



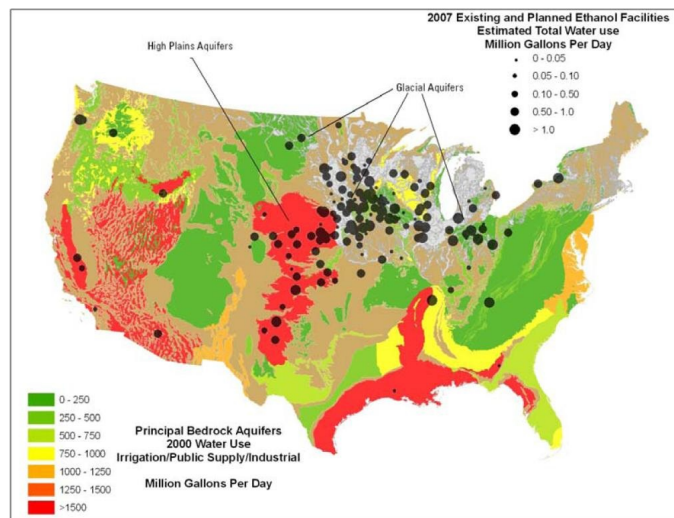
## The Implications of Biofuel Production for United States Water Supplies

Posted by [Nate Hagens](#) on November 29, 2007 - 11:00am

Topic: [Alternative energy](#)

Tags: [aquifer](#), [biodiesel](#), [biofuel](#), [corn](#), [environment](#), [ethanol](#), [hypoxia](#), [net energy](#), [nitrates](#), [pesticides](#), [water availability](#), [water quality](#) [[list all tags](#)]

In addressing the supply side of oil and gas depletion, much hope has been put into the scaling of 'biofuels', by applying new (and old) technologies to annual crops to create ethanol or biodiesel, thus providing chemically viable alternatives to the transportation liquids derived from crude oil. Much of the biofuels debate thus far has focused on their lower energy balance, vis-a-vis crude oil. While this is important, analysis of the impacts on non-energy inputs and impacts should a massive scaling of biofuels occur, urgently needs to be discussed. The National Academy of Sciences recently published a report titled "[Water Implications of Biofuel Production in the United States](#)". The paper outlines impacts and limitations on both water availability and water quality that would follow the pursuit of a national strategy to replace liquid fossil fuels with those made from biomass.



*Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000.(Source USGS) Click to enlarge.*

Some long time readers of theoil Drum.com think we have beaten the corn ethanol horse to death. While this may appear true to certain camps (especially ethanol stock investors!), the fact remains that corn ethanol technology is still at the forefront of our nations mitigation responses to 'energy security' and Peak Oil. Production is slated to increase from 5 billion gallons last year to 35 billion gallons in a decade. The DOE projects that biofuels can provide us with 30% of our liquid

fuel needs by 2030. However, given that we have limited amounts of high quality resources: crude oil, gasoline, fresh water, breathable air, healthy soil, productive ecosystems, etc., one of the highest policy priorities (in conjunction with attempts to change our conspicuous consumption paradigm) should be to establish the best use of these scarce resources to secure future energy flows. Two of the most precious of these are energy and water, and are the subject of today's post.

This post is a summary of an excellent recent report commissioned by the Natural Resource Council via the National Academy of Sciences, titled "*The Implications of Biofuel Production for United States Water Supplies*" It can be purchased in book form or downloaded as a pdf [here](#). (Editors note: As I've discussed here recently, two University of Vermont colleagues and I have written a related paper highlighting the critical and limiting role that water will play in future energy production, particularly from bioenergy. "*Burning Water - EROWI - The Energy Return on Water Invested*", is currently (still) in the review/rejection/resubmittal process so I've been unable to post it here, even though it was written over a year ago). Since corn ethanol looks to still be a key policy issue in the upcoming Presidential primaries in Iowa, I thought a brief overview of this important NAS paper would be informative to our readers. The grey boxes and graphs are from the paper, "Water Implications of Biofuel Production in the United States", interweaved throughout the authors summary. The 'bottom line' and graphic at the end, are my own.

## The Implications of Biofuel Production for United States Water Supplies

These were the scientists that oversaw/wrote the report:

COMMITTEE ON WATER IMPLICATIONS OF BIOFUELS PRODUCTION IN THE UNITED STATES

JERALD L. SCHNOOR, Chair, University of Iowa, Iowa City  
OTTO C. DOERING III, Purdue University, West Lafayette, Indiana  
DARA ENTEKHABI, Massachusetts Institute of Technology, Cambridge  
EDWARD A. HILER, Texas A&M University, College Station  
THEODORE L. HULLAR, Cornell University, Ithaca, New York  
G. DAVID TILMAN, University of Minnesota, St. Paul

### ABOUT BIOMASS, BIOFUELS AND WATER

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

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

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

SOURCE: U.S. CRS (2007).

*US Production of Biofuels from Various Feedstocks 2006 Click to enlarge.*

Recent increases in oil prices in conjunction with subsidy policies have led to a dramatic expansion in corn ethanol production and high interest in further expansion over the next decade. President Bush has called for production of 35 billion gallons of ethanol annually by 2017, which, if achieved, would comprise about 15 percent of U.S. liquid transportation fuels. This goal is almost certain to result in a major increase in corn production, at least until marketable future alternatives are developed.

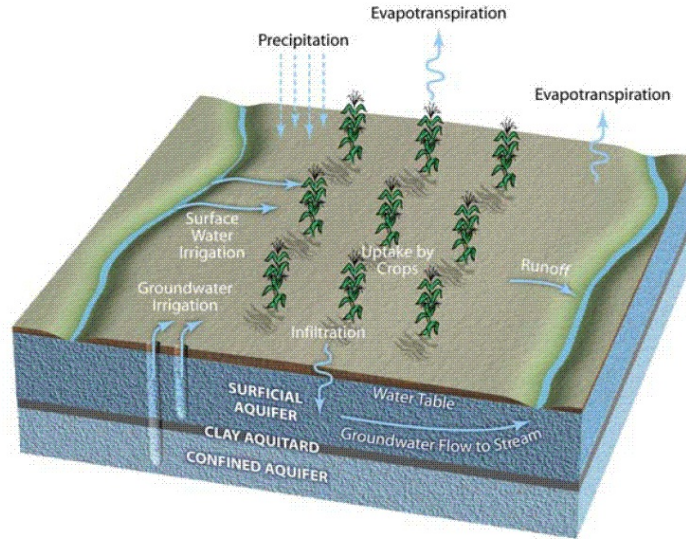
Among the possible challenges to biofuel development that may not have received appropriate attention are its effects on water and related land resources. The central questions are how water use and water quality are expected to change as the U.S. agricultural portfolio shifts to include more energy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

To help illuminate these issues, the Water Science and Technology Board (WSTB) of the National Research Council held a colloquium on “Water Implications of Biofuels Production in the United States” in Washington, D.C., on July 12, 2007, which was attended by more than 130 people from federal and state government, non-governmental organizations, academia, and industry. WSTB established a committee to organize and host the colloquium and to develop this report (see Box 1-1). This report draws some conclusions about the water implications of biofuels productions based on discussions at the colloquium, written submissions of participants, the peer-reviewed literature, and the best professional judgments of the committee.

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

In some areas of the country, water resources already are significantly stressed. For example, large portions of the Ogallala (or High Plains) aquifer, which extends from west Texas up into South Dakota and Wyoming, show water table declines of over 100 feet. Deterioration in water quality may further reduce available supplies. Increased biofuels production adds pressure to the water management challenges the nation already faces.

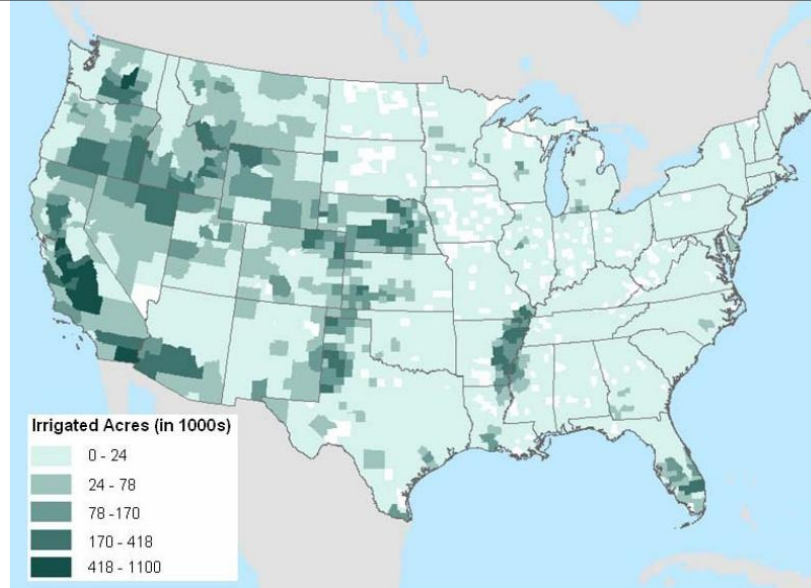
Some of the water needed to grow biofuel crops will come from rainfall, but the rest will come from irrigation from groundwater or surface water sources. The primary concern with regard to water availability is how much irrigation will be required—either new or reallocated— that might compete with water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



*FIGURE 1-1 The agricultural water cycle. Inputs to a crop include rainfall and irrigation from surface water and groundwater. Some water is “consumed” (that is, incorporated in the crop or evapotranspired), some returns to surface waterbodies for human or ecological use downstream, and some infiltrates into the ground. **Click to enlarge.***

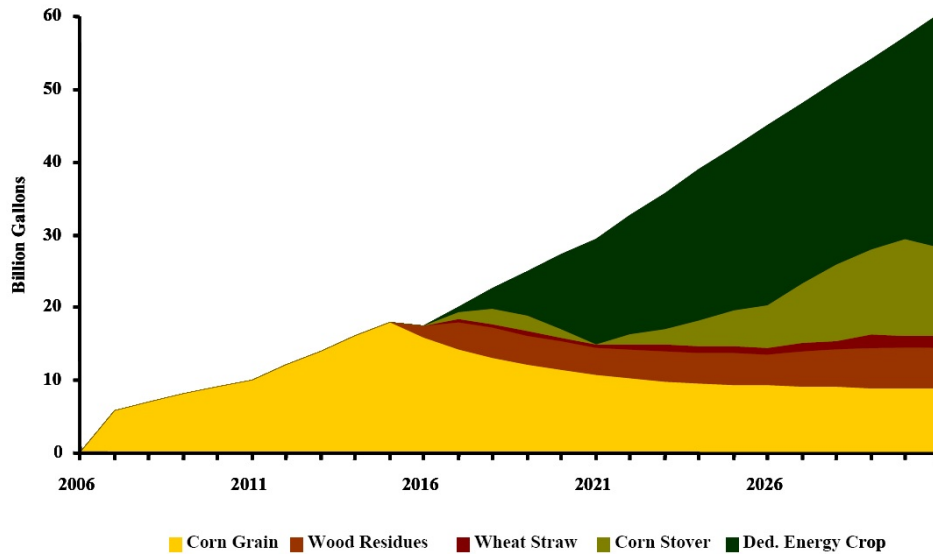
Figure 1-1 makes it clear that crop water may originate from one source, such as rain or groundwater, and be discharged to another, such as surface water. Precipitation, groundwater, and surface water sources—and groundwater and surface water discharges—are not only viewed differently in water law and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

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

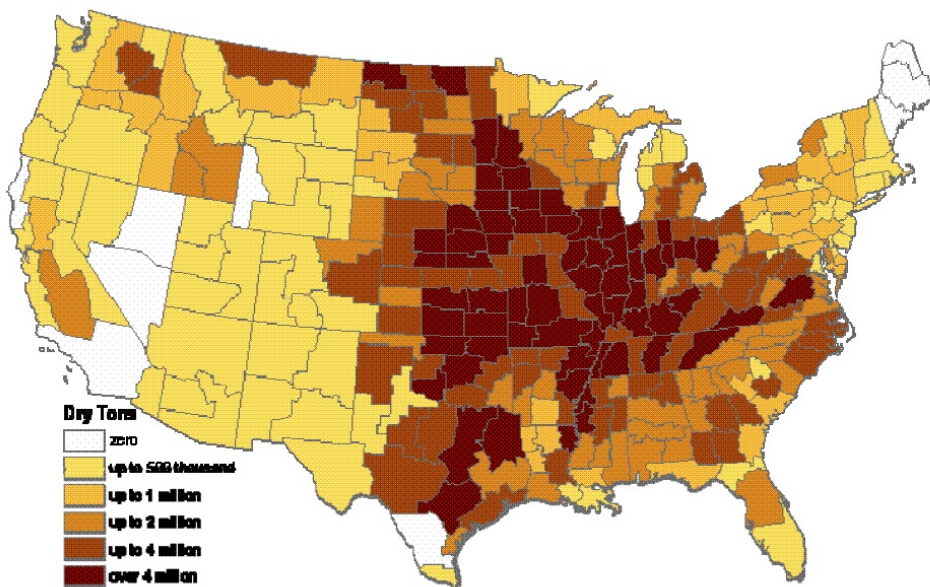


*FIGURE 1-2 Irrigated land in the United States. Note that most of this is located in the more arid regions of the country. SOURCE: N. Gollehon, USDA ERS, written commun., July 12, 2007. Based on data from U.S. Department of Agriculture (USDA) Economic Research Service (ERS) Census of Agriculture.. **Click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

Understanding water quantity impacts is dependent on understanding the agricultural water cycle depicted in Figure 1-1. Crops can be either rainfed or irrigated (see Figure 1-2). Irrigation water can come from groundwater or surface water, and groundwater can be withdrawn from either a surficial aquifer (connected directly to the surface) or a confined aquifer (overlain by a low permeability layer, or aquitard, such as clay). Some of the applied water is incorporated into the crop, but most of it leaves the fields as (1) evaporation from the soil and transpiration from plants (called evapotranspiration or ET), (2) runoff to rivers and streams (sometimes called “return flow”), and (3) infiltration to the surficial aquifer. The water that is incorporated into the crops or lost to evapotranspiration is referred to as “consumptive use,” because it cannot be reused for another purpose in the immediate vicinity. Rates of ET vary greatly by the type of crop. During a growing season, a leaf will transpire many times more water than its own weight. An acre of corn gives off about 3,000- 4,000 gallons of water each day while a large oak tree can transpire 40,000 gallons per year (USGS, 2007). Grasses that might be in cellulosic production have a slightly higher ET rate than corn, but considerably a lower ET rate than trees.



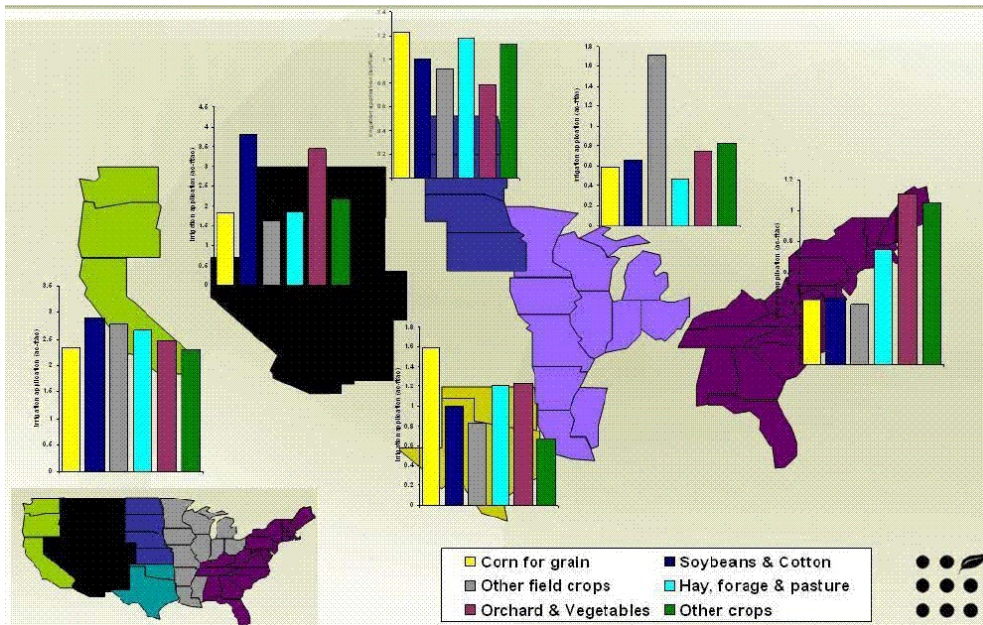
*Projection of ethanol production by feedstock assuming cellulose-to-ethanol production begins in 2015. Dedicated energy crops refer to those grown solely for energy production.*  
 SOURCE: D. Ugarte, University of Tennessee [Click to enlarge](#).



*Distribution of the production of cellulosic materials in dry tons by the year 2030.*  
 SOURCE: D. Ugarte, University of Tennessee [Click to enlarge](#).

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

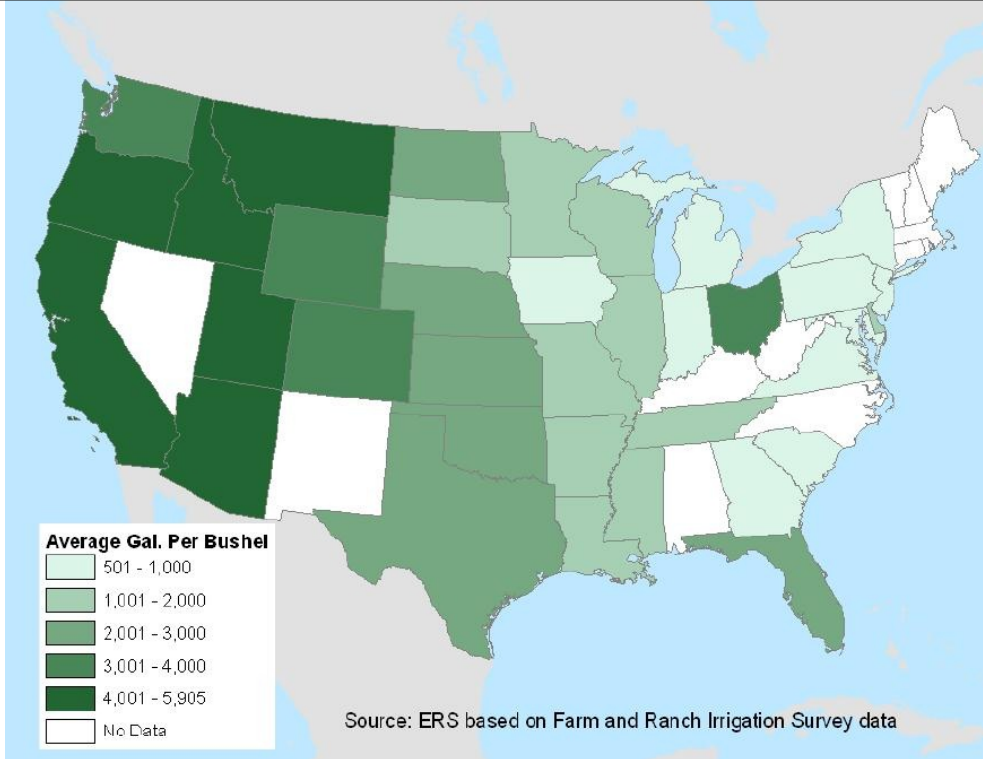
## CROP WATER AVAILABILITY AND USE



**FIGURE 2-1** Regional irrigation water application for various crops for six regions of the United States.

Irrigation application is normalized by area, and is in feet. *SOURCE: N. Gollehon, U.S. Department of Agriculture (USDA) Economic Research Service (ERS), written commun., July 12, 2007. Based on data from USDA Census of Agriculture.* **Click to enlarge.**

Shifting land from an existing crop (or noncrop plant species) to a crop used in biofuel production has the potential to change irrigation water use, and thus the local water availability. Conversion to the different type of biomass will result in increased water use in some cases, in other cases a decrease. As an example, in much of the country, the crop substitution is from soy to corn. The regional effects of this can be seen in Figure 2-1. Corn generally uses less water than soybeans and cotton in the Pacific and Mountain regions. The reverse is true in the Northern and Southern Plains, and the crops use about the same amount of water in the North Central and Eastern regions. Changes in agricultural water use would generally parallel these trends. Another example is in Northern Texas, where annual evapotranspiration (ET) rates per year for alfalfa, corn, cotton, and sorghum are estimated to be about 1,600, 760, 640, and 580 mm (63, 30, 25, and 23 inches), respectively. Therefore, regional water loss to ET will likely decrease if alfalfa acreage is converted to corn, but increase if cotton or sorghum is converted.



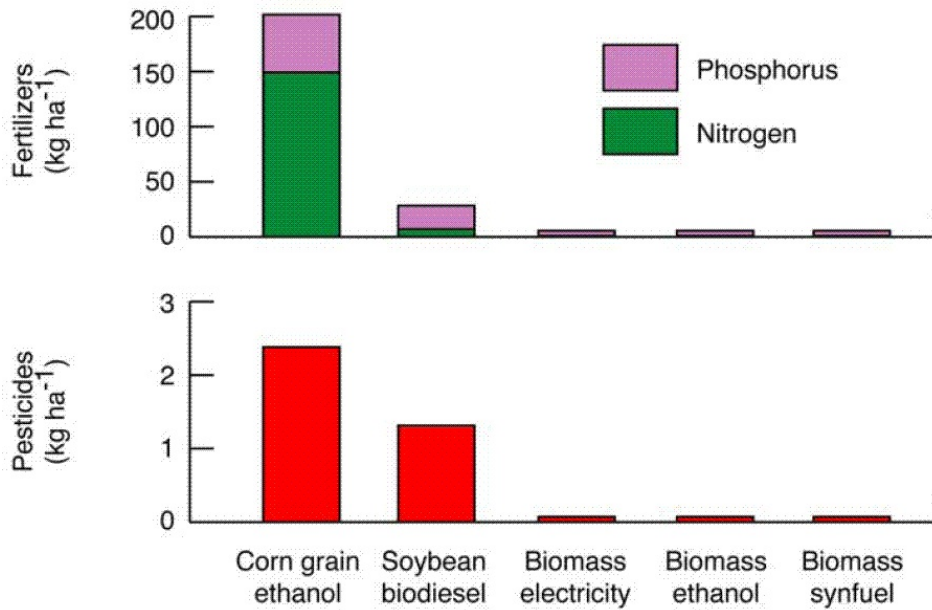
**FIGURE 2-2** State-by-state water requirements in 2003 of irrigated corn (gallons of irrigation water per bushel). *SOURCE: N. Gollehon, USDA ERS, Based on data from 2003 Farm and Ranch Irrigation Survey (USDA, 2003).*  
***Click to enlarge.***

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

In the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the national-aggregate view of water use. However, there are likely to be significant regional and local impacts where water resources are already stressed.

### **Water Quality Impacts**



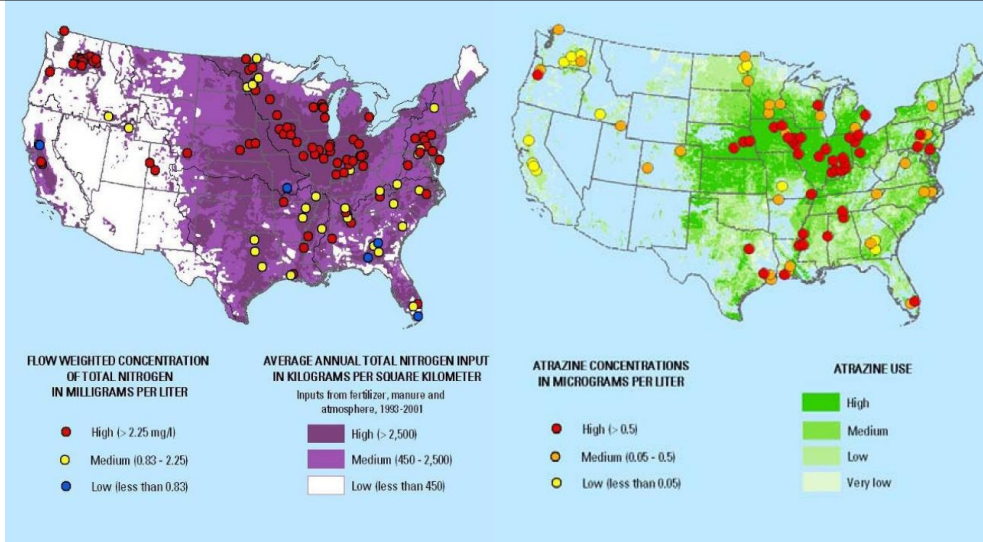


*FIGURE 3-1. Comparison of fertilizer (top) and pesticide (bottom) application rates for corn, soybean, and low-input high-diversity (LIHD; “biomass” in the figure) mixtures of native grassland perennials.*

*Fertilizer and pesticide application rates are U.S. averages. SOURCE: Tilman et al. (2006).*

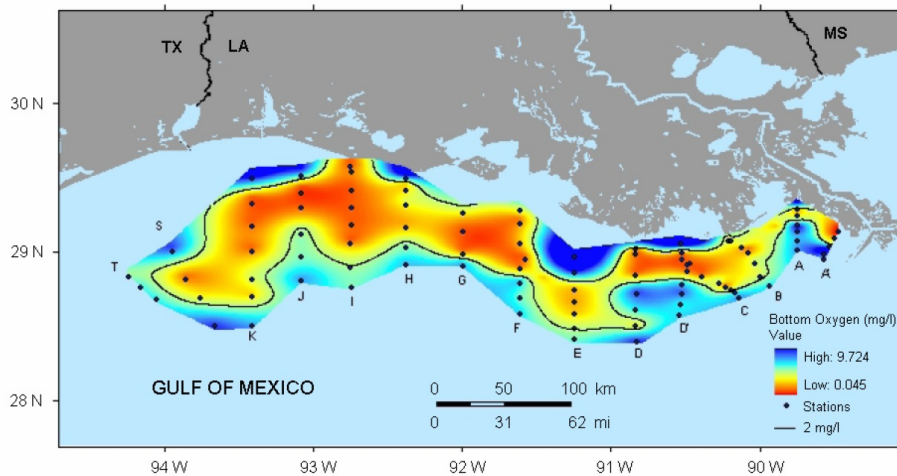
***Click to enlarge.***

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



**FIGURE 3-2** (left) N fertilization rates and stream concentrations of nitrate. (right) Atrazine application rates and stream concentrations of atrazine. **FIGURE SOURCE:** J. Ward, U.S. Geological Survey. **Click to enlarge.**

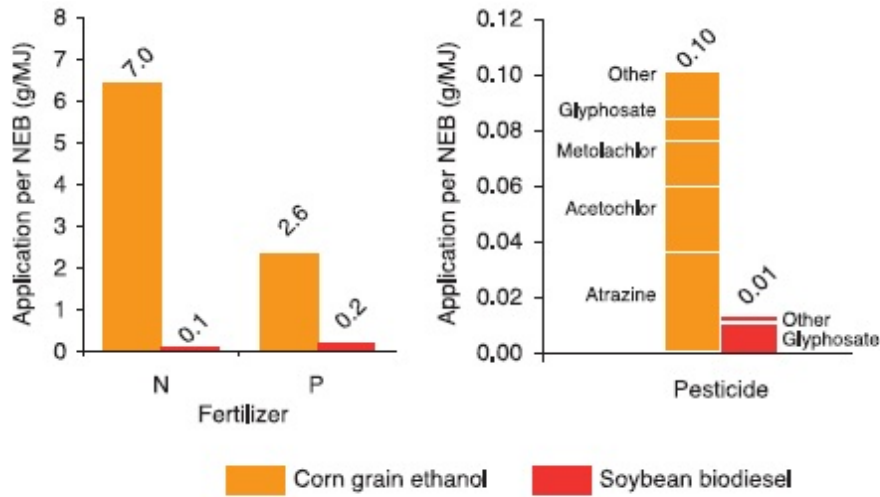
The impacts of these differences in inputs can be visualized nationally by comparing N inputs (such as fertilizer and manure) and the concentrations of nitrate in stream water (Figure 3-2, left). There are similar patterns for stream concentrations of atrazine, a major herbicide used in corn cultivation (Figure 3-2, right), although the environmental effects of pesticides in current use are difficult to decipher. Both of these maps show that regionally the highest stream concentrations occur where the rates of application are highest, and that these rates are highest in the U.S. “Corn Belt.”



**FIGURE 3-3** Dissolved oxygen contours (in milligrams per liter) in the Gulf of Mexico, July 21-28, 2007. **SOURCE:** Slightly modified from <http://www.gulfhypoxia.net/shelfwide07/PressRelease07.pdf>.

**Click to enlarge.**

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



**FIGURE 3-5** Environmental effects from the complete production and combustion lifecycles of grain ethanol and soybean biodiesel. The figure shows the application of both (a) fertilizers and (b) pesticides, per unit of net energy gained from biofuel production. SOURCE: Hill et al., 2006 [Click to enlarge](#).

There are many possible metrics, but an index that builds on the work shown in Figure 3-1 is inputs of fertilizers and pesticides per unit of the net energy gain captured in a biofuel. To estimate this first requires calculation of a biofuel’s net energy balance (NEB), that is, the energy content of the biofuel divided by the total fossil energy used throughout the full lifecycle of the production of the feedstock, its conversion to biofuel, and transport. U.S. corn ethanol is most commonly estimated to have a NEB of 1.25 to 1.3, that is, to return about 25-30 percent more energy, as ethanol, than the total fossil energy used throughout its production lifecycle. The NEB estimated for U.S. soybean biodiesel is about 1.8 to 2.0, or about a 100 percent net energy gain. Switchgrass ethanol via fermentation is projected to be much higher—between 4 and 15. Similarly high are the estimates for (a) cellulosic ethanol and (b) synthetic gasoline and diesel from certain mixtures of perennial prairie grasses, forbs, and legumes (NEB=5.5 and 8.1, respectively). Per unit of energy gained, corn ethanol and soybean biodiesel have dramatically different impacts on water quality. When fertilizer and pesticide application rates (Figure 3-1) are scaled relative to the NEB values of these two biofuels, they are

seen to differ dramatically (Figure 3-5). **Per unit of energy gained, biodiesel requires just 2 percent of the N and 8 percent of the P needed for corn ethanol.** Pesticide use per NEB differs similarly. Low input high-diversity prairie biomass and other native species would also compare favorably relative to corn using this metric. This is just one possible metric of biofuels' impact on water quality. Other measures might incorporate land requirements per unit of biofuel, soil erosion, or impacts of the associated biorefinery

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

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

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

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

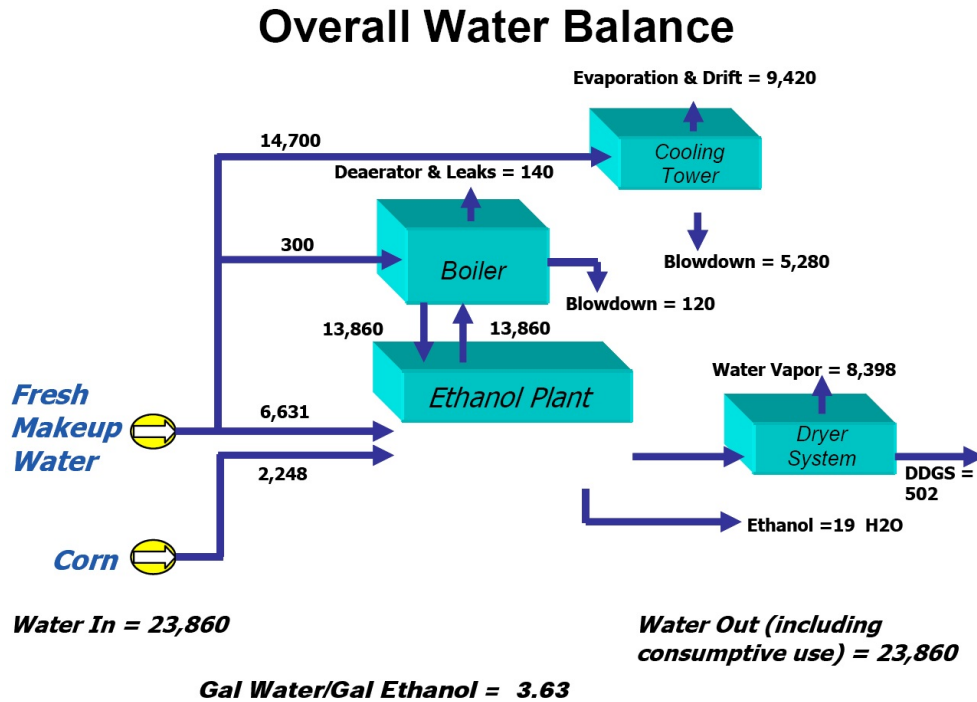
## **REDUCING WATER IMPACT THROUGH AGRICULTURAL PRACTICES**

There are many agricultural practices and technologies that, if employed, can increase yield while reducing the impact of crops on water resources. Many of these technologies have already been developed and applied to various crops, especially corn, and they could be applied to cellulosic feedstocks. Technologies include a variety of water-conserving irrigation techniques, soil erosion prevention techniques, fertilizer efficiency techniques, and precision agriculture tools that take into account site-specific soil pH (acidity, alkalinity), soil moisture, soil depth, and other measures. Best Management Practices (BMPs) are a set of established methods that can be employed to reduce the negative environmental impacts of farming. Such practices can make a large, positive environmental impact. For example, in 1985, incentives were put in place to encourage adoption

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of conservation tillage practices. According to data from the National Resources Inventory (NRI), maintained by the Natural Resources Conservation Service, overall annual cropland erosion fell from 3.06 billion tons in 1982 to about 1.75 billion tons in 2003, a reduction of over 40 percent (<http://www.nrcs.usda.gov/TECHNICAL/NRI/>).

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

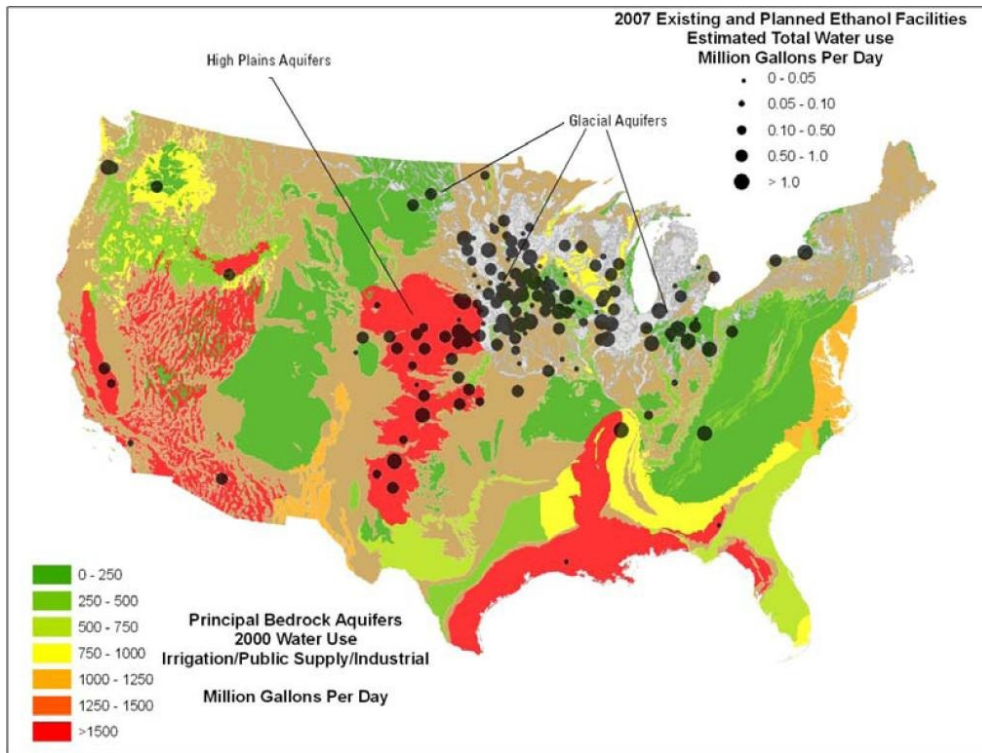
## WATER IMPACTS OF BIOREFINERIES



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

**Click to enlarge.**

Assuming the common figure of about 2.7 gallons of ethanol from one bushel of corn, 2,100 gallons of water/bushel \* 1 bushel/2.7 gallon of ethanol = about 780 gallons of water per gallon of ethanol. (Additionally), current estimates of the consumptive water use from biorefinery facilities are in the range of 4 gallons of water per gallon of ethanol produced (gal/gal) (Pate et al., 2007). For perspective, consumptive water use in petroleum refining is about 1.5 gal/gal. Overall water use in biorefineries may be as high as 7 gal/gal, but this number has been consistently decreasing over time and as of 2005 was only slightly over 4 gal/gal in 2005. Thus for a 100 million gallon per year plant, a little over 400 million gallons of water per year would be withdrawn from aquifers or surface water sources (1.1 million gallons per day). The total water requirements for ethanol from cellulose are thought to be large—about 9.5 gal/gal, but this likely will decline as efficiency increases with experience at cellulosic-ethanol plants.



*Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000. [Click to enlarge.](#)*

Siting of some ethanol plants is occurring where the water resource is already under duress. Figure 5-3 shows, for example, that many bioethanol plants that each require 0.1-1.0 million gallons per day are located on the High Plains aquifer. This aquifer is currently being pumped at a rate of more than 1.5 billion gallons per day for agriculture, municipalities, industry, and private citizens. Thus, 15 million gallons per day for bioethanol would represent only 1% of total withdrawals. But it is an incremental withdrawal from an already unsustainable resource. Current water withdrawals are much greater than the aquifer's recharge rate 0.02 to 0.05 foot per year in south-central Nebraska, resulting in up to 190-foot decline in the water table over the past 50 years. It is equivalent to "mining" the water resource, and the loss of the resource is essentially irreversible.

All biofuel facilities require process water to convert biomass to fuel. Water used in the biorefining process is modest in absolute terms compared to the water applied and consumed in growing the plants used to produce ethanol. However, because this water use is concentrated into a smaller area, its effects can be substantial locally. A biorefinery that produces 100 million gallons of ethanol per year would use the equivalent of the water supply for a town of about 5,000 people. Consumptive use of water in biorefineries is largely due to evaporation losses from cooling towers and evaporators during the distillation of ethanol following fermentation. However, consumptive use of water is declining as ethanol producers increasingly incorporate water recycling and

develop new methods of converting feedstocks to fuels that increase energy yields while reducing water use.

<u>Constituent</u> <sup>1</sup>	<b>Siouxland Ethanol Facility (Sioux Center, IA)</b>		<b>Little Sioux Ethanol Facility <i>Simulated Blowdown</i></b>	
	<u>Raw GW</u>	<u>Big Sioux RO Reject Water</u>	<u>Surface Water</u>	<u>Tower Eff.</u>
<i>TDS</i>	<i>2,113</i>	<i>7,288</i>	<i>703</i>	<i>3,240</i> <sup>2</sup>
Ca <sup>2+</sup>	305	1,033	129	638
Mg <sup>2+</sup>	138	458	58	185
K <sup>+</sup>	0	0	2	33
Na <sup>+</sup>	148	485	20	297
Cl <sup>-</sup>	23	131	35	27
SO <sub>4</sub> <sup>2-</sup>	1,420	4,716	107	2,265

<sup>1</sup>Concentrations in milligrams per liter.

<sup>2</sup>Concentration in milligrams per liter as CaCO<sub>3</sub>.

SOURCE: Parkin (2007)

*Water Quality of Waste Streams from Two Existing Ethanol Facilities in Iowa*  
[Click to enlarge.](#)

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

## KEY POLICY IMPLICATIONS

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

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

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

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

## CONCLUSIONS

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

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

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

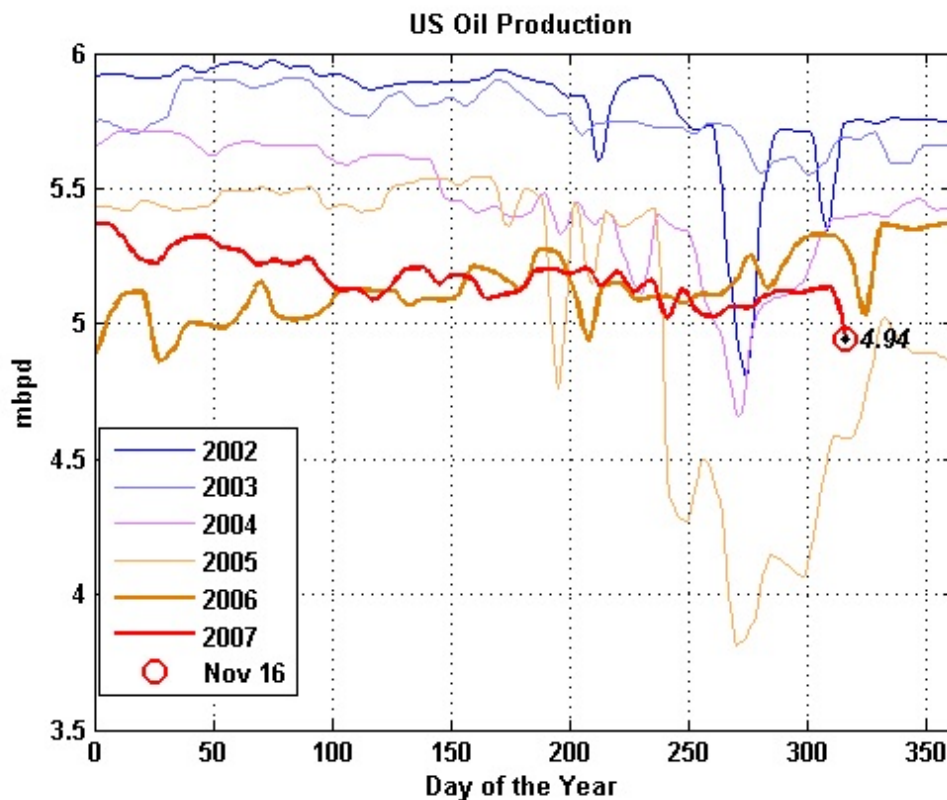
To move toward a goal of reducing water impacts of biofuels, a policy bridge will likely be needed to encourage development of new technologies that support cellulosic fuel production and develop both traditional and cellulosic feedstocks that require less water and fertilizer and are optimized for fuel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



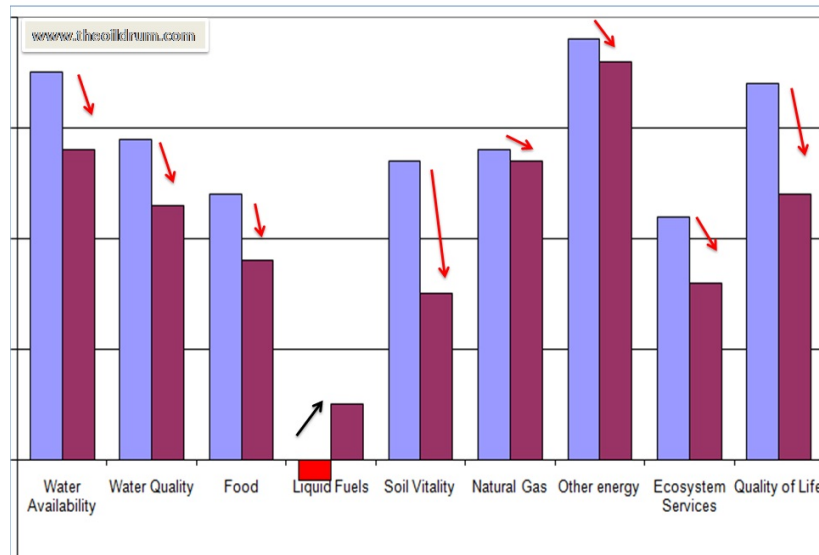
## THE BOTTOM LINE

As discussed often here in the past, biofuels not only have a much lower energy return vis-a-vis conventional crude, but have between one and two orders of magnitude lower in power density, (or how much energy we get per unit of land). Furthermore, in our 'Burning Water' paper, (and alluded to here in this NAS report), biofuels also require significantly more water than even the least efficient fossil fuel systems. There are also concerns about pesticides, nitrate and other environmental impacts. So when replacing energy with a 'substitute', all other things do not usually remain equal. I commend the National Academy scientists for highlighting what will be a central issue in upcoming natural resource science - that of systems, and tradeoffs.

It is highly likely we will have liquid fuel shortages in the not too distant future, either via higher prices, or through actual unavailability or rationing. The chart below (thanks Khebab) shows the progression of year over year declines, in different colored lines, of United States oil production. The trend is reasonably clear. We have found the cheap and easy oil.



### AN INCREASE IN LIQUID FUELS AT WHAT COST?



Energy and water are but 2 of the central inputs that power our modern society. Many of the key resources are either not currently valued by the market system, or may give too late a market signal of scarcity for effective mitigation. The figure above (not from the NAS report..) gives a conceptual example of potential tradeoffs that a concerted efforts to increase liquid fuel production (or any limiting variable that has linkages to other limiting inputs) might engender. The columns on the left in blue (and red) are when we are in a perceived liquid fuels shortfall. The columns in purple are hypothetical amounts of resources remaining after a portion has been devoted to an 'increase liquid fuel policy'. Focusing on the limiting input du-jour risks pulling in more resources from the periphery which are currently non-limiters. As can be visualized, successful addition of the variable in shortage may come at a cost, which might not be immediately visible or financially recognized, but a cost nonetheless.

We CAN increase our internal production of transportation liquids. In addition to ethanol and biodiesel, we can use coal-to-liquids via Fischer Tropsch; we can drill the Arctic or Alaska Wildlife Refuge; we can expand land to dedicated energy crops, etc. A joint study of the U.S. Department of Energy and the U.S. Department of Agriculture concludes that the United States could produce 60 billion gallons of ethanol by 2030 through a combination of grain and cellulosic feedstocks, enough to replace 30% of projected U.S. gasoline demand. Scientists and policymakers should be asking them 'at what cost'? When they reply XX billions, the comeback should be 'we didn't mean in \$ terms-what are the costs in other scarce inputs needed by society?'. In robbing Peter to pay Paul, we have to realize that Paul is pretty insatiable. Who will we rob after Peter?

The subject of the origins of exponential growth, habituation and "Pauls" addiction to oil will be the subject of next weeks post.



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