

Ethanol and the Environment: Delivering on the Promise of a Sustainable Biofuel

By Nathanael Greene*

Introduction

The United States has just 3 percent of the world's oil reserves, and domestic production has been declining since 1970. Demand is soaring—driven largely by the transportation sector, which is 97 percent reliant on oil. As a result, we are forced to import 60 percent of our oil, and by 2025, we will import nearly 70 percent. Our dependence funnels billions of dollars to shaky and hostile regions, and defense and foreign policy experts increasingly point to our oil addiction as a national security emergency.

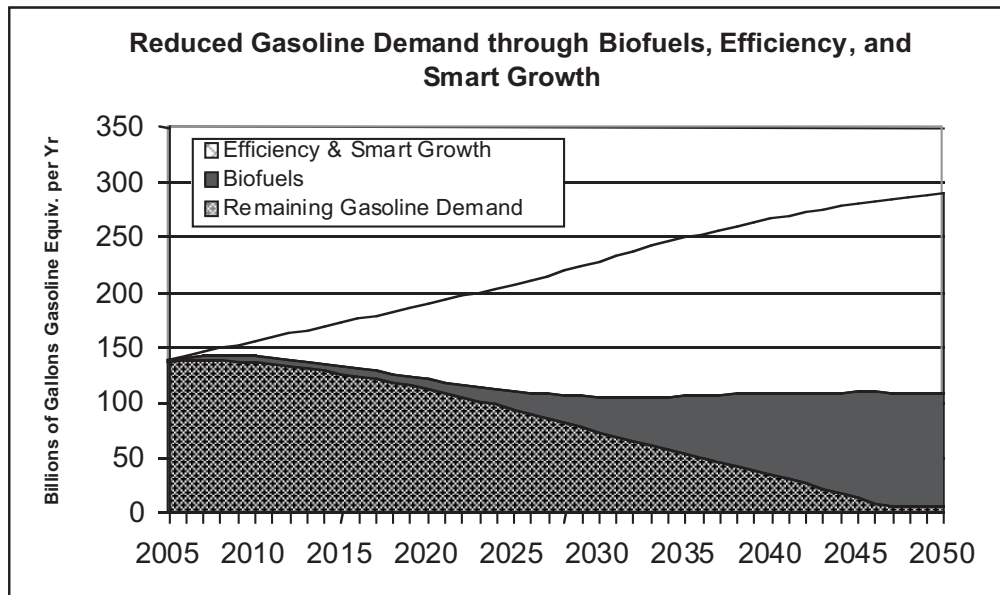
In addition America's cars, trucks, and buses account for 27 percent of U.S. global warming pollution, as well as soot and smog that damage human lungs, and oil price spikes have preceded each of the major recessions over the last 30 years. Oil is the Achilles' heel of America's security and economy and threatens the environment we want to leave to our children.

Biofuels, especially ethanol derived from the cellulosic part of plants rather than just the starch, are the most promising alternative fuels for the transportation sector. Replacing oil with biofuels would allow us to reinvest billions of dollars in our factories and farms. If we start now on an aggressive plan to develop and deploy advanced biofuels by 2050:

* *Nathanael Greene is Senior Policy Analyst at the Natural Resources Defense Council.*

- Cellulosic biofuels can displace nearly 8 million barrels of oil per day—nearly equal to all of the oil used by light-duty vehicles today;
- Biofuels can be second only to vehicle fuel economy improvements in the amount of oil they save;
- Biofuels, vehicle efficiency, and smart growth could eliminate virtually all our demand for gasoline; and
- Biofuels could reduce global warming pollution by 1.7 billion tons per year—22 percent of total U.S. emissions in 2002.

Figure 1. Biofuels Can Help Eliminate Our Demand for Gasoline by 2050.¹



Biofuels can make this contribution based on just the land already used to grow crops while we continue to meet our other existing agricultural demands. Furthermore, growing the biomass needed to make biofuels could help dramatically reduce the environmental footprint of agriculture.

The bottom line is that there are pathways on which biofuels can make a major contribution to reducing our dependency on oil in a sustainable way. However there are also many pathways that are not sustainable. To understand the full promise of advanced biofuels

and identify the policies necessary to realize this promise quickly and sustainably, it is crucial to understand the potential environmental impacts—positive and negative—associated with making and using biofuels.

There are three sets of environmental impacts that deserve particular attention. First, to make biofuels, we must first grow the biomass that will be the feedstock, and managing feedstock resources can impact the environment in many ways. Second, the amount of non-renewable energy and greenhouse gases must be accounted for and are most appropriately accounted for on a lifecycle basis. And third, we need to consider the air quality impacts of using biofuels in our cars and light-duty trucks.

Managing Feedstock Resources

In addition to energy and global warming pollution, agriculture can have a profoundly positive or negative impact on soil quality, water quality, water use, habitat, and land-use. There are crops and management practices that yield very large amounts of biomass per acre while dramatically reducing the environmental footprint of agriculture. For instances, switchgrass is a native perennial prairie grass. It does not need irrigation, requires less fertilizers and pesticides than traditional row crops, and provides a better habitat for wildlife. (See Tables 1 and 2.) As a perennial grass, it is mowed annually and thus there is no tillage, which reduces soil erosion. Finally and counter intuitively, it actually sequesters more carbon annually when it is harvested than when it is simply let to grow.

Table 1. Runoff from Corn, Soybeans, and Switchgrass¹

	Typical Nitrogen application (Kg/hectare/year)	Percent of typical Nitrogen application that ends up in runoff	Nitrogen Runoff (Kg/hectare/year)
Corn	135	58%	78.8
Soybeans	20	81%	16.25
Switchgrass	50	19%	9.7

Table 2. Habitat Quality and Diversity for Different Crops¹

Habitat Type ^a	Number of Breeding Pairs per 40 ha	Total Number of Breeding Species	Number of Sites Sampled
Dense switchgrass	182	10	8
Poor switchgrass	178	9	8
Reed canary grass ^b	246	9	6
Mixed warm-season grasses	126	13	7
Corn	32	5	16
Beans	22	2	9

a: Habitat types were categorized as follows: reed canary grass sites were not monotypes-they were fields where reed canary grass was the most common grass species (cover values ranged from 15% to 97%); dense switchgrass sites had >40% cover of switchgrass and <4% cover of other warm season grasses; poor switchgrass sites had <40% cover of switchgrass and <9% cover of other warm season grasses; mixed warm season grass sites had >72% cover of native warm season grasses other than switchgrass; bean and corn sites were on commercial bean (soy or snap) or corn fields, respectively.

b: Reed canary grass ranked highest in bird density primarily due to the influence of the large number of red-winged blackbirds (*Agelaius phoeniceus* L.) that nest in it.

Farmers have proven very innovative and capable at meeting market demand and reducing environmental impacts when they are given the right incentives. For instance, in recent years, corn farmers have dramatically increased yield per acre while reducing the amount of fertilizer used per bushel. Similarly many farmers are adopting low-till and no-till practices to protect their soil and soil quality. These practices and others have been driven both by the cost of inputs and by smarter and more effective conservation policies in recent farm bills.

To date our farmers and foresters have had essentially no market for biomass for biofuels. As this demand grows, it will put pressure on our agricultural lands and forests and could potentially encourage the use of types of biomass and management practices that are decidedly not renewable. So far, there has been a greater focus on biomass derived from croplands and while there are certainly ways to manage these lands that are unsustainable, a switch to high-yield cellulosic crops could make managing these lands easier. Forest lands represent a greater challenge since they are in general less intensively managed and wilder places. Thus increased demands for forest biomass pose a greater risk of environmental degradation.

Biofuels derived from forest biomass should be restricted to fuels

made from trees removed from the immediate vicinity of homes, or pre-commercial thinnings where endangered forests are already protected and low-impact logging is faithfully implemented. Endangered forests, which include old growth forests, critical habitat for rare, vulnerable, or endangered species, and roadless areas are not a “renewable” resource; once cut down, they can take centuries to replicate. There is a role, however, for the federal government to support the removal of the most flammable wood biomass from communities at risk of forest fires. In addition, on a going-forward basis, where natural forests are converted to plantations or non-forest uses, fuels derived from the forest biomass and from the ensuing uses should be excluded from the definition of acceptable biomass for biofuels.

As we increase our use of biofuels, we should enable and encourage farmers and foresters to do better by the lands they manage. Eventually, as the market grows, consumers will demand and suppliers will market biofuels that are derived through more sustainable practices. This sort of market differentiation can be seen in almost every consumer product today. However, at a minimum, as the market develops, we must ensure that the production of biomass for biofuels does not increase environmental impacts of agriculture and forestry.

Improving the Efficiency of Biofuels Production

Efficiency is critical to every environmental aspect of biofuels and is crucial if biofuels are to play a major role in reducing our dependency on oil. Efficiency of land use (yield per acre), efficiency of conversion of biomass into biofuels (gallons per ton of biomass), efficiency of end use (miles per gallon), and efficiency of transportation (miles traveled per vehicle) all combine to determine the overall scale of each environmental impact from biofuels. Looking simply at the total land use gives a clear picture of how these factors combine. Under a business-as-usual scenario by 2050, our demand for gasoline will more than double from the current 140 billion gallons to 289 billion. Meeting all of this with current crops and current cellulosic conversion technologies would require over 1.7 billion acres of land.

Readily achievable advances in vehicle fuel economy, overall transportation efficiency, crop yields and conversion efficiency could reduce the land requirement to just 114 million acres. All of this land does not need to be solely devoted to producing biomass for biofuels. As the demand for cellulosic biomass is integrated into existing agricultural markets, farmers will find ways to sell as many valuable products as possible. For instance, corn farmers will happily sell corn stover (the cobs, stalks and leaves of the plant) as well as corn kernels, though they will have to weigh the income from the stover against the lost nutrients and soil organic matter and the need to protect their soil from erosion. Similarly, if the protein in a high cellulose-yield crop such as switchgrass proves to be equally or more valuable for animal feed than the protein in soybeans, then soy farms may choose to switch crops in order to be able to sell both cellulose and animal feed protein. A third example of integration involves meeting environmental goals. Switchgrass is currently grown on much of the farm land put aside in the Conservation Reserve Program (CRP) to protect soil, water, and habitat. It should be possible to harvest some of this while still meeting the goals of the CRP and thus make the program more financially self sufficient. These three measures alone would further reduce the amount of additional land needed to produce enough biofuels by 2050 to entirely eliminate our demand for gasoline to between 6 and 48 million acres. (See Table 3.)

Farmers will find other ways to integrate the production of cellulose into current markets. Other crops may well be able to achieve higher yields, and there are other sources of cellulosic biomass beyond just what can be produced from existing crop lands. Furthermore, our cars and trucks can certainly be more efficient than we have estimated here. The message should be clear though. Biofuels can either require an entirely unsustainable amount of land and thus be limited to a small role in an unsustainable future, or we can improve the efficiency of every stage of the lifecycle of biofuels, especially the fuel economy of our cars and trucks, and biofuels can provide virtually all our remaining demand.

The two other environmental impacts directly impacted by the overall efficiency of biofuels are fossil fuel energy use and global

Table 3. How Much Land to Meet Gasoline Energy Needs in 2050?¹

	Gasoline Demand (billions gals of gas equiv)	Switchgrass Yield (dt/acre/yr)	Conversion Efficiency (Gals gas equiv/dry ton)	Land needed to meet gasoline demand (millions of acres)	
Production and efficiency gains					
Status quo in 2050	289	5	33	1753	
Smart growth and fuel economy by 2050	108	5	33	657	
Increase conversion efficiency	108	5	69	313	
Biofuels coproduction	108	5	77	282	
Increased switchgrass yield by 2050	108	12.4	77	114	
Alternative sources of land and biomass				Aggressive Integration	Partial Integration
Protein recovery	73 million acres of soybeans, 50% to 100% conversion to switchgrass			41	77
Corn stover	323 million tons of corn stover, 75% collected for biofuels			21	58
CRP land	30 million acres, 33% to 50% conversion to switchgrass			6	48

warming pollution. The corn ethanol industry has spent over two decades improving the efficiency of corn production and corn ethanol production and shifting the fuel used to drive the ethanol production process from coal to natural gas. The result is that the industry currently provides a modest but clearly positive energy return on the non-renewable energy invested and a reduction in global warming pollution relative to gasoline. Cellulosic biofuels production technology is expected to provide dramatically higher energy returns and larger greenhouse gas reductions.

Two recent peer-reviewed studies, one in *Science* and the other in *Environmental Science and Technology*, reviewed recent reports on the energy return of corn and cellulosic ethanol. Both studies show that there is actually a very strong consensus in the scientific community about the positive return from both corn and cellulosic ethanol. This is important because of an outdated public perception

that the production process uses more fossil fuel energy than is available for use in the ethanol that is produced.

Cellulosic ethanol has a better energy return and global warming pollution profile in large part because cellulosic biomass arrives at the ethanol production facility combined with a renewable source of energy more than sufficient to drive the production process. Cellulose, a central component to most plant matter, is bound up with lignin, another major component. While lignin cannot be fermented into ethanol, it does have a significant energy value—enough energy in fact not only to power the entire ethanol production process but also to export energy either as electricity or, possibly, as biofuels using gas-to-liquids technology.

End Use

Currently ethanol is mostly used as an additive to gasoline in low blends up to 10 percent ethanol and 90 percent gasoline. However, the use of ethanol as an additive presents air quality challenges. NRDC research points to two key policy approaches to achieve clean air standards while advancing the use of biofuels and breaking our addiction to oil:

- Carefully manage the use of ethanol in small amounts as an additive to reduce harmful emissions.
- Push for a rapid transition to the use of ethanol as a gasoline alternative, with a focus on making it accessible to consumers.

Although originally introduced into gasoline specifications to combat ozone formation, ethanol in low blends can actually contribute to pollution. Studies by the California Air Resources Board and the Environmental Protection Agency (EPA) have concluded that low ethanol blends (E-5.7 in California) in the current fleet of vehicles increase ground-level ozone pollution by increasing emissions of two pollutants that lead to ozone formation—nitrogen oxides (NO_x) and volatile organic compounds (VOCs)—more than they decrease the ozone-forming impact of a third pollutant—carbon monoxide (CO).

Nitrogen Oxides. Low ethanol blends boost the fuel-oxygen content and create an air-rich fuel, which, when combusted in traditional engines, results in higher levels of NO_x. This effect is especially prevalent in vehicles built before the mid-1990s that cannot automatically adjust the amount of oxygen in the fuel before it is burned.

Volatile Organic Compounds. Low blends increase evaporative VOC emissions in two ways: by raising the vapor pressure of the blended fuel and by increasing “permeation.” The change in vapor pressure can be controlled by changing the gasoline used in the blending. Permeation occurs when hydrocarbons from the gasoline migrate through the rubber and plastic components of a vehicle’s fuel system, such as the fuel tank and hoses. Ethanol changes the properties of the fuel, allowing more VOCs to permeate the components and evaporate into the atmosphere. Recent studies suggest that if not accounted for by other changes in the fuel, this effect would substantially increase emissions. In Los Angeles, an area that currently suffers from a deficit of measures to reduce ozone pollution enough to meet clean air laws, these emissions could increase that deficit by about 10 percent.

Carbon Monoxide. Low blends of ethanol reduce CO emissions, but the ozone liabilities of permeation emissions outweigh the benefits from reduced carbon monoxide. While increased oxygen levels in fuels provide a beneficial effect of reducing the emissions of CO, this pollutant is only a relatively weak precursor to ozone.

Fortunately, newer vehicles, especially those that meet the current California Low Emission Vehicle II program and EPA Tier 2 emission standards, are equipped with engine and pollution control technologies that dramatically reduce these pollution impacts. Unfortunately, it takes 15 years or more for new vehicles to become the dominant technology on the road, so the air pollution liabilities with using low-blend ethanol will persist for many years unless proper safeguards are put into place.

By far the best way to avoid the air quality problems associated with ethanol is to use it as a high blend, such as E-85. High-blend ethanol fuels reduce evaporative emissions compared to low blends. E-85 is burned in flexible-fuel vehicles (FFVs) specifically calibrated to run on

any fuel from regular gasoline to E-85. FFVs also have improved fuel systems that help minimize permeation and the latest oxygen-sensing technology to minimize NOx emissions. With the proper incentives, FFVs can ultimately take a large bite out of oil dependence.

There are about 5 million flexible-fuel vehicles on U.S. roads today, but due to the scarcity of E-85 pumps and a lack of awareness among owners, practically all of them are being run on gasoline. E-85 needs to be made more widely available, and the remaining 212 million gasoline cars and trucks should be replaced with FFVs. States can take the lead in making both happen.

Ethanol is good for blending, so it is likely to continue to be mixed into gasoline even in areas with severe air pollution problems. But any increase in ozone-forming pollution can and should be fully offset through more stringent and cleaner gasoline standards.

Because state and federal ambient air quality standards set thresholds for ozone levels, states are in a position to reach and maintain air quality standards by properly managing the use of ethanol blends. Some guidelines for state-level ethanol management are listed below:

- Prioritize aggressive measures to promote ethanol use in high blends, especially in areas that fail to meet ozone standards.
- Provide the maximum flexibility to refiners to blend ethanol in the winter, when smog formation is not a problem.
- Opt out of the provision that allows conventional (i.e., non-reformulated) gasoline to have higher vapor pressure (and thus higher evaporative emissions) when blended with ethanol.

Conclusion

Corn ethanol is currently providing us with modest but important environmental benefits, and it is building the market for an alternative to gasoline. Cellulosic biofuels promise to dramatically increase both the amount of biofuels we can sustainably produce and the benefits per gallon of biofuels that we use. But behind these

general truths, the fact of the matter is that not all corn ethanol is created equal and not all cellulosic ethanol will be created equal.

There are feedstock resource management practices, ethanol production practices, and ways of using ethanol that are better for the environment than others. For instance, low-till and no-till harvesting practices are increasingly common and greatly reduce soil erosion and help maintain soil quality. On the production side, the current high prices of natural gas are driving many in the corn ethanol industry to consider powering their ethanol plants on coal, and they are pressuring the U.S. Environmental Protection Agency to allow greater air pollution to accommodate this shift. Meanwhile others are finding innovative ways to power ethanol plants off of animal waste, gasified biomass, and solar power.

Whether these types of measures are adopted can greatly increase or entirely eliminate the benefits of ethanol. To maximize the benefits from biofuels as we push the technology and market to develop quickly, we need to develop clear metrics of the performance we want from ethanol. The obvious ones are greenhouse gas reductions and oil displacement, but many consumers and policy makers will also demand that biofuels actually improve water, air, soil, and habitat quality. They may also want to be able to buy locally produced ethanol or ethanol from farmer-owned production facilities. This means not just developing certification systems but also the transparency and accountability in the market so that consumer preferences and standards can be directly relayed to farmers and producers.

The risks that our addiction to oil poses to our economy, our national security, and our environment are simply too great to leave the evolution of biofuels and our transportation energy needs to chance. We need to develop the technology from crops through to cars and pumps, push this technology from the labs to the consumers, and guide the market so that we do in fact take a sustainable path to delivering on the promise of biofuels.

1. Greene N. *et al.*, "Growing Energy: How Biofuels Can Help End America's Dependence on Oil," Natural Resources Defense Council, December 2004.