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## THE ENERGY-WATER COLLISION

# Corn Ethanol's Threat to Water Resources



**P**OLLUTION FROM CORN FARMING is a leading cause of water quality problems in the Upper Mississippi River watershed, polluting drinking water in agricultural areas and degrading rivers and lakes, while also expanding the Gulf of Mexico's "dead zone" (a large area deprived of oxygen). These problems—and their associated economic and health impacts—are exacerbated by government policies that increase

demand for corn ethanol, in turn expanding U.S. corn production. Better agricultural practices that keep fertilizer out of freshwater can mitigate the water quality problems associated with corn cultivation and corn ethanol production, but if we want to protect water quality while also reducing U.S. oil dependence, biofuel production must move beyond corn to more diverse and environmentally friendly crops and waste materials.

### The Corn Belt and Mississippi River Basin

The Mississippi-Atchafalaya River Basin drains 31 states that cover 40 percent of the contiguous United States (Figure 1) (Committee on Environment and Natural Resources 2010). The Corn Belt states of Illinois, Indiana, Iowa, Kansas, Minnesota, Nebraska, Ohio, and South Dakota grow more than three-quarters of the corn grown in America. This corn is used for livestock feed, processed food, and ethanol, which is produced in more than 100 facilities in these states (Figure 2, p. 2) (NASS 2011; RFA 2011). Over the last decade the share of corn grown for ethanol rose from 5 percent to 40 percent.\* Ethanol accounts for the vast

majority of the overall growth in corn production over the same period (Figure 3, p. 2) (ERS 2010).

This increase in corn production—and the fertilizer use associated with it—has implications for water quality from the Corn Belt to the Gulf of Mexico. Rains wash nitrogen and phosphorus pollution from farm fields into creeks, then small rivers, large rivers, and ultimately the ocean. Along the way this pollution contributes to algae blooms in lakes and streams as well as in the Gulf of Mexico, where the algae causes a seasonal dead zone that threatens important fisheries (Rabalais et al. 2010).

\* The leftovers of the ethanol production process, called distillers grains, are typically sold as animal feed. Eliminating the corn that becomes distillers grains from the total grown for ethanol production results in a figure of 25 percent for the share of the U.S. corn crop that goes directly into ethanol.

**FIGURE 1 The Mississippi River Basin and the Gulf of Mexico "Dead Zone"**

The Mississippi River basin drains 40 percent of the contiguous United States including the entire Corn Belt. The outlet, near New Orleans, delivers the high levels of nitrogen and phosphorus pollution that are responsible for the seasonal dead zone.



## Conventional Corn Production

In the Corn Belt, cornfields are typically bare (other than leftover husks and stalks) between the October harvest and early summer of the following year, when new plants begin to grow (NASS 2010). For more than half the year there are no growing plants to hold on to nutrients or shield the soil from erosion, so by the time snowmelt and harsh spring rains arrive, they do significant damage by washing both fertilizer and sediment into waterways.

Rainfall that is not absorbed by the soil becomes runoff, carrying with it dissolved nitrogen and phosphorus from fertilizer and manure, along with topsoil. Additionally, many Corn Belt farms use artificial drainage that facilitates the movement of nitrogen pollution, especially in the form of nitrate, from fields to waterways (see the text box “Drainage Problems and Solutions”).

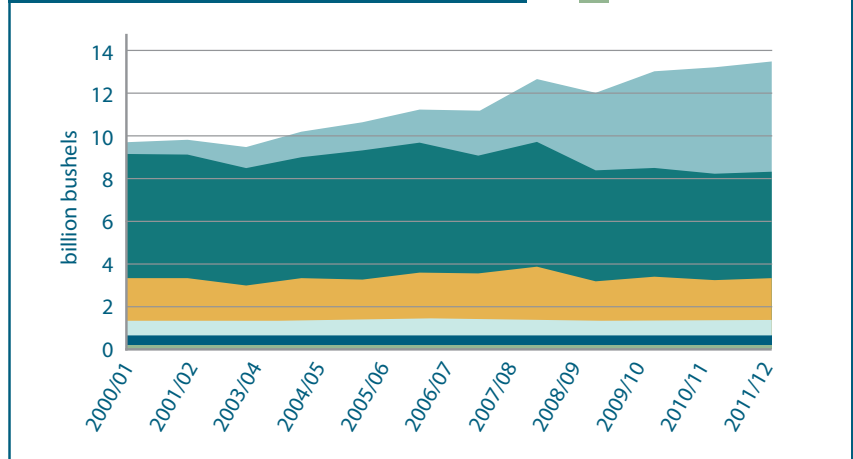
While many fertilized crops contribute to the problem, corn—a particularly resource-intensive crop—is the leading culprit. Corn is planted

*continued on page 4*

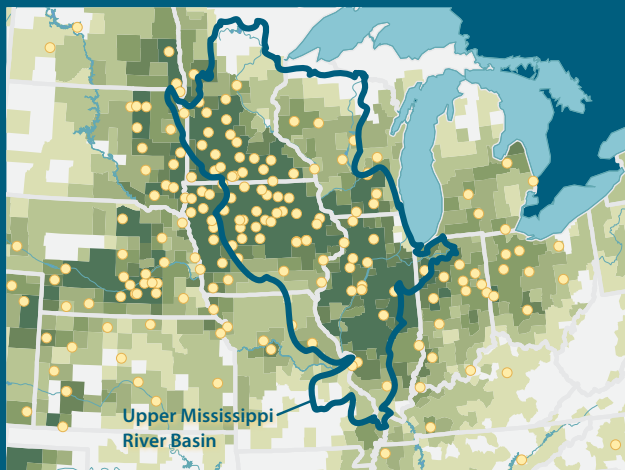
**FIGURE 3 Trends in Use of U.S. Corn for Ethanol and Other Purposes**

Ethanol has grown from a minor use of corn to the largest single use over the last 10 years.

Source: ERS 2011a.



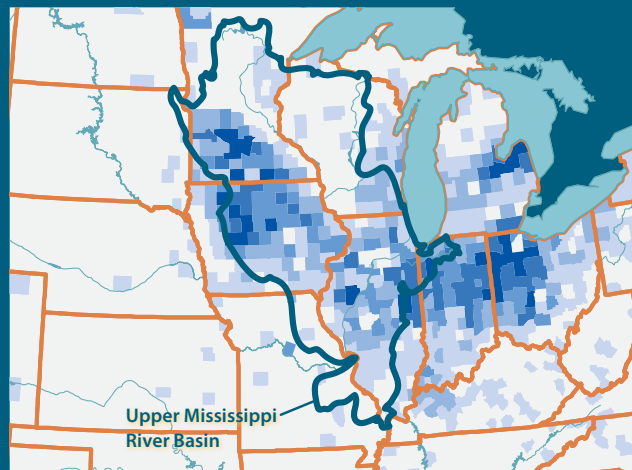
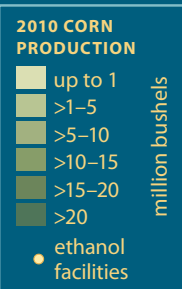
**Corn is the leading source of nitrogen pollution, and corn ethanol accounts for the vast majority of the growth in corn production over the last 10 years.**



**FIGURE 2 U.S. Corn and Ethanol Production**

Corn and ethanol production are highly concentrated in the Corn Belt.

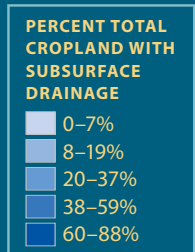
Data sources: California Biomass Collaborative 2011; NASS 2011.



**FIGURE 4 U.S. Land with Subsurface Tile Drainage**

Tile drains have been installed for a century in the Upper Mississippi River Basin, where they increase crop yields and loss of nitrogen into surface waters.

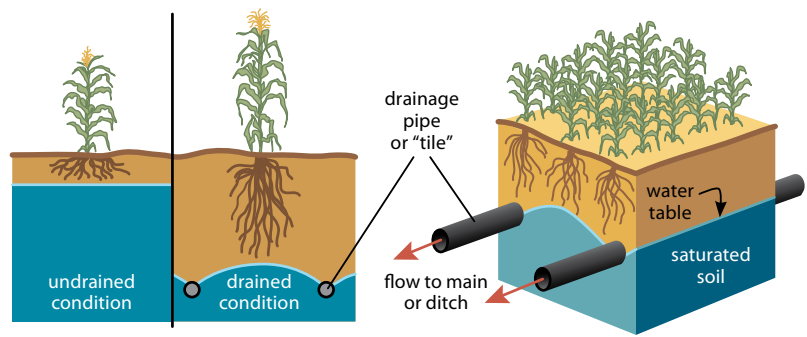
Data source: Sugg 2007.



## Drainage Problems and Solutions

Some of the most productive land in the Corn Belt was once wetlands that were drained over the last century to increase available cropland and improve yields (Figure 4). Perforated plastic pipes or “tiles” buried two to four feet under the surface draw water away from plant roots into ditches or streams (Figure 5) (Blann et al. 2009); these so-called tile drains increase crop yield but also dramatically speed the flow of pollutants into surface waters. Because tile-drained land is both highly productive and highly “leaky,” it is responsible for a disproportionate amount of nitrogen pollution in the Upper Mississippi Basin (Figure 6) (David, Drinkwater, and McIsaac 2010).

Strategies to mitigate this pollution from tile drainage include the planting of cover crops that can absorb excess fertilizers in the soil, more complex crop rotations that reduce the need for chemical fertilizers, and construction of bioreactors (filters made of wood chips) in drain lines (Schipper et al. 2010) or wetlands constructed at drain outlets in order to remove nitrate at the edge of the field (before it can escape into surface waters) (Crumpton et al. 2005). Strategies for stopping erosion and limiting losses of



**FIGURE 5 How Tile Drainage Works**

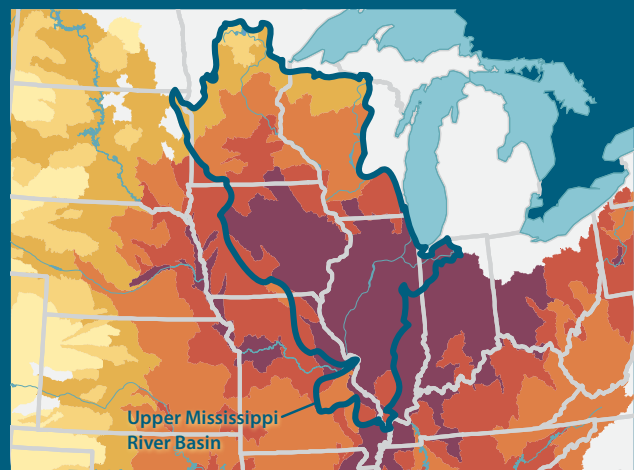
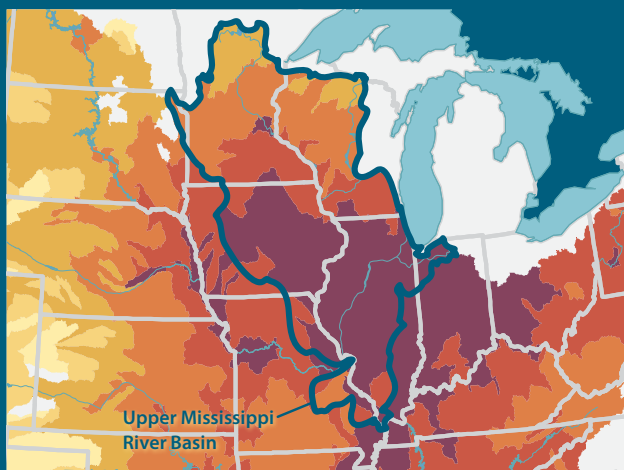
**Tile drainage speeds drainage and lowers the water table, which improves crop yields but also increases loss of nitrogen into surface waters.**

Source: Courtesy of University of Minnesota Extension Service (adapted with permission).

sediment, nitrogen, and phosphorus from the surface of fields include planting grass in areas prone to erosion, changing the orientation of crop rows to follow the contour of the land, and adding terraces and grass buffers between crops and waterways.

According to U.S. Department of Agriculture models, conservation measures have been able to reduce surface nitrogen losses by 46 percent in the Upper Mississippi River Basin, but have only reduced nitrogen losses in subsurface flow by 5 percent. This points to the need for greater investment in targeted

“edge-of-field” treatments that capture pollution from drainage systems before it enters surface water. Widespread adoption of best practices, which could significantly improve water quality, will require robust funding, administration, and enforcement of agricultural conservation programs. But these practices alone are not always sufficient, and shifting to less polluting crops is still the most effective means of mitigating pollution problems. Meeting watershed protection goals may therefore require taking the most vulnerable acres out of corn production (NRCS 2010).



### TOTAL NITROGEN DELIVERED (INCREMENTAL YIELD)



**FIGURE 6 Nitrogen and Phosphorus Delivery to the Gulf of Mexico**

A combination of tile drainage and intensive corn production results in regional “hot spots” that are responsible for the lion’s share of nitrogen pollution and a large share of phosphorus.

Data source: Alexander et al. 2008.

### TOTAL PHOSPHORUS DELIVERED (INCREMENTAL YIELD)

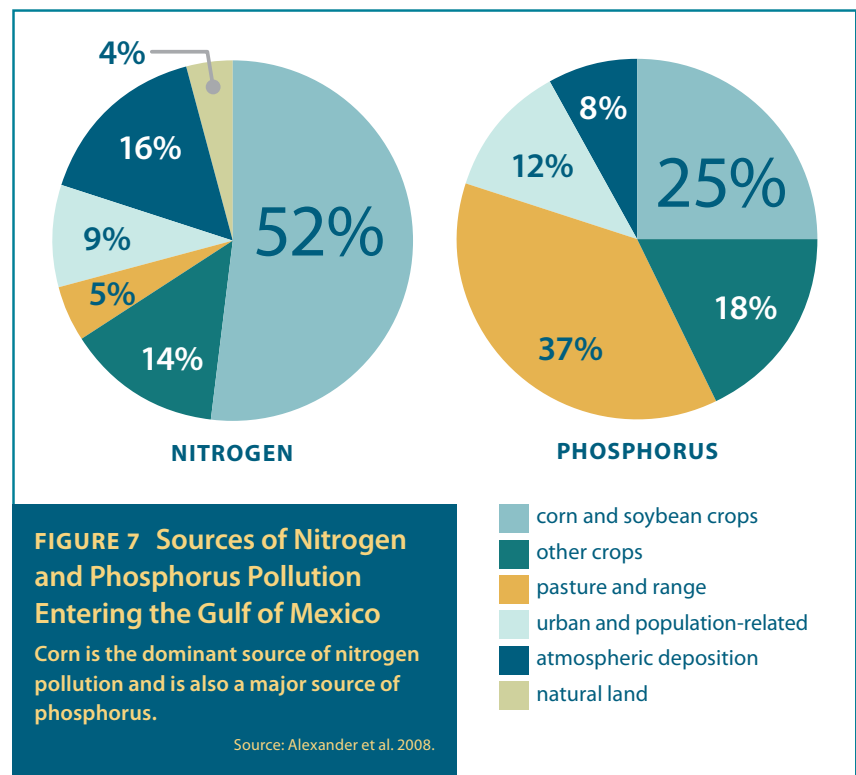


on less than 23 percent of U.S. cropland (USDA 2009), but receives 40 percent of the fertilizer (ERS 2011b). Best practices for the timing and application of fertilizer can reduce water pollution, but these practices are not consistently followed. For example, according to a recent U.S. Department of Agriculture assessment of conservation practices in the Upper Mississippi River Basin, 62 percent of the farmland there requires improved management of fertilizers to address excessive losses of nitrogen and phosphorus. Planting a winter cover crop could help reduce erosion and provide fertilizer uptake year-round, but cover crops are currently used on less than 1 percent of the basin's acres (NRCS 2010).

### Water Resources at Risk

**Groundwater.** Nitrogen and pesticides applied to farm fields get into streams and the shallow groundwater that many rural households rely on for drinking water. The U.S. Geological Survey (USGS) found elevated levels of nitrate and pesticides in the shallow groundwater of more than half of America's rural watersheds (Dubrovsky et al. 2009; Sullivan et al. 2009). In more than 20 percent of these watersheds, the groundwater was unsafe to drink according to U.S. Environmental Protection Agency (EPA) standards due to high levels of nitrate (EPA 2008)—a potential risk factor for cancer, reproductive problems, and methemoglobinemia or “blue-baby syndrome,” which interferes with oxygen transport in the blood of infants (Townsend et al. 2003).

**Streams and lakes.** The EPA found high levels of phosphorus contamination in 31 percent of the nation's streams and high levels of nitrogen contamination in 32 percent of streams; agriculture is the largest source of this pollution by far (EPA 2008). Thirteen percent of these streams were unsafe for drinking due to nitrate. Reducing nitrate



concentrations to safe levels requires treatments that are expensive and consume a great deal of energy (Twomey, Stillwell, and Webber 2010). Furthermore, the USGS found that all streams in agricultural watersheds contain some pesticides, and 57 percent had at least one pesticide present at a level the EPA deems unhealthy for aquatic life (EPA 2008).

Nitrogen and phosphorus escaping from farms are also a threat to lakes because elevated levels stimulate the growth of algae (through a process called eutrophication) and, on occasion, toxin-producing microorganisms. The result is slimy green water, altered aquatic vegetation, loss of fish habitat, and fish kills (Hudnell 2008). Corn farming is responsible for much of this pollution in the Mississippi River Basin: it is the dominant source of nitrogen pollution and the second-largest source of phosphorus pollution after animal manure on pasture and rangelands (Figure 7) (Alexander et al. 2008).

Algae blooms also decrease the beauty and usability of lakes. A recent study found that the cost of

eutrophication in lakes and rivers exceeds \$2 billion a year; while many of the costs are hard to measure precisely, the most significant are associated with reduced property values along lakefronts and lost recreational use (Dodds et al. 2009).

**The Gulf of Mexico.** Just as in lakes upriver, nitrogen and phosphorus flowing into the Gulf of Mexico stimulate algae growth. When the algae die and decompose, oxygen in the water is consumed, leading to severe oxygen depletion or hypoxia, which either kills fish and other marine life or forces them to seek more suitable habitats. The resulting dead zone peaks in size each summer; over the last five years it has averaged more than 6,000 square miles—larger than Connecticut. The lack of oxygen threatens not only aquatic species but also the gulf's \$2.8 billion-a-year commercial and recreational fishing industry (Committee on Environment and Natural Resources 2010).

Corn and soybean crops contribute half the nitrogen and a quarter of the phosphorus that cause the

dead zone (Figure 7) (Alexander et al. 2008). These crops are counted together because corn and soybeans are typically grown in rotation, but corn is the more heavily fertilized of the two, accounting for essentially all the nitrogen (97 percent) and most of the phosphorus (80 percent) applied (ERS 2011b). A coordinated effort by state and federal agencies to restore the health of affected marine fisheries and ecosystems in the gulf has set a target to reduce the average size of the dead zone by more than two-thirds (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2009).

### Corn's Role in Climate Change

The heavy use of nitrogen fertilizer associated with agriculture in general, and corn production in particular, is a significant source of the heat-trapping emissions responsible for global warming (Smith et al. 2007). In addition to the direct impact corn production has on our climate, the expanded use of corn for ethanol production has an indirect impact on land use globally, which exacerbates the problem (ERS 2011c). As forested land around the world is converted to agriculture in order to meet the increasing demand for food and fuel crops (West 2010), the trees that are cut down represent a potentially very large source of heat-trapping emissions (though the exact amount is difficult to project with a high degree of certainty) (Plevin et al. 2010).



### Corn Expands into the Mississippi Delta

While the lion's share of America's corn is grown in the Corn Belt, the expansion of ethanol production is having spillover effects elsewhere. For example, the USGS has found that the ethanol boom is shifting planting in the Mississippi Delta (in northwestern Mississippi) away from cotton and

toward corn. Because corn requires more irrigation and more nitrogen fertilizer than cotton, the shift will likely threaten the sustainability of the region's groundwater resources, both in terms of water level and nitrate pollution (which contributes to the nitrate entering the Mississippi River and ending up in the Gulf of Mexico) (Welch et al. 2010).

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## More intensive corn production means higher rates of fertilizer application and, with it, the potential for higher losses of nitrogen and phosphorus into ground and surface waters and, ultimately, the Mississippi River and Gulf of Mexico.

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### The Impacts of High Ethanol Demand

#### More intensive corn production.

Corn production has been increasing rapidly in recent years due primarily to the demand for ethanol (Figure 3). More demand for corn ethanol means higher prices for corn, which translates into changes in agricultural practices. For example, the corn-soybean rotations that were typical in the Corn Belt have given way to more intensive corn production, with either two years of corn between soybean plantings, or continuous corn (Secchi et al. 2009). More intensive corn production means higher rates of

fertilizer application and, with it, the potential for higher losses of nitrogen and phosphorus into ground and surface waters and, ultimately, the Mississippi River and Gulf of Mexico (Helmets et al. 2011; Secchi et al. 2011; Donner and Kucharik 2008).

Higher corn prices also lead to corn being planted on highly erodible and marginally productive land that had been set aside for natural vegetation under the federal Conservation Reserve Program for the past 10 years or more. Bringing this land back into production has a significantly negative impact on erosion, soil carbon, and wildlife habitat (Secchi et al. 2009).

Even after the corn has been processed into ethanol, the problems associated with excess nitrogen and phosphorus remain. Only the starch in the corn kernel is converted into fuel, leaving behind the fiber, protein, and nutrients—a product called distillers grains that is fed to livestock, poultry, and fish. Because the act of removing the starch concentrates the nutrients in this animal feed compared with whole corn, the animals' manure will be phosphorus-rich and, if used as fertilizer, will further increase phosphorus pollution in surface waters (Simpson et al. 2008).

### Potential removal of corn stover.

Corn stover, the leaves and stalks left behind after corn is harvested, is generally left on fields or, in some cases, used as animal feed, but it could supply large quantities of biomass for renewable electricity or next-generation cellulosic biofuels. This potentially large and untapped fuel source (DOE 2011; Graham et al. 2007) is also attractive because using both the corn kernels and corn stalks to make ethanol could allow more fuel to be extracted from fewer acres.

However, because corn stover and other crop residues play a critical role in maintaining soil health, removing it from fields could exacerbate the water quality problems associated with corn production. Residues reduce erosion, provide nutrients for the following year's crop, and build carbon into the soil. When they are removed, therefore, erosion increases, more fertilizer must be applied to make up for lost nutrients, and nutrient runoff worsens because chemical fertilizers are less stable than the nutrients in crop residues (Marshall and Sugg 2009). In some circumstances a portion of the stover can be removed without problems, especially in conjunction with additional conservation practices such as winter cover crops.

In reviewing the implications of biofuel production on the Gulf of Mexico dead zone, the National Research Council concluded that, "The potential for additional corn-based ethanol production to increase the extent of these hypoxic regions is considerable" (NRC 2008). A study cited in that report found that expanded production of corn ethanol to meet government biofuel mandates would increase nitrogen pollution in the Mississippi River by 10 to 18 percent and would make it much more difficult to meet the nitrogen pollution reduction targets the government has set to restore health to the gulf (Donner and Kucharik 2008). Another study found that meeting government biofuel mandates using corn ethanol and cellulosic ethanol made from corn stover would

increase nitrogen pollution in the gulf by more than 25 percent compared with producing the same amount of fuel from switchgrass, again making the pollution reduction targets for the gulf much harder to meet (Costello et al. 2009).

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## Diverse sources of biofuel would reduce the pressure on corn production while expanding the geographic scope of the resources available to make biofuel.

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### Strength in Diversity

Expansion of biofuels should proceed at a pace consistent with the capacity of our agricultural system to produce food and fuel while protecting the water resources we need for drinking, fishing, recreation, and wildlife habitat. Improvements in management practices can reduce the environmental burden of existing agricultural production, but expanded biofuel production will require better biofuels—that is, we must look beyond corn ethanol.

Because the water quality problems caused by corn ethanol arise from the extreme concentration of corn production in the Corn Belt, the solution lies in diversity. Clean cellulosic biofuels can be produced from perennial grasses (such as

switchgrass), wood waste, and even ordinary household garbage (although this has not yet been done at a commercial scale). Diverse sources of biofuel would reduce the pressure on corn production while expanding the geographic scope of the resources available to make biofuel (DOE 2011). And commercializing the necessary technologies would allow advanced biofuels to be produced across the country, providing economic opportunities and reducing the impacts currently associated with producing biofuels from a single crop.

To make the most of these opportunities, the United States should support the first commercial-scale cellulosic biofuel production facilities with loan guarantees, tax credits, and policies that reward plant owners for producing cleaner, more sustainable fuels (Martin 2010). The United States should also seek to diversify its agricultural lands by encouraging the use of perennial energy crops and crop rotations that reduce fertilizer use and pollution. Perennial grasses already play a prominent role in conservation practices, and can play a similarly prominent role in an expanded market for bioenergy and biofuel. Advanced biofuels made from such environmentally friendly crops offer a path away from intensive corn production and toward dramatically reduced heat-trapping emissions (compared with either corn ethanol or gasoline) (Martin 2010), better water quality, economic opportunities for rural communities inside and outside the Corn Belt, and less dependence on oil.



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