduct of ethanol production used in animal feed, also contains high levels of phosphorous and contributes to overenrichment of surface and marine waters.

[13]Diaz, Robert and Rutger Rosenberg, "Spreading Dead Zones and Consequences for Marine Ecosystems," *Science*, vol. 321 (2008): pp. 926-929.

[14]Alexander, Richard, Richard Smith, Gregory Schwarz, Elizabeth Boyer, Jacqueline Nolan, and John Brakebill, "Difference in Phosphorous and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin," *Environmental Science and Technology*, vol. 42, no. 3 (2008): pp. 822-830.

affect surface water and groundwater quality. For example, a 10-year nationwide study by USGS detected pesticides in 97 percent of streams in agricultural and urban watersheds.[15] As would be expected, the highest concentrations of pesticides have been found in those areas that have the highest use. For instance, application rates of atrazine, a commonly used pesticide for corn production, are highest in the Corn Belt, and atrazine was also the most widely detected pesticide in watersheds in this area, according to the USGS nationwide study. USGS determined that the concentrations of atrazine and other pesticides detected had the potential to adversely affect aquatic plants and invertebrates in some of the streams, since organisms are vulnerable to short-term exposure to relatively small amounts of certain pesticides. Similarly, increased pesticide use for the cultivation of corn could impair groundwater supplies. USGS found pesticides in 61 percent of shallow wells sampled in agricultural areas. Once groundwater is contaminated, it is difficult to clean up, according to the experts we contacted.

According to some of the experts and officials we spoke with, increased demand for biofuel feedstocks may also create incentives for farmers to place marginal lands back into production. Marginal lands generally have lower productivity soils, so cultivating them may require more nutrient and pesticide inputs than more productive lands, potentially leading to further water quality impairments. Furthermore, delivery of sediments, nutrients, and pesticides to surrounding water bodies may increase if these lands are placed back into production because these lands are often highly susceptible to erosion due to wind and water. Of particular concern to many of the experts with whom we spoke are the millions of acres of land currently enrolled in the Conservation Reserve Program (CRP). This federal program provides annual rental payments and cost share assistance to landowners who contractually agree to retire highly erodible or other environmentally-sensitive cropland from agricultural purposes. As part of the contract, farmers are generally required to plant or maintain vegetative covers (such as native grasses) on the land, which provide a range of environmental benefits, including improved water quality, reduced erosion, enhanced wildlife habitat, and preserved soil productivity. However, many experts and officials we spoke with from the five selected states are concerned that higher corn prices and increased demand for biofuel feedstocks may encourage farmers to return CRP land

[15]Gilliom et al., "The Quality of Our Nation's Waters—Pesticides in the Nation's Streams and Ground Water, 1992-2001," USGS Circular 1291 (2006): p. 172.

to crop production. If such conversion does occur, these officials noted that water quality may further decline in the future.

Little Is Yet Known about the Water Resource Implications of Next Generation Feedstocks

Next generation feedstocks for biofuels have the potential for fewer negative effects on water resources, although several of the experts and officials that we spoke with said that the magnitude of these effects remains largely unknown because these feedstocks have not yet been grown on a commercial scale. These experts suggested that certain water resource impacts were likely for the following potential feedstocks:

- Agricultural residues, such as corn stover, collected from fields that have already been harvested, can provide feedstock for cellulosic ethanol production. The primary advantage of using agricultural residues is that they are a byproduct of crop cultivation and thus do not require additional water or nutrient inputs. However, removal of these residues has consequences for both soil and water quality, so there may be limits on how much agricultural residues can be removed for cellulosic ethanol production. According to the experts we spoke with, leaving crop residues unharvested on the field benefits soil quality by providing nutrients that help maintain long-term soil productivity, enhancing soil moisture retention, increasing net soil carbon, and reducing the need for nutrient inputs for future crops.[16] In addition, leaving crop residues on the field helps prevent soil erosion due to wind and water and nutrient runoff into the water supply. Farmers could reduce the negative effects of residue removal by harvesting only corn cobs or part of the stover, but the optimal removal rate is not yet fully known, and is currently being studied by several federal agencies and academic institutions.

- Perennial grasses may require less water and provide some water quality benefits. Perennial grasses such as mixed prairie and switchgrass can grow with less water than corn. But some experts cautioned that any water supply benefits from these grasses will only occur if they are rainfed. For instance, officials in Minnesota told us that because the state's crops are primarily rainfed, shifting to the cultivation of cellulosic feedstocks, like perennial grasses, without irrigation would have a minimal impact on the state's water supply. However, other experts and local

[16]While some agricultural residues must be left on the ground to maintain soil moisture and carbon content, a significant portion of the total can be removed in many areas. According to a DOE official, in some parts of the country removal of a portion of the residue is needed because the excess residue does not degrade quickly enough and interferes with subsequent crop growth.

officials pointed out that if farmers choose to irrigate perennial grasses in order to achieve maximum yields and profits as they do for other crops, then producing these feedstocks could have the same detrimental effects on water supplies as do other crops. This concern was reiterated by the National Research Council, which stated that while irrigation of native grasses is unusual now, it could easily become more common as cellulosic biofuel production gets under way.[17]

Perennial grasses can also help preserve water quality by reducing soil, nutrient, and pesticide runoff. Research indicates that perennial grasses cycle nitrogen more efficiently than some row crops and protect soil from erosion due to wind and water. As a result, they can reduce the need for most fertilizers after crops are established, and the land on which these crops are grown do not need to be tilled every year, which reduces soil erosion and sedimentation. According to experts, farmers could also plant a mix of perennial grasses, which could minimize the need for pesticides by promoting greater diversity and an abundance of natural enemies for agricultural pests. In addition, perennial grasses cultivated across an agricultural landscape may help reduce nutrient and chemical runoff from farm lands. Grasses can also be planted next to water bodies to help filter out nutrients and secure soil and can serve as a windbreak to help minimize erosion. However, the type of land and cultivation methods used to grow perennial grasses will influence the extent to which they improve water quality. For instance, if perennial grasses were harvested down to the soil, they would not reduce soil erosion as compared to conventional feedstocks in the long run, according to some experts. In addition, according to some experts, if farmers choose to use fertilizers to maximize yields from these crops as they do for other crops or if these crops are grown on lands with decreased soil quality that require increased nutrient application, then cultivation of perennial grasses could also lead to water quality impairments.

- Woody biomass, such as biomass from the thinning of forests and cultivation of certain fast-growing tree varieties, could serve as feedstock for cellulosic ethanol production, according to some experts. Use of thinnings is not expected to impact water supply, as they are residuals from forest management. Thinning of forests can have the added benefit of reducing the intensity of wildfires, the aftermath of which facilitates runoff of nutrients and sediment into surface waters. Waste from urban areas or

[17]National Research Council, *Water Implications of Biofuels Production in the United States.* The National Academies Press, Washington, D.C. (2008).

lumber mills may also provide another source of biomass that would not require additional water resources. This waste would include the woody portions of commercial, industrial, and municipal solid waste, as well as byproducts generated from processing lumber, engineered wood products, or wood particles; however, almost all of the commercial wood waste is currently used as fuels or raw material for existing products. In addition, some experts said that fast-growing tree species, such as poplar, willow, and cottonwood, are potential cellulosic feedstocks. However, these experts also cautioned that some of these varieties may require irrigation to cultivate and may have relatively high consumptive water requirements.

- Algae are also being explored as a possible feedstock for advanced biofuels. According to several experts, one advantage of algae is that they can be cultivated in brackish or degraded water and do not need freshwater supplies. However, currently algae cultivation is expected to consume a great deal of water, although consumption estimates vary widely—from 40 to 1,600 gallons of water per gallon of biofuel produced, according to experts—depending on what cultivation method is used. With open-air, outdoor pond cultivation, water loss is expected to be greater due to evaporation, and additional freshwater will be needed to replenish the water lost and maintain the water quality necessary for new algal growth. In contrast, when algae are cultivated in a closed environment, as much as 90 percent less water is lost to evaporation, according to one expert.[18]

The Extent to Which Biofuel Conversion May Affect Water Resources also Depends on the Feedstock Used and Biofuel Produced

During the process of converting feedstocks into biofuels, biorefineries not only need a supply of high-quality water, but also discharge certain contaminants that could impact water quality. The amount of water needed and the contaminant discharge vary by type of biofuel produced and type of feedstock used in the conversion process. For example, ethanol production requires greater amounts of high-quality water than does biodiesel. Conversion of corn to ethanol requires approximately 3 gallons of water per gallon of ethanol produced, which represents a decrease from an estimated 5.8 gallons of water per gallon of ethanol in 1998.[19] According to some experts, these gains in efficiency are, for the

[18]Water is still lost with closed cultivation due to the cooling needs of the closed systems, among other uses.

[19]In comparison, the recovery and refining of 1 gallon of crude oil requires a total of 3.6 to 7.0 gallons of water. Wu, M. et al., "Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory (Argonne, Ill., January 2009).

most part, the result of ethanol plants improving their water recycling efforts and cooling systems.

According to some experts we spoke with, the biofuel conversion process generally requires high-quality water because the primary use for ethanol production is for cooling towers and boilers, and cleaner water transfers heat more efficiently and does less damage to this equipment. As a result, ethanol biorefineries prefer to use groundwater because it is generally cleaner, of more consistent quality, and its supply is less variable than surface water. Furthermore, the use of lesser-quality water leaves deposits on biorefinery equipment that require additional water to remove. However, despite water efficiency gains, some communities have become concerned about the potential impacts of withdrawals for biofuel production on their drinking water and municipal supplies and are pressuring states to limit ethanol facilities' use of the water. For example, at least one Minnesota local water district denied a permit for a proposed biorefinery due to concerns about limited water supply in the area.

Current estimates of the water needed to convert cellulosic feedstocks to ethanol range from 1.9 to 6.0 gallons of water per gallon of ethanol, depending on the technology used. Conversion of these next generation feedstocks is expected to use less water when compared to conventional feedstocks in the long run, according to some experts.[20] For example, officials from a company in the process of establishing a biorefinery expect the conversion of pine and other cellulosic feedstocks to consume less water than the conversion of corn to ethanol once the plant is operating at a commercial scale. However, some researchers cautioned that the processes for converting cellulosic feedstocks currently require greater quantities of water than needed for corn ethanol. They said the technology has not been optimized and commercial-scale production has not yet been demonstrated, therefore any estimates on water use by cellulosic biorefineries are simply projections at this time.

In contrast, biodiesel conversion requires less water than ethanol conversion—approximately 1 gallon of freshwater per gallon of biodiesel.

[20]DOE's Energy Information Administration's (EIA) *Annual Energy Outlook 2009* projects that there is a sufficient growth in use of biomass-to-liquids (BTL) fuels to meet the EISA cellulosic biofuel requirement and that the production process for BTL fuels does not require continuous water inputs. BTL refers to processes for converting biomass into a range of liquid fuels, such as gasoline and diesel. In addition, EIA noted that certain oils currently eligible for inclusion as cellulosic biofuels also do not use process water.

Similar to ethanol conversion, much of this water is lost during the cooling and feedstock drying processes. Biodiesel facilities can use a variety of plant and animal-based feedstocks, providing more options when choosing a location. This flexibility in type of feedstock that can be converted allows such facilities to be built in locations with plentiful water supplies, lessening their potential impact.

In addition to the water supply effects, biorefineries can have water quality effects because of the contaminants they discharge. However, the type of contaminant discharged varies by the type of biofuel produced. For example, ethanol biorefineries generally discharge chemicals or salts that build up in cooling towers and boilers or are produced as waste by reverse osmosis, a process used to remove salts and other contaminants from water prior to discharge from the biorefinery.[21] EPA officials told us that the concentrated salts discharged from reverse osmosis are a concern due to their effects on water quality and potential toxicity to aquatic organisms. In contrast, biodiesel refineries discharge other pollutants such as glycerin that may be harmful to water quality. EPA officials told us that glycerin from small biodiesel refineries can be a problem if it is released into local municipal wastewater facilities because it may disrupt the microbial processes used in wastewater treatment.[22] Glycerin is less of a concern with larger biodiesel refineries because, according to EPA officials, it is often extracted from the waste stream prior to discharge and refined for use in other products.

Several state officials we spoke with told us these discharges are generally well-regulated under the Clean Water Act. Under the act, refineries that discharge pollutants into federally regulated waters are required to obtain a federal National Pollutant Discharge Elimination System (NPDES) permit, either from EPA or from a state agency authorized by EPA to implement the NPDES program. These permits generally allow a point

[21]Reverse osmosis is a filtration process used to purify freshwater by, for example, removing the salts from it. This process is used to treat water prior to discharging it from the ethanol plant.

[22]Glycerin results in elevated levels of biological oxygen demand, which is a measure of how much oxygen it will take to break down the material. According to EPA officials, biodiesel wastewater with small amounts of glycerin and efficient recovery of methanol has a biological oxygen demand of 10,000-15,000 mg/liter, compared to a normal wash water biological oxygen demand of about 200 mg/liter. With glycerin, biodiesel wastewater has a biological oxygen demand of 80,000 mg/liter. Pure glycerin has a biological oxygen demand of 1,000,000 mg/liter.

source, such as a biorefinery, to discharge specified pollutants into federally regulated waters under specific limits and conditions. State officials we spoke with reported they closely monitor the quality of water being discharged from biofuel conversion facilities, and that the facilities are required to treat their water discharges to a high level of quality, sometimes superior to the quality of the water in the receiving water body.

Storage and Distribution of Biofuels Can Have Some Water Quality Consequences

The storage and distribution of ethanol-blended fuels could result in water quality impacts in the event that these fuels leak from storage tanks or the pipes used to transport these fuels. Ethanol is highly corrosive and there is potential for releases into the environment that could contaminate groundwater and surface water, among other issues.[23] When ethanol-blended fuels leak from underground storage tanks (UST) and aboveground tank systems, the contamination may pose greater risks than petroleum. This is because the ethanol in these blended fuels causes benzene, a soluble and carcinogenic chemical in gasoline, to travel longer distances and persist longer in soil and groundwater than it would in the absence of ethanol,[24] increasing the likelihood that it could reach some drinking water supplies.[25] Federal officials told us that, because it is illegal to store ethanol-blended fuels in tanks not designed for the purpose, they had not encountered any concerns specific to ethanol storage. However, officials from two states did express concern about the possibility of leaks and told us that ethanol-blended fuels are still sometimes stored in tanks not designed for the fuel.

[23]There are other hazards that may occur from releases of ethanol-blended fuels. For example, some spills of gasoline with ethanol may pose an explosion risk. Large-scale releases of ethanol have been shown to degrade under anaerobic conditions to produce explosive concentrations of methane. According to EPA, this can pose a significant challenge for remediation contractors mitigating biofuel spills. In addition, the methane generated in the subsurface can migrate into overlying buildings, degrading indoor air quality.

[24]When ethanol is present, the ethanol is consumed by micro-organisms in the soil before other, more harmful fuel constituents. This decomposition takes up nutrients and oxygen needed to break down benzene and related compounds. As a result, the benzene plume extends a greater distance.

[25]Mackay, Douglas, Nicholas R. de Sieyes, Murray D. Einarson, Kevin P. Feris, Alexander A. Pappas, Isaac A. Wood, Lisa Jacobson, Larry G. Justice, Mark N. Noske, Kate M. Scow, and John T. Wilson. "Impact of Ethanol on the Natural Attenuation of Benzene, Toluene, and o-Xylene in a Normally Sulfate-Reducing Aquifer." *Environmental Science Technology*, vol. 40 (2006): pp. 6123-6130; and Ruiz-Aguilar, G., K. O'Reilly, and P. Alvarez. "A Comparison of Benzene and Toluene Plume Lengths for Sites Contaminated with Regular vs. Ethanol-Amended Gasoline." *Ground Water Monitoring & Remediation*, vol. 23, no. 1 (winter 2003): pp. 48-53.

For instance, one of these states reported a 700-gallon spill of ethanol-blended fuels due to the scouring of rust plugs in a UST.[26]

According to EPA officials, a large number of the 617,000 federally regulated UST systems currently in use at approximately 233,000 sites across the country are not certified to handle fuel blends that contain more than 10 percent ethanol.[27] Moreover, according to EPA officials, most tank owners do not have records of all the UST systems' components, such as the seals and gaskets. Glues and adhesives used in UST piping systems were not required to be tested for compatibility with ethanol-blended fuel until recently. Thus there may be many compatible tanks used for storing ethanol-blended fuels that have incompatible system components, increasing the potential for equipment failure and fuel leakage, according to EPA officials. EPA told us that it is continuing to work with government and industry partners to study the compatibility of these components with various ethanol blends. EPA officials also stressed the importance of understanding the fate and transport of biofuels into surface water because biofuels are transported mainly by barge, rail, and truck. The officials noted that spills of biofuels or their byproducts have already occurred into surface waters.

The Effect of Increased Biofuel Production Will Vary by Region, Due to Differences in Water Resources and State Laws

According to many experts and officials that we contacted, as biofuel production increases, farmers and the biofuel production industry will need to consider regional differences in water supply and quality when choosing which feedstocks to grow and how and where to expand their biofuel production capacity. Specifically, they noted that in the case of cultivation, certain states may be better suited to cultivate particular feedstocks because of the amount and type of water available. Some examples they provided include the following:

[26]EIA noted that use of E10 has dramatically increased over the past few years and that there are governmental and industry efforts, such as the U.S. Department of Transportation's Pipeline and Hazardous Material Safety Administration, that work with industry groups to address risks associated with handling ethanol blends.

[27]Some UST systems are specifically designed to store fuel containing 85 percent ethanol. According to EPA officials, owners using blends containing 85 percent ethanol generally work with a licensed installer to use certified, compatible storage and dispensing equipment. UST systems comprise many components; however, some of these components have not been tested for use with high ethanol fuel blends.

- Certain cellulosic feedstocks, such as switchgrass, would be well-suited for areas with limited rainfall, such as Texas, because these feedstocks generally require less water and are drought tolerant.

- In the Midwest, switchgrass and other native perennial grasses could be grown as stream buffer strips or as cover crops, which are crops planted to keep the soil in place between primary plantings.

- In Georgia, some experts said pine was likely to be cultivated as a next generation biofuel feedstock because the state has relatively limited land available for cultivation and increased cultivation of pine or other woody biomass without irrigation would not cause a strain on water supplies.

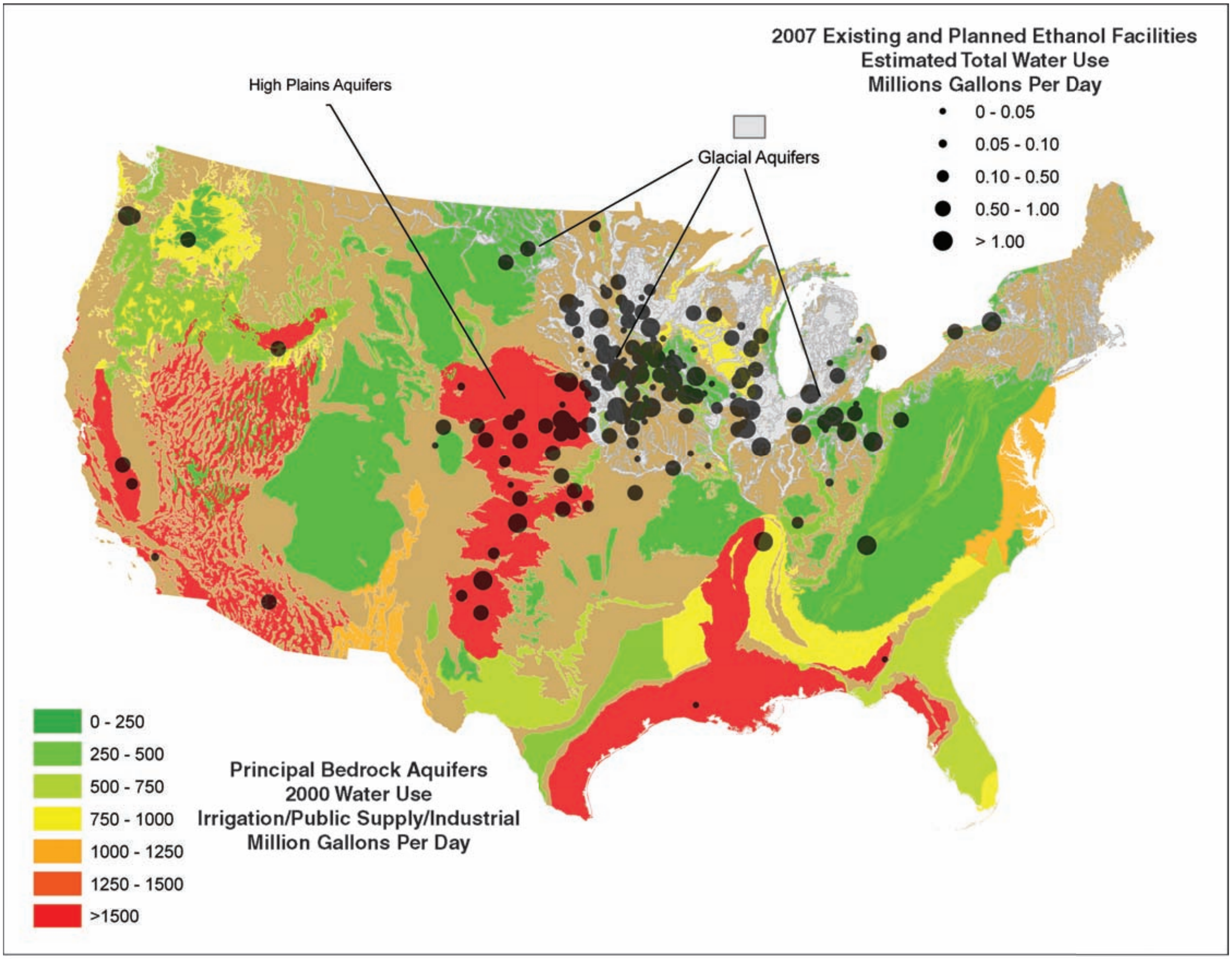
- In the Southeast and Pacific Northwest, waste from logging operations and paper production was identified as a potential feedstock for cellulosic ethanol production.

- Areas with limited freshwater supplies and a ready supply of lower-quality water, such as brackish water or water from wastewater treatment plants, would be better suited to the cultivation of algae. For example, Texas was identified as a state suitable for algae cultivation because of the large amounts of brackish water in many of its aquifers, as well as its abundant sunlight and supplies of carbon dioxide from industrial facilities.

Research indicates that in making decisions about feedstock production for biofuels it will be important to consider the effects that additional cultivation will have on the quality of individual water bodies and regional watersheds. Farmers need to consider local water quality effects when making decisions regarding the suitability of a particular feedstock or where to employ agricultural management practices that minimize nutrient application. In addition, state officials should consider these effects when deciding where programs such as the CRP may be the most effective. For example, experts and officials told us it will be important to identify watersheds in the Midwest that are delivering the largest nutrient loads into the Mississippi River basin and, consequently, contributing to the Gulf of Mexico dead zone, in order to minimize additional degradation that could result from increased crop cultivation in these watersheds. In addition, research has shown it is important that management practices be tailored to local landscape conditions, such as topography and soil quality, and landowner objectives, so that efforts to reduce nutrient and sediment runoff can be maximized.

In the case of biofuel conversion, some experts and officials said that state regulators and industry will need to consider the availability of freshwater supplies and the quality of those supplies when identifying and approving sites for biorefineries. Currently, many biorefineries are located in areas with limited water resources. For instance, as figure 4 shows, many existing and planned ethanol facilities are located on stressed aquifers, such as the Ogallala, or High Plains, Aquifer. These facilities require 100,000 to 1 million gallons of water per day, and as mentioned earlier, the rate of water withdrawal from the aquifer is already much greater than its recharge rate, allowing water withdrawals in Nebraska or South Dakota to affect water supplies in other states that draw from that aquifer. Experts noted that states with enough rainfall to replenish underlying aquifers may be more appropriate locations for biorefineries.

Figure 4: Existing and Planned Ethanol Facilities (as of 2007) and Their Estimated Total Water Use Mapped with the Principal Bedrock Aquifers, including the Ogallala, or High Plains, Aquifer, of the United States and Total Water Use in 2000



Source: Created by USGS for use in the National Research Council 2008 report *Water Implications of Biofuels Production in the U.S.*

Finally, relevant water laws in certain states may influence the location of future biorefineries. Specifically, several states have enacted laws that require permits for groundwater or surface water withdrawals and this requirement could impact where biorefineries will be sited. These laws specify what types of withdrawals must be permitted by the responsible regulatory authority and the requirements for receiving a permit. For instance, Georgia's Environmental Protection Division grants permits for certain withdrawals of groundwater and surface water, including for use by a biorefinery, when the use will not have unreasonable adverse effects on other water uses. According to state officials, there has not yet been a case where a permit for a biorefinery was denied because the amount of projected withdrawal was seen as unreasonable. In contrast, groundwater decisions are made at the local level in Texas, where more than half of the counties have groundwater conservation districts, and Nebraska. In deciding whether to issue a permit, the Texas groundwater conservation districts consider whether the proposed water use unreasonably affects either existing groundwater and surface water resources or existing permit holders, among other factors. In Nebraska, permits are only required for withdrawals and transfers of groundwater for industrial purposes. In addition, in Nebraska, where water supplies are already fully allocated in many parts of the state, natural resource districts can require biofuel conversion facilities to offset the water they will consume by reducing water use in other areas of the region. The volume of withdrawals can also factor into the need for a permit. While Texas conservation district permits are required for almost all types of groundwater wells, Georgia state withdrawal permits are only required for water users who withdraw more than an average of 100,000 gallons per day.[28]

Agricultural Practices, Technological Innovations, and Alternative Water Sources Can Mitigate Some Water Resource Effects of Biofuels Production, but There Are Barriers to Adoption

Agricultural conservation practices can reduce the effects of increased biofuel feedstock cultivation on water supply and water quality, but there are several barriers to widespread adoption of these practices. Similarly, the process of converting feedstocks to biofuels, technological innovations, and the use of alternative water sources can help reduce water supply and water quality impacts, but these options can be cost prohibitive and certain noneconomic barriers to their widespread use remain.

[28]Any entity that withdraws more than 100,000 gallons a day (monthly average) of surface water or 100,000 gallons a day (daily average) of groundwater requires a water permit.

Certain Agricultural Practices Can Benefit Water Supply and Water Quality, but Barriers May Limit Widespread Adoption

Many experts and officials we spoke with highlighted the importance of using agricultural conservation practices to reduce the potential effects of increased biofuel feedstock cultivation on water resources. These practices can reduce nutrient and pesticide runoff as well as soil erosion by retaining additional moisture and nutrients in the soil and disturbing the land less. For example, several experts and officials we spoke with said that installing and maintaining permanent vegetation areas adjacent to lakes and streams, known as riparian zones, could significantly reduce the impacts of agricultural runoff. More specifically, several experts and officials said that planting buffer strips of permanent vegetation, such as perennial grasses, or constructing or restoring wetlands in riparian areas would reduce the effects that crop cultivation can have on water quality, as shown in figure 5.

Figure 5: Example of a Riparian Buffer Adjacent to Cropland

Source: USDA.

Experts also identified conservation tillage practices—such as "no-till" systems or reduced tillage systems, where the previous year's crop residues are left on the fields and new crops are planted directly into these residues—as an important way to reduce soil erosion (see fig. 6). Research conducted by USDA has shown a substantial reduction in cropland erosion since 1985, when incentives were put in place to encourage the adoption of conservation tillage practices.[29] Another practice, crop rotation, also reduces erosion and helps replenish nutrients in the soil. This contrasts with practices such as continuous corn cultivation—in which farmers plant corn on the same land year after year instead of rotating to other crops—which often leads to decreased soil quality. Furthermore, experts identified cover crops, a practice related to crop rotation, as a way to mitigate some of the impacts of agricultural runoff. Cover crops are planted prior to or following a harvested crop, primarily for seasonal soil protection and nutrient recovery before planting the next year's crops. These crops, which include grains or perennial grasses, absorb nutrients and protect the soil surface from erosion caused by wind and rain, especially when combined with conservation tillage practices.

[29] See the USDA-NRCS 2003 Annual National Resources Inventory (http://www.nrcs.usda.gov/technical/NRI/2003/nri03eros-mrb.html).

Figure 6: Example of Conservation Tillage

Source: USDA.

Note: The picture depicts conservation tillage, a process in which last year's crop residues are left on the field and planting occurs directly into this minimally tilled soil.

Experts also identified "precision agriculture" as an important tool that can reduce fertilizer runoff and water demand by closely matching nitrogen fertilizer application and irrigation to a crop's nutrient and water needs. Precision agriculture uses technologies such as geographic information systems and global positioning systems to track crop yield, soil moisture content, and soil quality to optimize water and nutrient application rates. Farmers can use this information to tailor water, fertilizer, and pesticide application to specific plots within a field, thus potentially reducing fertilizer and pesticide costs, increasing yields, and reducing environmental impacts. Other precision agriculture tools, like low-energy precision-application irrigation and subsurface drip irrigation systems, operate at lower pressures and have higher irrigation water application and distribution efficiencies than conventional irrigation systems, as shown in figure 7.[30] Several experts and officials said that in order to promote such practices, it is important to continue funding and enrollment in federal programs, such as USDA's Environmental Quality Incentives Program, which pay farmers or provide education and technical support. See appendix II for an expanded discussion of agricultural conservation practices.

Figure 7: Example of Low-Energy Precision-Application Irrigation

Source: USDA.

Several experts and officials we spoke with also said that genetic engineering has the potential to decrease the water, nutrient, and pesticide requirements of biofuel feedstocks.[31] According to an industry trade group,

[30]Low-energy precision-application center-pivot systems discharge water between alternate crop rows planted in a circle. In subsurface drip irrigation, drip tubes are placed from 6 to 12 inches below the soil surface, the depth depending on the soil type, crop, and tillage practices.

[31]In addition to genetically engineering crops, USDA officials commented that traditional breeding techniques offer great potential for decreasing water, nutrient, and pesticide requirements of biofuels feedstocks.

biotechnology firms are currently developing varieties of drought-resistant corn that may be available to farmers within the next several years. These varieties could significantly increase yields in arid regions of the country that traditionally require irrigation for corn production. Companies are also working to develop crops that absorb additional nutrients or use nutrients more efficiently, giving them the potential to reduce nutrient inputs and the resulting runoff. However, industry officials believe it may be up to a decade before these varieties become available commercially. Furthermore, according to EPA, planting drought-resistant crops, such as corn, may lead to increased cultivation in areas where it has not previously occurred and may result in problems including increased nutrient runoff.

Experts and officials told us there are both economic and noneconomic barriers to the adoption of agricultural conservation practices.

- *Economic barriers*. According to several experts, as with any business, farming decisions are made in an attempt to maximize profits. As a result, experts told us that some farmers may be reluctant to adopt certain conservation practices that may reduce yields and profits, especially in the short term. Furthermore, experts and officials also said that some of these agricultural conservation practices can be costly, especially precision agriculture. For example, the installation of low-energy precision irrigation and subsurface drip irrigation systems is significantly more expensive than conventional irrigation systems because of the equipment needed, among other reasons.[32] Farmers may also hesitate to switch from traditional row crops to next generation cellulosic crops because of potential problems with cash flow and lack of established markets. Specifically, it can take up to 3 years to establish a mature, economically productive crop of perennial grasses, and farmers would be hard-pressed to forgo income during this period. Moreover, farmers may not be willing to cultivate perennial grasses unless they are assured that a market exists for the crop and that they could earn a profit from its cultivation. Furthermore, efficient cultivation and harvest could require farmers to buy new equipment, which would be costly and would add to the price they would have to receive for perennial grasses in order to make a profit.

- *Noneconomic barriers*. Experts and officials we contacted said that many farmers do not have the expertise or training to implement certain practices, and some agricultural practices may be less suited for some

[32]USDA officials noted that use of precision agriculture may also be limited in the cultivation of cellulosic feedstocks due to the costs involved.

places. For example, state officials told us that farmers usually need a year or more of experience with reduced tillage before they can achieve the same crop yields they had with conventional tillage. In addition, precision agriculture relies on technologies and equipment that require training and support. Officials told us that to help address this training need, USDA and states have programs in place that help educate farmers on how to incorporate these practices and, in some cases, provide funding to help do so. In addition, some experts and officials cited regional challenges associated with some agricultural practices and the cultivation of biofuel feedstocks. For example, these experts and officials said that the amount of agricultural residue that can be removed would vary by region and even by farm. Similarly, cultivation of certain cover crops as biofuel feedstocks may not be suitable in the relatively short growing seasons of northern regions.

Use of Innovative Technologies and Alternative Water Sources Could Reduce the Water Resource Effects of Biorefineries, but Costs and Logistics Impede Adoption

Technological improvements have already increased water use efficiency in the ethanol conversion process. Newly built biorefineries with improved processes have reduced water use dramatically over the past 10 years, and some plants have reduced their wastewater discharge to zero. Of the remaining water use, water loss from cooling towers for biorefineries is responsible for approximately 50 to 70 percent of water consumption in modern dry-milling ethanol plants.[33]

Some industry experts we spoke with said that further improvements in water efficiency at corn ethanol plants are likely to come from minimizing water loss from cooling towers or from using alternative water sources, such as effluent from sewage treatment plants. One alternative technology that can substantially reduce water lost through cooling towers is a dry cooling system,[34] which relies primarily on air rather than water to transfer heat from industrial processes.[35] In addition, some ethanol plants are beginning to replace freshwater with alternative sources of water, such as

[33]Cooling towers are used to control temperatures during the conversion process by transferring the heat to cooler water. This heat is then transferred via evaporation to the atmosphere.

[34]In one type of dry cooling system, steam flows through condenser tubes and is cooled directly by fans blowing air across the outside of these tubes to condense the steam back into liquid water.

[35]GAO, *Energy-Water Nexus: Improvements to Federal Water Use Data Would Increase Understanding of Trends in Power Plant Water Use*, GAO-10-23 (Washington, D.C.: Oct. 16, 2009).

effluent from sewage treatment plants, water from retention ponds at power plants, or excess water from adjacent rock quarries. For example, a corn ethanol conversion plant in Iowa gets a third of its water from a local wastewater treatment plant. By using these alternative water sources, the biorefineries can lower their use of freshwater during the conversion process. While these strategies of improved water efficiency at biorefineries show considerable promise, there are barriers to their adoption. For example, technologies such as dry cooling systems are often prohibitively expensive and can increase energy consumption. Furthermore, according to industry experts, alternative water sources can create a need for expensive wastewater treatment equipment. Some industry experts also told us that the physical layout of a conversion facility may need to be changed to make room for these improvements. Because of the considerable costs of such improvements, several experts told us, it is difficult for biorefineries to integrate these water-conserving technologies while remaining competitive in the economically strained ethanol industry.

Many experts and officials stated that technological innovations for next generation biofuel conversion also have the potential to reduce the water supply and water quality impacts of increased biofuel production. For example, thermochemical production of cellulosic ethanol could require less than 2 gallons of water per gallon of ethanol produced.[36] In addition, some next generation biofuels, known as “drop-in” fuels, are being developed that are compatible with the existing fuel infrastructure, which could reduce the risk that leaks and spills could contaminate local water bodies. For example, biobutanol is produced using fermentation processes similar to those used to make conventional ethanol, but it does not have the same corrosive properties as ethanol and could be distributed through the existing gasoline infrastructure.[37] In addition, liquid hydrocarbons derived from algae have the potential to be converted to gasoline, diesel, and jet fuel, which also can be readily used in the existing fuel

[36]Wu, M. et al., “Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline,” Center for Transportation Research, Energy Systems Division, Argonne National Laboratory (Argonne, Ill., January 2009).

[37]Similar to ethanol, biobutanol is an alcohol that can be produced from domestic feedstocks. However, biobutanol has a few advantages over ethanol. Biobutanol has a higher energy content than ethanol and is compatible with the existing infrastructure.

infrastructure.[38] However, while these proposed technological innovations can reduce the water resource impacts of increased biofuel production, the efficacy of most of these innovations has not yet been demonstrated on a commercial scale, and some innovations' efficacy has not yet been demonstrated on a pilot scale.

Experts Identified a Variety of Key Research and Data Needs Related to Increased Biofuels Production and Local and Regional Water Resources

Many of the experts and officials we spoke with identified areas where additional research is needed to evaluate and understand the effects of increased biofuel production on water resources. These needs fall into two broad areas: (1) research on the water effects of feedstock cultivation and conversion and (2) better data on local and regional water resources.

Experts and officials identified the following research needs on the water resource effects of feedstock cultivation and conversion processes:

Genetically engineered biofuel feedstocks. Many experts and officials cited the need for more research into the development of drought-tolerant and water- and nutrient-efficient crop varieties to decrease the amount of water needed for irrigation and the amount of fertilizer that needs to be applied to biofuel feedstocks. According to the National Research Council, this research should also address the current lack of knowledge on the general water requirements and evapotranspiration rates of genetically engineered crops, including next generation crops.[39] Regarding nutrient efficiency, some experts and officials noted that research into the development of feedstocks that more efficiently take up and store nitrogen from the soil would help reduce nitrogen runoff. In addition, USDA officials added that research to determine the water requirements for conventional biofuel feedstocks and new feedstock varieties developed specifically for biofuel production is also needed.

Effects of cellulosic crops on hydrology. Many experts and officials also told us there is a need to better understand the water requirements of cellulosic crops and the impact of commercial-scale cellulosic feedstock cultivation on hydrology, which is the movement of water through land

[38]Liquid hydrocarbons, such as petroleum, are a class of chemical compounds containing only hydrogen and carbon. Potentially, hydrocarbons can be derived from substitutes such as oils from plants or algae.

[39]Evapotranspiration refers to the water lost to the atmosphere from soil and water bodies (evaporation) and from plant leaves (transpiration).

and the atmosphere into receiving water bodies. According to one expert, these feedstocks differ from corn in their life cycles, root systems, harvest times, and evapotranspiration levels, all of which may influence hydrology. In addition, some research suggests that farmers may cultivate cellulosic feedstocks on marginal or degraded lands because these lands are not currently being farmed and may be suitable for these feedstocks. However, according to the National Research Council, the current evapotranspiration rates of crops grown on such lands is not well known.[40]

Effects of cellulosic crops on water quality. Many experts and officials we spoke with said research is needed to better understand the nutrient needs of cellulosic crops grown on a commercial scale. Specifically, field research is needed on the movement of fertilizer in the soil, air, and water after it is applied to these crops. One expert explained there are water quality models that can describe what happens to fertilizer when applied to corn, soy, and other traditional row crops. However, such models are less precise for perennial grasses due to the lack of data from field trials. Similarly, several experts and officials told us that additional research is also needed on the potential water quality impacts from the harvesting of corn stover. In particular, research is needed on the erosion and sediment delivery rates of different cropping systems in order to determine the acceptable rates of residue removal for different crops, soils, and locations and to develop the technology to harvest residue at these rates.

Cultivation of algae. Although algae can be cultivated using lower-quality water, the impact on water supply and water quality will ultimately depend on which cultivation methods are determined to be the most viable once this nascent technology reaches commercial scale. Many experts we spoke with noted the need for research on how to more efficiently cultivate algae to minimize the freshwater consumption and water quality impacts. For example, research on how to maximize the quantity of water that can be recycled during harvest will be essential to making algae a more viable feedstock option. Further research is also needed to determine whether the pathogens and predators in the lower-quality water are harmful to the

[40] National Research Council, *Water Implications of Biofuels Production in the United States*, 2008.

algae.[41] In addition, research is also needed on how to manage water discharges during cultivation and harvest of algae. Although it is expected that most water will be recycled, a certain amount must be removed to prevent the buildup of salt. This water may contain pollutants—such as nutrients, heavy metals, and accumulated toxics—that need to be removed to meet federal and state water quality standards.

Data on land use. Better data are needed on what lands are currently being used to cultivate feedstocks, what lands may be most suitable for future cultivation, and how land is actually being managed, according to experts and officials. For example, some experts and officials told us there is a need for improved data on the status and trends in the CRP. According to a CRP official, USDA does not track what happens to land after it is withdrawn from the CRP. Such data would be useful because it would help officials gain a better understanding of the extent to which marginal lands are being put back into production. In addition, improved data on land use would help better target and remove the least productive lands from agricultural production, resulting in water supply and water quality benefits because these lands generally require greater amounts of inputs, according to these experts and officials. Research is also needed to determine optimal placement of feedstocks and use of agricultural conservation practices to get the best yields and minimize adverse environmental impacts.

Farmer decision making. Several experts and officials told us that a better understanding of how farmers make cultivation decisions, such as which crops to plant or how to manage their lands, is needed in the context of the water resource effects of biofuel feedstocks. Specifically, several experts and officials said that research is needed to better understand how farmers decide whether to adopt agricultural conservation practices. In particular, some experts and officials said research should explore how absentee ownership of land affects the choice of farming practices. These experts and officials told us it is common for landowners to live elsewhere and rent their farmland to someone else. For example, in Iowa, 50 percent of agricultural land is rented, according to one expert, and renters may be making cultivation

[41]U.S. Department of Energy, "National Algal Biofuels Technology Roadmap," Draft, 2009. In December 2008, DOE convened a workshop to discuss and identify the critical barriers currently preventing the economical production of algal biofuels at a commercial scale. As a result of this workshop, DOE assembled a draft roadmap that highlights a number of areas in need of additional research.

decisions that maximize short-term gains rather than focusing on the long-term health of the land. In addition, several experts and officials said that research is needed to understand the cultural pressures that may make farmers slow to adopt agricultural conservation practices. For example, some experts and officials we spoke with said that some farmers may be hesitant to move away from traditional farming approaches.

Conversion. Existing and emerging technology innovations, such as those discussed earlier in the report, may be able to address some effects of conversion on water resources, but more research into optimizing current technologies is also needed, according to experts. For example, research into new technologies that further reduce water needs for biorefinery cooling systems would have a significant impact on the overall water use at a biorefinery, according to several experts. Congress is considering legislation—the Energy and Water Research Integration Act—that would require DOE's research, development, and demonstration programs to seek to advance energy and energy efficiency technologies that minimize freshwater use, increase water use efficiency, and utilize nontraditional water sources with efforts to improve the quality of that water.[42] It would also require the Secretary of Energy to create a council to promote and enable, in part, improved energy and water resource data collection. Similarly, with regard to conversion facilities for the next generation feedstocks, further research is needed to ensure that the next generation of biorefineries is as water efficient as possible. For example, for the conversion of algae into biofuels, research is needed on how to extract oil from algal cells so as to preserve the water contained in the cell, which would allow some of that water to be recycled.

Storage and distribution. EPA officials noted that additional research related to storage and distribution of biofuels is also needed to help reduce the effects of leaks that can result from the storage of biofuel blends in incompatible tank systems. Although EPA has some research under way, more is needed into the compatibility of fuel blends containing more than 10 percent ethanol with the existing fueling infrastructure. In addition, research should evaluate advanced conversion technologies that can be used to produce a variety of renewable fuels that can be used in the existing infrastructure. Similarly, research is needed into biodiesel distribution and storage, such as assessing the compatibility of blends

[42] H.R. 3598, 111th Cong. (2009).

greater than 5 percent with the existing storage and distribution infrastructure.

In addition, experts and officials identified the following needs for better data on local and regional water resources:

Water availability data. Because some local aquifers and surface water bodies are already stressed, many experts called for more and better data on water resources.[43] Although USGS reports data on water use every 5 years, the agency acknowledges that it does not have good estimates of water use for biofuel production for irrigation or fuel production, so it is unclear how much water has been or will be actually consumed with increases in cultivation and conversion of biofuel feedstocks. Furthermore, some experts and officials told us that even when local water data are available, the data sources are often inconsistent or out of date. For example, the data may capture different information or lack the information necessary for making decisions regarding biofuel production.

According to several experts and officials, better data on water supplies would also help ensure that new biorefineries are built in areas with enough water for current and future conversion processes. Although biorefineries account for only a small percentage of water used during the biofuel production process, the additional withdrawals from aquifers can affect other users that share these water sources. Improving water supply data would help determine whether the existing water supplies can support the addition of a biorefinery in a particular area. Some experts also noted the need for research on the availability of lower-quality water sources such as brackish groundwater, which could be used for cultivation of some next generation feedstocks, especially algae. Better information is necessary to better define the spatial distribution, depth, quantity, physical and chemical characteristics, and sustainable withdrawal rates for these lower-quality water sources, and to predict the long-term effects of water extraction.

[43]The Omnibus Public Land Management Act of 2009 requires, in part, the Secretary of Interior, in coordination with the National Advisory Committee on Water Information and state and local water resource agencies, to establish a national water availability and use assessment program. Pub. L. No. 111-11, § 9508(a) (2009), *codified at* 42 U.S.C. § 10368(a). This program will, among other things, provide a more accurate assessment of the status of the water resources of the United States. The program may address some of the water availability data needs identified by the experts we spoke with.

Linkages between datasets. Some experts also cited a need for better linkages between existing datasets. For example, datasets on current land use could be combined with aquifer data to help determine what land is available for biofuel feedstock cultivation that would have minimal effects on water resources. In addition, some experts said that while there are data that state agencies and private engineering companies have collected on small local aquifers, a significant effort would be required to identify, coordinate, and analyze this information because linkages do not currently exist.

Geological process data. Several experts and officials also said that research into geological processes is needed to understand the rate at which aquifers are replenished and the impact of increased biofuel production on those aquifers. Although research suggests there should be sufficient water resources to meet future biofuel feedstock production demands at a national level, increased production may lead to significant water shortages in certain regions. For example, additional withdrawals in states relying heavily on irrigation for agriculture may place new demands on already stressed aquifers in the Midwest. Even in water-rich states, such as Iowa, concerns have arisen over the effects of increased biofuel production, and research is needed to assess the hydrology and quality of a state's aquifers to help ensure it is on a path to sustainable production, according to one state official.

Agency Comments and Our Evaluation

We provided a draft of this report to USDA, DOE, DOI, and EPA for review and comment. USDA generally agreed with the findings of our report and provided several comments for our consideration. Specifically, USDA suggested that we consider condensing our discussion of agricultural practices, equipment, and grower decisions, as these items may or may not be relevant depending on the feedstock or regulatory control. However, we made no revisions to the report because we believe that cultivation is a significant part of the biofuels life cycle, and these items are relevant and necessary to consider when discussing the potential effect of biofuel production on water resources. USDA also noted that the report is more focused on corn ethanol production than next generation biofuels and that we had not adequately recognized industry efforts to be more sustainable through a movement toward advanced biofuels. Given the maturity of the corn ethanol industry, the extent of knowledge about the effects on water supply and quality from cultivation of corn and its conversion into ethanol, and the uncertainty related to the effects of next generation biofuel production, we believe the balance in the report is appropriate. Moreover, although the shift toward next generation biofuels is a positive step in terms of sustainability, this industry is still developing and the full extent of the environmental benefits from this shift is still unknown. USDA also provided technical comments, which we incorporated as appropriate. See appendix III for USDA's letter.

DOE generally agreed with our findings and approved of the overall content of the report and provided several comments for our consideration. Specifically, DOE noted that it may be too early to make projections on the amount of CRP land that will be converted and the amount of additional inputs that will be needed for cultivation of biofuel feedstocks. In addition, DOE suggested we expand our discussion of efforts to address risks of ethanol transport and note the water use associated with the production of biomass-to-liquid fuels. We adjusted the text as appropriate to reflect these suggestions. DOE also suggested that the report should discuss water pricing; however, this was outside the scope of our review. See appendix IV for DOE's letter.

In its general comments, DOI stated that the report is useful and agreed with the finding on the need for better data on water resources to aid the decision about where to cultivate feedstocks and locate biorefineries. DOI also suggested that the report should include a discussion of the other environmental impacts of biofuel production, such as effects on wildlife habitat or effects on soil. In response, we note that this report was specifically focused on the impacts of biofuel production on water resources; however, for a broader discussion of biofuel production, including other environmental effects, see our August 2009 report.[44] DOI also provided additional technical comments that we incorporated into the report as appropriate. See appendix V for DOI's letter.

EPA did not submit formal comments, but did provide technical comments that we incorporated into the final report as appropriate.

We are sending copies of this report to interested congressional committees; the Secretaries of Agriculture, Energy, and the Interior; the Administrator of the Environmental Protection Agency; and other interested parties. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

[44] GAO-09-446.

If you or your staff have questions about this report, please contact us at (202) 512-3841 or mittala@gao.gov or gaffiganm@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix VI.

Sincerely yours,

Ms. Anu K. Mittal
Director, Natural Resources
and Environment

Mark E. Gaffigan
Director, Natural Resources
and Environment

Appendix I: Objectives, Scope, and Methodology

Our objectives for this review were to describe (1) the known water resource effects of biofuel production in the United States; (2) the agricultural conservation practices and technological innovations that exist or are being developed to address these effects and any barriers that may prevent the adoption of these practices and technologies; and (3) key research needs regarding the effects of biofuel production on water resources.

To address each of these objectives, we conducted a systematic analysis of relevant articles of relevant scientific articles, U.S. multidisciplinary studies, and key federal and state government reports addressing the production of biofuels and its impact on water supply and quality, including impacts from the cultivation of biofuel feedstock and water use and effluent release from biofuel conversion processes. In conducting this review, we searched databases such as SciSearch, Biosis Previews, and ProQuest and used a snowball technique to identify additional studies, asking experts to identify relevant studies and reviewing studies from article bibliographies. We reviewed studies that fit the following criteria for selection: (1) the research was of sufficient breadth and depth to provide observations or conclusions directly related to our objectives; (2) the research was targeted specifically toward projecting or demonstrating effects of increased biofuel feedstock cultivation, conversion, and use on U.S. water supply and water quality; and (3) typically published from 2004 to 2009. We examined key assumptions, methods, and relevant findings of major scientific articles, primarily on water supply and water quality. We believe we have included the key scientific studies and have qualified our findings where appropriate. However, it is important to note that, given our methodology, we may not have identified all of the studies with findings relevant to these three objectives. Where applicable, we assessed the reliability of the data we obtained and found them to be sufficiently reliable for our purposes.

In collaboration with the National Academy of Sciences, we identified and interviewed recognized experts affiliated with U.S.-based institutions, including academic institutions, the federal government, and research-oriented entities. These experts have (1) published research analyzing the water resource requirements of one or more biofuel feedstocks and the implications of increased biofuels production on lands with limited water resources, (2) analyzed the possible effects of increased biofuel production on water, or (3) analyzed the water impacts of biofuels production and use. Together with the National Academy of Sciences' lists of experts, we identified authors of key agricultural and environmental studies as a basis for conducting semistructured interviews to assess what is known about the effects of the increasing production of biofuels and important areas that need additional research. The experts we interviewed included research scientists in such fields as environmental science, agronomy, soil science, hydrogeology, ecology, and engineering.

Furthermore, to gain an understanding of the programs and plans states have or are developing to address increased biofuel production, we conducted in-depth reviews of the following five states: Georgia, Iowa, Minnesota, Nebraska, and Texas. We selected these states based on a number of criteria: ethanol and biodiesel production levels, feedstock cultivation type, reliance on irrigation, geographic diversity among states currently producing biofuels, and approaches to water resource management and law. For each of the states, we analyzed documentation from and conducted interviews with a wide range of stakeholders to gain the views of diverse organizations covering all stages of biofuel production. These stakeholders included relevant state agencies, including those responsible for oversight of agriculture, environmental quality, and water and soil resources; federal agency officials with responsibility for a particular state or region, such as officials from the Department of the Interior's U.S. Geological Survey (USGS), the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service, and the Environmental Protection Agency (EPA); university researchers; industry representatives; feedstock producers; and relevant nongovernmental organizations, such as state-level corn associations, ethanol producer associations, and environmental organizations. We also conducted site visits to Iowa and Texas to observe agricultural practices and the operation of selected biofuels production plants.

We also interviewed senior officials, scientists, economists, researchers, and other federal officials from USDA, the Departments of Defense and Energy, EPA, the National Aeronautics and Space Administration, the Department of Commerce's National Oceanic and Atmospheric Administration, the National Science Foundation, and USGS about effects on the water supply and water quality during the cultivation of biofuel feedstocks and the conversion and storage of the finished biofuels. In addition, we interviewed state officials from Georgia, Iowa, Minnesota, Nebraska, and Texas as well as agricultural producers and representatives of biofuel conversion facilities to determine the impact of biofuels production in each state. We also interviewed representatives of nongovernmental organizations, such as the Renewable Fuels Association, the Biotechnology Industry Organization, the Pacific Institute, and the Fertilizer Institute.

To conduct the interview content analysis, we reviewed interviews, selected relevant statements from the interviews, and identified and labeled trends using a coding system. Codes were based on trends identified by previous GAO biofuel-related work, background information collected for the review, and the interviews for this review. The methodology for each objective varied slightly, because the first objective focused on regional differences and therefore relied on case study interviews, while analysis performed for the remaining two objectives used expert interviews in addition to case study interviews. Once relevant data were extracted and coded, we used the coded data to identify and analyze trends. For the purposes of reporting our results, we used the following categories to quantify responses of experts and officials: “some” refers to responses from 2 to 3 individuals, “several” refers to responses from 4 to 6 individuals, and “many” refers to responses from 7 or more individuals.

We conducted our work from January 2009 to November 2009 in accordance with all sections of GAO’s Quality Assurance Framework that are relevant to our objectives. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our stated objectives and to discuss any limitations in our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for any findings and conclusions in this product.

Appendix II: Examples of Agricultural Practices Available to Reduce the Water Quality and Water Supply Effects of Feedstock Cultivation for Biofuels

Agricultural conservation practice	Description	Potential environmental benefits
Soil erosion prevention		
Crop residue management	Any tillage method that leaves a portion of the previous crop residues (unharvested portions of the crop) on the soil surface.	• Reduces soil erosion caused by tillage and exposure of bare soil to wind and water. • Reduces water lost to evaporation. • Improves soil quality. • Reduces sediment and fertilizer runoff.
No-till	Method that leaves soil and crop residue undisturbed except for the crop row where the seed is placed in the ground.	• Reduces soil erosion caused by tillage and exposure of bare soil to wind and water. • Reduces water lost to evaporation. • Improves soil quality by improving soil organic matter. • Reduces sediment and fertilizer runoff.
Cover crops	A close-growing crop that temporarily protects the soil during the interim period before the next crop is established.	• Reduces erosion. • Reduces nitrate leaching. • Integrates crops that store nitrogen from the atmosphere (such as soy), replaces the nitrogen that corn and other grains remove from the soil. • Reduces pesticide use by naturally breaking the cycle of weeds, insects, and diseases. • Improves soil quality by improving soil organic matter.
Nutrient pollution reduction		
Crop rotation	Change in the crops grown in a field, usually in a planned sequence. For example, crops could be grown in the following sequence, corn-soy-corn, rather than in continuous corn.	• Integrates crops that obtain nitrogen from the atmosphere (such as soy), replaces the nitrogen that corn and other grains remove from the soil. • Reduces pesticide use by naturally breaking the cycle of weeds, insects, and diseases.
Nutrient management	Use of nutrients to match the rate, timing, form, and application method of fertilizer to crop needs.	• Reduces nutrient runoff and leaching.
Subsurface fertilizer application	Injection of fertilizer below the soil surface.	• Reduces runoff and gaseous emission from nutrients.
Controlled-release fertilizers	Use of fertilizers with water-insoluble coatings that can prevent water-soluble nitrogen from dissolving.	• Reduces nutrient runoff and leaching. • Increases the efficiency of the way nutrients are supplied to and are taken up by the plant, regardless of the crop.
Controlled drainage	Water control structures, such as a flashboard riser, installed in the drainage outlet allow water level to be raised or lowered as needed.	• Minimizes transport of nutrients to surface waters.

Agricultural conservation practice	Description	Potential environmental benefits
Irrigation techniques		
Subsurface drip irrigation systems	Irrigation systems buried directly beneath the crop apply water directly to the root zone.	• Minimizes water lost to evaporation and runoff.
Low-energy precision-application systems	Irrigation systems that operate at lower pressures and have higher irrigation-water application and distribution efficiencies.	• Minimizes net water loss and energy use.
Reclaimed water use	Water recovered from domestic, municipal, and industrial wastewater treatment plants that has been treated to standards that allow safe reuse for irrigation.	• Reduces demand on surface and ground waters.
Multiple benefits		
Wetland restoration	Restoration of a previously drained wetland by filling ditches or removing or breaking tile drains.	• Reduces flooding downstream. • Filters sediment, nutrients, and chemicals. • Provides habitat for wetland plants, amphibians, and birds.
Riparian buffer zones	Strips or small areas of land planted along waterways in permanent vegetation that help control pollutants and promote other environmental benefits.	• Traps sediment. • Filters nutrients. • Provides habitat and corridors for fish and wildlife.
Precision agriculture	A system of management of site-specific inputs (e.g., fertilizer, pesticides) on a site-specific basis such as land preparation for planting, seed, fertilizers and nutrients, and pest control. Precision agriculture may be able to maximize farm production efficiency while minimizing environmental effects. Key technological tools used in this approach include global positioning systems, geographic information systems, real-time soil testing, real-time weather information, etc.	• Reduces nutrient runoff and leaching. • Reduces erosion. • Reduces pesticide use.

Source: GAO analysis.

Appendix III: Comments from the U.S. Department of Agriculture

USDA

United States Department of Agriculture

Research, Education, and Economics
Agricultural Research Service

NOV 1 9 2009

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Ms. Anu Mittal
Government Accountability Office
Director, Natural Resources and Environment
441 G. Street, NW.
Washington, D.C. 20548

Dear Ms. Mittal:

Thank you for the opportunity to review the U.S. Government Accountability Office Draft Report, Energy-Water Nexus: *Many Uncertainties Remain About National and Regional Effects of Increased Biofuel Production on Water Resources* (GAO-10-116).

The Department of Agriculture (USDA) has reviewed the GAO Draft Report and is in general agreement with its findings. We are impressed with its comprehensiveness, the broad scope of topics covered, and accurate assessment of those issues. We agree with the report's general contention regarding the uncertainties of the availability of water resources to sustain increased biofuel production. Moreover, several of the specific issues cited—such as the potential for ground water contamination from benzene production in underground storage tanks (UST)—provide great insight into the many infrastructure deployment challenges currently facing biofuels production and distribution. The report also does an excellent job laying out the parameters that frame the link between bioenergy and water resource management, thus providing an excellent starting point for the establishment of research and development needs to address water availability and quality issues related to increased production of biofuels. Some substantive comments on the report are as follows:

1. We note that some topics stray from the overarching issue of bioenergy production and water management. For instance, the report discusses details of conservation tillage practices, the need for planting and harvesting equipment, and decisions that a grower might or might not make related to production and environmental concerns. Some of these questions may or may not be relevant depending on the biofeedstock to be produced or may be more dependent on regulatory control. Condensing and shortening these areas could improve the focus of the report.

2. The report documents the move toward advanced biofuels development and notes that many producers are beginning to adopt feedstocks that use less water. The report fails to adequately recognize the degree to which industry is already moving along a more sustainable development path.

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Ms. Anu Mittal 2

3. The Draft report allocates significant space and attention to grain based ethanol production, even as concentrated efforts and policies are focusing on next generation biofuels.

USDA's technical and specific comments are attached.

Again, thank you for the opportunity to review.

Sincerely,

Steven Kappes

for EDWARD B. KNIPLING
Administrator

Enclosure

Appendix IV: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

NOV 12 2009

2009 NOV 13 AM 11:50

Mr. Mark Gaffigan
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street., NW
Washington, DC 20548

Dear Mr. Gaffigan:

Thank you for the opportunity to comment on the draft GAO Report titled: *"Energy-Water Nexus: Many Uncertainties Remain About National and Regional Effects of Increased Biofuel Production on Water Resources"* (GAO-10-116). The Department of Energy (DOE) appreciates the effort put forth by GAO with regard to this report and is in general agreement with GAO's findings and approves of the overall content of the report, but would like to take this occasion to reiterate its assertion that certain sections of the report would benefit from further revision.

First, statements regarding the likely need for additional nutrients and pesticide inputs on marginal lands (page 11) and the role of biofuels in motivating farmers to return Conservation Reserve Program (CRP) land to row crop production (page 12) are speculative. It could be noted that alternative views exist and that it is too early to make projections for CRP conversion and for whether or not additional inputs are needed.

Second, the section on storage and distribution is appropriate but could be expanded. This section would provide a clearer overview of risks of biofuels if they were put into context. The inclusion of a brief description of the risks associated with storing and transporting petroleum products would be a useful comparison to the risks of biofuels storage and distribution. The EIA suggests that the report recognize the dramatic expansion of E10 motor fuel over the past few years and the governmental and industry efforts to address the associated risks of handling ethanol blends. The Department of Transportation and its Pipeline and Hazardous Material Safety Administration (PHMSA) division, in conjunction with industry groups, are engaged in efforts to deal with the associated risks in handling ethanol blends.

Third, it should be noted that in EIA's *Annual Energy Outlook 2009* http://www.eia.doe.gov/oiaf/aeo/index.html projections there is a growing use of biomass-to-liquids (BTL) fuels (5 billion gallons by 2030) to satisfy the EISA 2007 cellulosic biofuels mandate. EIA believes it might be worth mentioning that the production process for BTL requires no continuous water inputs (water is used for cooling but in a closed loop system).

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Moreover, pyrolysis oils which are also being currently considered as cellulosic biofuels use no process water as well. The table in the Appendix that summarizes the potential environmental benefits of the agricultural practices is very useful. The inclusion of a similar table summarizing the pros and cons of the various biofuel conversion processes discussed in the text would be a useful addition.

Finally, DOE believes it would be appropriate to raise the issue of price reform for water in this report. Price sends an important signal to consumers. Distorted prices are resulting in overconsumption of water because the full cost of water is not always passed on to the consumer. In areas where water is too inexpensive to monitor, incomplete data on water use exists.

DOE trusts that GAO will consider these suggestions, but does not deem it necessary that the report be revised on account of the three issues raised. Thank you again for the opportunity to comment on the draft Report. We look forward to working with GAO as we continue our efforts to develop the potential of biofuels.

If you have any questions, please contact me or Ms. Martha Oliver, Office of Congressional and Intergovernmental Affairs, at (202) 586-2229.

Sincerely,

Jacques Beaudry-Losique
Deputy Assistant Secretary for Renewable Energy
Office of Technology Development
Energy Efficiency and Renewable Energy

Appendix V: Comments from the Department of the Interior

United States Department of the Interior
OFFICE OF THE SECRETARY
Washington, DC 20240

TAKE PRIDE IN AMERICA

NOV 1 2 2009

Ms. Anu Mittal
Director, Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Ms. Mittal:

Thank you for providing the Department of the Interior the opportunity to review and comment on the draft Government Accountability Office report entitled, "*ENERGY-WATER NEXUS: Many Uncertainties Remain about National and Regional Effects of Increased Biofuel Production on Water Resources*" (GAO-10-116).

The GAO report explicitly makes no recommendations; however, we would like to provide technical comments and some general comments. We hope these comments will assist you in preparing the final report. If you have any questions or need additional information, please contact Donna Myers, Chief, National Water-Quality Assessment Program, United States Geological Survey, at (703) 648-5012.

Sincerely,

Anne J. Castle

Anne J. Castle
Assistant Secretary for
Water and Science

Enclosures

Appendix VI: GAO Contacts and Staff Acknowledgments

GAO Contacts

Anu Mittal, (202) 512-3841 or mittala@gao.gov

Mark Gaffigan, (202) 512-3841 or gaffiganm@gao.gov

Staff Acknowledgments

In addition to the contact named above, Elizabeth Erdmann, Assistant Director; JoAnna Berry; Mark Braza; Dave Brown; Muriel Brown; Colleen Candrl; Miriam Hill; Carol Kolarik; Micah McMillan; Chuck Orthman; Tim Persons; Nicole Rishel; Ellery Scott; Ben Shouse; Jeanette Soares; Swati Thomas; Lisa Vojta; and Rebecca Wilson made significant contributions to this report.

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