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OFFICE OF THE LEGISLATIVE AUDITOR
STATE OF MINNESOTA

EVALUATION REPORT

Biofuel Policies and Programs

APRIL 2009

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O|L|A **OFFICE OF THE LEGISLATIVE AUDITOR**
STATE OF MINNESOTA • James Nobles, Legislative Auditor

April 2009

Members of the Legislative Audit Commission:

There are conflicting claims about the energy, environmental, and economic impacts of biofuels, particularly corn-based ethanol. At your request, OLA examined these claims, as well as Minnesota's biofuel policies and programs.

We found that traditional biofuels like corn-based ethanol and soy-based biodiesel serve a useful purpose. However, land constraints and economic considerations limit the extent to which traditional biofuels can replace petroleum-based fuels. Cellulosic ethanol appears to have significant environmental and energy advantages over corn-based ethanol, but questions remain about its economic viability and its potential land use and environmental impacts. We make recommendations to the Legislature for changes in Minnesota's subsidy program for ethanol producers. In addition, we make various recommendations to state agencies.

Our evaluation was conducted by John Yunker. We thank the Department of Agriculture and other state agencies that assisted us during this evaluation.

Sincerely,

Jim Nobles

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Summary

Traditional biofuels continue to serve a useful purpose, but the state needs to rethink its subsidy programs and increase its planning for advanced biofuels like cellulosic ethanol.

Major Findings:

- Corn-based ethanol and soy biodiesel help reduce the consumption of petroleum and other fossil fuels, but their overall ability to reduce dependence on fossil fuels is constrained by land resources and other considerations (pp. 21-33).
- The environmental impacts of corn-based ethanol and soy biodiesel are unclear in some respects and more complicated than is often acknowledged by both supporters and detractors of these biofuels (pp. 62-63).
- The environmental impacts of corn-based ethanol and soy biodiesel are relatively modest at the production levels that are achievable nationwide without a large increase in the land devoted to their production (p. 63).
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- The producer payment program, while very helpful in stimulating corn-based ethanol production in the 1980s and 1990s, has continued to provide subsidies even when producers made large profits (pp. 82-83).
- Although the financial condition of the ethanol industry has deteriorated during the last year, maintaining the producer payment program may have little effect on future ethanol production (pp. 84-85).

Recommendations:

- The Legislature should consider ending the producer payment program for corn-based ethanol and redirecting the funds to programs designed to further reduce fossil fuel energy use and greenhouse gas emissions (p. 85).
- The Department of Employment and Economic Development should not use the JOBZ program for biofuel plants unless they need subsidies and offer significant energy and environmental benefits (p. 87).
- The Environmental Quality Board (EQB) and its member agencies should examine what land could be used to grow biomass for cellulosic ethanol production and how the biomass could be grown and harvested with minimal environmental impact (p. 65).

Report Summary

Traditional biofuels reduce the consumption of petroleum and other fossil fuels, but are limited in their overall ability to replace petroleum-based fuels.

Minnesota has been a leader in requiring the use of ethanol in gasoline and biodiesel in diesel fuels. The state currently requires nearly all gasoline sold in the state to contain 10 percent ethanol and nearly all diesel fuel for motor vehicles to include 2 percent biodiesel. State law calls for the ethanol blend percentage to increase to 20 percent in 2013 provided the Environmental Protection Agency (EPA) approves its use in motor vehicles. The state's biodiesel blend rate is scheduled to increase to 5 percent in May 2009, with subsequent increases for warm weather months in 2012 and 2015.

The federal government has long subsidized the use of ethanol and approved a tax credit for blending of biodiesel in 2004. The state's main program for subsidizing ethanol producers has been a producer payment program, which began in 1987. In addition, the state's Job Opportunity Building Zones (JOBZ) program has provided tax breaks for more recently built ethanol plants and several biodiesel facilities.

Corn-based ethanol and soy biodiesel reduce fossil fuel energy consumption, but the fossil fuel energy savings are limited due to land constraints and other considerations.

In general, corn-based ethanol and soy biodiesel provide more energy than the fossil fuel energy used to produce them. For each gallon of pure corn-based ethanol (E100), the fossil fuel savings—including petroleum, natural gas, and coal—are the equivalent of the energy content in 0.26 to 0.37 gallons of gasoline. A gallon of pure soy biodiesel (B100) has fossil fuel savings equal to the energy content in 0.83 gallons of diesel fuel. If only petroleum savings are considered, a gallon of E100 saves about 0.69 gallons of gasoline, while a gallon of B100 replaces 0.96 gallons of diesel fuel.

The overall petroleum savings from corn-based ethanol and soy biodiesel are limited, however, by land and other constraints. About 31 percent of the corn crop and 7 percent of the soybean crop harvested in the United States in 2008 is expected to be used for biofuels. These usage levels have raised concerns about the impact of biofuels on world food supplies and prices. Yet, we estimate that only 5.2 percent of gasoline use and 0.6 percent of diesel use would be replaced by these biofuels in 2009.

Future growth in crop and biofuel yields will probably allow corn ethanol and soy biodiesel to replace a greater percentage of gasoline and diesel fuel use. By 2020, only a slight increase in the land used to make corn-based ethanol in 2008 would be needed to power all motor vehicles in the nation with E10. But that level of biofuel consumption would replace only 7 percent of gasoline use. Nationwide B2 usage is not achievable using soybeans alone without a major increase in acreage used for soy biodiesel. To achieve nationwide use of E20 and B5 by 2020 would require about two-thirds of all of the land planted with corn in 2008 and slightly more than half of all the land planted with soybeans. While Minnesota could achieve these higher levels of biofuel consumption using traditional biofuels, their achievement at the national level depends on developing more advanced biofuels like cellulosic ethanol and algae-based biodiesel.

Certain environmental impacts of corn-based ethanol and soy biodiesel are unclear, particularly their impact on greenhouse gas emissions.

A number of studies have concluded that corn-based ethanol and soy biodiesel reduce greenhouse gas emissions. An Argonne National Laboratory analysis found that the average reduction in greenhouse gas emissions was 19 percent for E100, which is about 2 percent for E10, compared with gasoline. The average reduction for Minnesota is probably somewhat higher due to its reliance on petroleum from Canadian oil sands and the implementation of fossil fuel saving technology by three ethanol plants. Studies of pure biodiesel estimate greenhouse gas reductions between 41 and 94 percent compared with diesel fuel. For B2 blends, the reduction is between 1 and 2 percent.

The environmental impacts of biofuels are unclear in a number of respects.

These studies have been criticized for a number of reasons. The greatest attention has been paid to land use impacts, since significant amounts of greenhouse gases may be emitted when non-cropland is converted to corn and soybean production. If biofuel production expands quickly and requires more land for corn and soybeans, emissions from land conversion could offset the reductions from biofuel use for many years. Indirect land use changes could occur in other countries if commodity price increases spurred by biofuel use cause land conversions elsewhere.

Biofuel expansion may have had a modest impact on land use in the United States. Since 2001, the amount of corn used for ethanol has expanded more than 400 percent and has consumed all of the increase in corn production even after accounting for the distillers grains that are a by-product of ethanol production. The acres used for corn and soybeans have grown 8 percent since 2001.

This issue has been controversial in part because the estimated land use impacts are based on projections, not actual land use changes, both in the United States and in other countries. The EPA is currently developing regulations that will determine whether, after considering land use impacts, various biofuels meet the greenhouse gas reductions required by federal law for advanced biofuels and corn ethanol produced at new plants.

Similarly, the impacts of corn and soybean production on water quality may depend on land use impacts. If biofuel expansion increases the number of acres planted with corn or soybeans, there will likely be an increase in the amount of fertilizers and pesticides that reach surface waters or groundwater supplies. But if biofuel expansion occurs without the need for additional land, there may be no marginal impact on water quality from crop production.

The impact of corn-based ethanol on various air pollutants is also subject to dispute. Total life-cycle emissions of five key air pollutants are higher for ethanol than gasoline, but urban emissions are lower. As a result, it has been generally believed that corn-based ethanol has a positive impact since overall air pollution levels are higher in urban areas. A recent study casts doubt on this conclusion at least for particulate matter. The study found greater overall health problems from particulate matter when ethanol is used instead of gasoline. The study used EPA models to measure the incidence of particulate matter and the health impacts.

Studies suggest that cellulosic ethanol will provide greater energy savings and better environmental results than corn-based ethanol, but some uncertainties remain.

Preliminary estimates indicate that, compared with corn-based ethanol, cellulosic ethanol would reduce overall fossil fuel consumption, provide greater reductions in greenhouse gas emissions, and require significantly less fertilizers and pesticides. Biomass for cellulosic ethanol would come from forest residues, corn cobs or other portions of the corn plant, and dedicated energy crops like switchgrass, prairie grasses, or willow and poplar trees. Furthermore, grasses and trees may be grown on marginal land that is not suitable for traditional crop production.

Additional study is needed on the potential land use and environmental impacts of cellulosic ethanol.

However, cellulosic ethanol is in the pilot project stage and is not yet being produced commercially. There is considerable uncertainty about how cellulosic ethanol will be produced and whether it can be economically competitive even with the federal tax credit that began in 2009. Cellulosic ethanol can also have adverse impacts on greenhouse gas emissions if the biomass is produced on land previously used for traditional crop production. There are also concerns about whether growing biomass on marginal lands means that lands will be removed from the Conservation Reserve Program with adverse impacts on the environment and wildlife.

The Legislature should consider ending the producer payment program and redirecting the funds to efforts designed to further reduce fossil fuel energy consumption and greenhouse gas emissions.

The state's subsidy programs for biofuels are not designed to maximize the energy and environmental benefits of biofuels.

The producer payment program was instrumental in spurring the early growth of the state's ethanol industry. However, the program is not designed to maximize overall energy savings or reduce environmental impacts and may no longer have much impact on overall ethanol production. While several producers have implemented significant energy and environmental improvements to reduce natural gas or electricity costs, the state's producer payment program had little impact on those decisions. Ethanol plants constructed in recent years have received JOBZ tax breaks. However, some of these plants were built during very favorable economic conditions and may not have even needed subsidies.

Additional energy and environmental savings are possible in the future either by developing a cellulosic ethanol industry or through additional improvements to existing corn ethanol plants. However, the largest subsidy programs are not designed for these purposes. A small grant program administered by the Next Generation Energy Board has recently provided some funds for these and related purposes, but its funds are small compared with the other programs.

Furthermore, the producer payment program has paid $93 million over the last five years to companies that have earned profits of $619 million over this period. While financial conditions for ethanol producers have deteriorated in the past year, it is unlikely that maintaining these payments will influence production decisions. The subsidies are only a little more than 1 percent of sales.

Legislators should look carefully at this program in light of the current budget deficit and the state's goals of reducing energy consumption and greenhouse gas emissions. About $44 million is scheduled to be spent on the producer payment program from fiscal year 2010 through 2012.

The Next Generation Energy Board has funded a number of studies and demonstration projects that will increase knowledge about the potential for cellulosic ethanol. But more attention and funding is needed to achieve a better understanding of the potential sources and supplies of biomass for cellulosic ethanol production, as well as the potential land use and environmental impacts.

Introduction

Minnesota has been a leader in biofuel policy. Earlier mandates to use ethanol in gasoline distributed in the Twin Cities area were expanded statewide in the fall of 1997. In 2002, the Legislature passed the nation's first mandate to mix biodiesel into diesel fuel. In addition to these consumption mandates, Minnesota has provided financial incentives for the production of biofuels, particularly ethanol.

There has been considerable controversy over the energy, environmental, and economic impacts of biofuels, particularly corn-based ethanol.

Supporters of biofuels claim that their production and use have energy, environmental, and economic benefits. Proponents say that domestically produced biofuels decrease fossil fuel use and reduce the nation's dependence on oil from foreign governments. They also claim that ethanol and biodiesel reduce greenhouse gas emissions—thus mitigating the trend toward global warming—and lower emissions of carbon monoxide and other air pollutants. Finally, supporters say that greater reliance on biofuels increases economic activity in the United States, particularly in rural areas. Greater use of biofuels reduces the amount of money sent to foreign oil producers and increases the income of domestic biofuel producers and corn and soybean growers.

Critics of biofuels argue that these benefits are limited and may be offset by other factors. Some critics charge that more fossil fuel energy is consumed in the production of corn and ethanol than is contained in corn-based ethanol. Other critics concede that biofuels produce a modest amount of net energy, but they argue that corn and soybeans can only replace a limited portion of the petroleum-based fuels used in transportation. Critics also say that corn-based ethanol has limited air quality benefits and adverse impacts on greenhouse gas emissions, water quality and supply, and wildlife habitat. Finally, critics question the economic benefits of crop-based biofuels. They cite higher food prices and negative impacts on livestock producers.

As a result of the controversy over biofuels, the Legislative Audit Commission directed the Office of the Legislative Auditor to evaluate Minnesota's programs and policies for biofuels. Legislators wanted us to examine and attempt to resolve the competing claims over the benefits and costs of biofuels. In addition, they wanted us to review the state programs that provide financial incentives to biofuel producers and consider where changes were needed in these programs. In response to these legislative concerns, this report addresses the following issues:

- **Do biofuels produce more energy than the fossil fuel energy consumed in their production? How much can we rely on biofuels, particularly those made from agricultural crops, to replace petroleum-based fuels used for transportation?**

- **What are the environmental impacts of biofuels, including those on global warming, air quality, water quality and availability, and wildlife habitat?**

- **What are the economic effects of increasing production and use of biofuels?**

- **What purposes are served by Minnesota's current subsidy programs for biofuel production? Could these programs be better designed to meet energy, environmental, and economic goals?**

To address these questions, we examined a wide variety of studies and literature. While our primary focus was on academic studies appearing in peer-reviewed journals, we also reviewed other types of studies from university scholars. In addition, we examined studies and information from government agencies, biofuel advocacy groups, environmental groups, and others. Finally, we examined available data on a variety of topics including, but not limited to, biofuel and crop production, transportation fuel demand and supply, and crop irrigation.

This report attempts to provide legislators and others with direct and clear answers to the above questions. In some instances, however, this was not possible because existing research does not provide definitive answers. For example, the scientific debate about the impact of biofuels on land use is still evolving. As a result, the worldwide impact of biofuels on greenhouse gas emissions is unclear. Regarding economic impacts, we were able to review and comment on existing research and reports but were not able to reach definitive answers about the overall economic impact of the biofuels industry.

This report also attempts to provide information specific to Minnesota's biofuel and petroleum usage where possible. Providing such information was difficult because most studies focus on national issues and would be difficult to replicate on a state level without considerable technical expertise and data. However, in some cases such as Minnesota's source of petroleum, we were able to provide insights into how Minnesota may differ from the national averages used in most studies.

1

Background

There are two types of biofuels currently used in motor vehicles in the United States. Ethanol, which is blended with gasoline, is the most widely used biofuel. Production of ethanol was about 6.5 billion gallons in 2007. The use of biodiesel, which is blended with diesel fuel, has been slower to grow. In 2007, only about 0.5 billion gallons of biodiesel were produced. In addition, a third type of biofuel—cellulosic ethanol—is beginning to be produced in a number of pilot or demonstration plants across the country.

In the United States, biofuels are produced mostly from agricultural crops like corn and soybeans.

In Minnesota and the United States, biofuels are mostly produced using traditional agricultural crops. Most ethanol is made from corn, and most biodiesel is made from soybeans. Outside the United States, other types of crops dominate the production of biofuels. In Brazil, sugarcane is used to produce ethanol, while wheat is used in Canada. Rapeseed is used in European Union countries to produce biodiesel.

In this chapter, we examine the policies used at the state and federal levels to foster an increase in the production and consumption of ethanol and biodiesel. Second, we review the trends in biofuel production in Minnesota and the United States. Finally, we examine the trends in the production of corn and soybeans, since they have been the principal feedstocks used to produce biofuels in the United States.

FEDERAL AND STATE POLICIES

Over several decades, the federal government and Minnesota state government have provided significant financial incentives and other support for the production and use of ethanol. In addition, both have been active in mandating certain levels of use as a fuel additive. More recently, Minnesota became the first state to mandate the use of biodiesel. In addition, the federal government has begun to provide certain financial incentives for the production of biodiesel. In this section, we review the various policies the federal government and the state of Minnesota have implemented to encourage the production and use of biofuels.

Federal Policies

Financial Support

The federal government has provided financial incentives for ethanol production over the last 30 years. From 1978 through 2004, the federal government provided the payers of federal excise taxes on motor fuel with a tax credit for the amount of ethanol blended with gasoline. Over the years, the tax credit ranged from 40 to 60 cents per gallon of ethanol. Due to concerns about the loss of

The federal government provides financial incentives for the use of both ethanol and biodiesel.

federal revenue for transportation purposes, the tax credit was replaced in 2005 with a federal tax refund to blenders of motor fuel. From 2005 through 2008, the tax credit was 51 cents per gallon of ethanol blended with gasoline, or a little more than 5 cents per gallon of E10.[1] For 2009, the credit has been reduced to 45 cents per gallon of traditional ethanol. However, cellulosic biofuel would receive a tax credit of $1.01 per gallon.[2]

Federal financial support for the biodiesel industry began more recently with the enactment of a tax credit in 2004. The credit was $1.00 per gallon of agri-biodiesel, which was defined as fuel made from virgin oils derived from agricultural commodities or animal fats. A reduced credit of 50 cents per gallon was provided for biodiesel made from nonvirgin feedstocks such as recycled grease from restaurants. For 2009, Congress set the credit at $1.00 per gallon for all types of biodiesel. In addition, Congress closed a loophole, which previously allowed foreign-produced biodiesel to be imported to the United States to receive the tax credit without being used in the United States. The so-called "splash-and-dash" loophole provided the tax credit to foreign biodiesel that entered the United States, was blended with a small amount of diesel fuel, and was then shipped to a foreign country for use.

In addition, the federal government has tax credits for small producers of ethanol and biodiesel. The credit is 10 cents per gallon of ethanol or agri-biodiesel on the first 15 million gallons produced by a producer. Only producers with an annual capacity of 60 million gallons or less are eligible for the credit. The small producer tax credit was first enacted in 1990 but was used infrequently because of technical difficulties in applying the credit to farmer owners of cooperatives that owned ethanol plants. Legislation passed in 2004 allowed the credit to be passed through to farmer owners of a cooperative. Congressional action in 2005 changed the cutoff for small producers from 30 million gallons per year to 60 million. In addition, a similar tax credit was created for small producers of agri-biodiesel.

Beyond these tax-related incentives, the federal government has provided two other types of financial support for the biofuels industry in the United States. The first type of support comes through a tariff that applies to ethanol imported from other countries. The tariff, which has been in effect since 1980, is currently 54 cents per gallon of imported ethanol plus a 2.5 percent duty or tax on the value of the imported ethanol. The tariff was enacted by Congress to prevent cheaper ethanol from other countries, particularly Brazil, from taking market share from domestic producers of ethanol. In effect, the tariff limits the benefits of the 45 cent blender's credit to domestically produced ethanol by offsetting the blender's tax credit received by imported ethanol. The second type of financial

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[1] E10 is a blend of 10 percent ethanol and 90 percent gasoline. Other blends discussed in this report are E20 and E85, which contain 20 percent and 85 percent ethanol, respectively.

[2] Cellulosic biofuel is defined as any renewable fuel made from renewable biomass that has lifecycle greenhouse gas emissions that are at least 60 percent less than the baseline lifecycle greenhouse gas emissions, as determined by the administrator of the Environmental Protection Agency. Traditional corn-based ethanol would not be eligible for the $1.01 tax credit, but cellulosic ethanol made from corn cobs might qualify.

support includes federal grants, demonstration projects, and research and development. This support has been used to promote a wide range of biofuels, including cellulosic ethanol.

Mandates

In 1992, the federal government first began requiring the use of oxygenated gasoline in federally designated areas that did not meet certain air pollution standards. Federal law required the use of oxygenated gasoline during the months of October through January in areas that did not meet carbon monoxide standards. "Non-attainment areas," like the 10-county Twin Cities metropolitan area, were required to use gasoline containing 2.7 percent oxygen by weight. This could be achieved either by using a mixture of 7.7 percent ethanol by volume or by using methyl tertiary-butyl ether (MTBE), a product obtained using fossil fuels. In Minnesota, ethanol was used as an oxygenate, but about two-thirds of the oxygenate used nationwide was MTBE.

In addition, the federal government required the use of reformulated gasoline in areas of the nation with high levels of smog. These ozone non-attainment areas were required to use reformulated gasoline containing 2 percent oxygen by weight. Again, MTBE and ethanol were the most commonly used oxygenates in reformulated gasoline.

Federal law requires substantial increases in the use of biofuels through 2022.

In recent years, however, the federal government has implemented policies requiring the use of certain volumes of biofuel. In 2005, Congress enacted a law requiring the use of 4 billion gallons of renewable fuel beginning in calendar year 2006, with the amount growing to 7.5 billion gallons in 2012.[3]

Those requirements were superceded by the renewable fuel standard (RFS) enacted in 2007.[4] As Table 1.1 indicates, the RFS requires use of 9 billion gallons of renewable fuel by 2008, 20.5 billion gallons by 2015, and 36 billion gallons by 2022. The federal RFS further specifies the amounts of those standards that must come from "advanced" biofuel.[5] In 2008, none of the 9 billion gallons must come from advanced biofuel. However, the amount increases to 5.5 billion gallons by 2015 and to 21 billion gallons by 2022. All increases in the overall RFS after 2015 come from advanced biofuel and not from conventional renewable fuel like corn-based ethanol. The amount of conventional renewable fuel allowed under the RFS grows from 9 billion gallons in 2008 to 15 billion gallons in 2015 and then remains constant.

[3] Under Public Law 109-58, renewable fuel included any motor vehicle fuel made from various agricultural commodities, animal fats, or biogas. Each gallon of ethanol from cellulosic or waste sources was considered to be the equivalent of 2.5 gallons of renewable fuel.

[4] Public Law 110-140, sec. 201-202, 121 Stat. 1519-1528 (2007).

[5] Advanced biofuels may include ethanol from cellulose, hemicellulose, or lignin; ethanol derived from sugar or starch other than corn starch; ethanol derived from waste material including crop waste; biomass-based diesel; biogas, butanol, or other alcohols produced through the conversion of organic matter from renewable biomass; and fuel other than ethanol derived from cellulosic biomass.

After 2015, only growth in advanced biofuels can be used to meet the increasing levels of renewable fuel use mandated by federal law.

Table 1.1: Current United States Renewable Fuel Standard, in Billions of Gallons per Year

			Advanced Biofuels[a]			
Year	Total Renewable Biofuel	Conventional Biofuels[b]	Cellulosic	Biomass-Based Diesel	Other Advanced Biofuels	Total Advanced Biofuels
2006	4.00	4.00				
2007	4.70	4.70				
2008	9.00	9.00				
2009	11.10	10.50		0.50	0.10	0.60
2010	12.95	12.00	0.10	0.65	0.20	0.95
2011	13.95	12.60	0.25	0.80	0.30	1.35
2012	15.20	13.20	0.50	1.00	0.50	2.00
2013	16.55	13.80	1.00		1.75	2.75
2014	18.15	14.40	1.75		2.00	3.75
2015	20.50	15.00	3.00		2.50	5.50
2016	22.25	15.00	4.25		3.00	7.25
2017	24.00	15.00	5.50		3.50	9.00
2018	26.00	15.00	7.00		4.00	11.00
2019	28.00	15.00	8.50		4.50	13.00
2020	30.00	15.00	10.50		4.50	15.00
2021	33.00	15.00	13.50		4.50	18.00
2022	36.00	15.00	16.00		5.00	21.00

[a] Advanced biofuels and biomass-based diesel must reduce greenhouse gas emissions by at least 50 percent, while cellulosic biofuel must reduce greenhouse gas emissions by at least 60 percent. Biomass-based diesel and cellulosic biofuels are subcategories within the category of advanced biofuels. Federal law requires the Environmental Protection Agency to establish rules that make it clear what biofuels meet these emissions requirements after considering indirect land use impacts.

[b] Corn-based ethanol is considered a conventional biofuel. Any conventional biofuel plants that began construction after the enactment of the 2007 Renewable Fuel Standard must reduce greenhouse gas emissions by at least 20 percent.

SOURCE: Public Law 110-140, sec. 202(a), 121 Stat. 1522-1523 (2007).

The RFS also requires certain portions of advanced biofuels to come from cellulosic biofuel and biomass-based diesel fuel.[6] The portion of advanced biofuel that must come from cellulosic biofuel grows from 0.1 billion gallons in 2010 to 3 billion gallons in 2015 and 16 billion gallons in 2022. Biomass-based diesel must grow from 0.5 billion gallons in 2009 to 1 billion gallons in 2012. In effect, the RFS requires the amount of cellulosic ethanol used to become larger than conventional biofuel by 2022.

[6] Cellulosic biofuel is defined in federal law as renewable fuel derived from cellulose, hemicellulose, or lignin that comes from renewable biomass. More generally speaking, cellulosic ethanol can be made from perennial and prairie grasses, plant residues, and wood waste materials. Biomass-based diesel is biodiesel produced from renewable sources such as soy oil or other agriculturally derived oils, animal wastes or waste materials, and municipal solid waste and sludges or oils derived from wastewater or the treatment of wastewater.

To qualify under federal law, advanced biofuels and conventional biofuels from new facilities must meet certain greenhouse gas emission requirements.

Federal law establishes requirements that certain renewable fuels must reduce lifecycle greenhouse gas emissions below the emissions from petroleum-based fuels sold in 2005. For example, transportation fuel produced from facilities that commence construction after the date of enactment for the 2007 legislation qualifies as renewable fuel only if it achieves at least a 20 percent reduction in greenhouse gas emissions.[7] In addition, to qualify as an advanced biofuel, a transportation fuel must reduce lifecycle greenhouse gas emissions by at least 50 percent.[8] Cellulosic biofuels must reduce greenhouse gas emissions by at least 60 percent.

Federal law prescribes the general method that the Environmental Protection Agency must use to determine whether a biofuel qualifies as an advanced or cellulosic biofuel. According to federal law, lifecycle greenhouse gas emissions must include emissions from "all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer."[9] In addition, the emissions must include all "direct emissions and significant indirect emissions such as significant emissions from land use changes."[10] The Environmental Protection Agency is currently developing regulations for determining the exact methods to be used in making this calculation.

State Policies

Minnesota has been a leader in biofuel production and consumption.

Minnesota has been a leader in the production and consumption of biofuels in part due to its early adoption of both financial incentives and consumption mandates. In addition, Minnesota has been among the top three or four states in the production of corn and soybeans. As a result, it has an abundance of agricultural crops that can be used to make ethanol and biodiesel. In this section, we provide information on the specific policies Minnesota has adopted to encourage the production of biofuels.

Financial Support

For many years, Minnesota has provided financial incentives for the production of ethanol. Beginning in 1980, Minnesota provided a tax credit for those blending ethanol with gasoline. But the credit reduced funding for transportation and was seen by some as ineffective in increasing ethanol production in the state. As a result, the Legislature phased out the blenders's credit in the mid-1990s. At its peak in fiscal year 1994, the cost of the blender's credit was close to $25 million per year, although it was significantly lower during most of the years of its existence.

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[7] For calendar years 2008 and 2009, federal law stipulates that any ethanol plant fired with natural gas or biomass is deemed to be in compliance with the 20 percent requirement.

[8] The greenhouse gas emissions reduction required for biomass-based diesel is also 50 percent.

[9] Public Law 110-140, sec. 201, 121 Stat. 1520 (2007).

[10] *Ibid*.

Minnesota's producer payment program has provided $314 million in subsidies to ethanol plants built before 2000.

To address the lack of stimulus from the blender's credit, the Legislature enacted the producer payment program, which provided financial assistance directly to ethanol producers beginning in fiscal year 1987. Although program details have varied over the years, Minnesota has generally paid instate ethanol producers 20 cents per gallon of ethanol for the first 15 million gallons of annual production. For any individual producer, annual payments have usually been limited to $3 million per year and were scheduled to last 10 years from the start of production.

About 20 ethanol plants have received a total of about $314 million from the start of the producer payment program through fiscal year 2008. Only 11 plants remain in the program, and these are the plants that began production before June 30, 2000.[11] Minnesota's remaining commitments to these plants include $7.4 million in regular payments during fiscal year 2009, $1.2 million in regular payments during fiscal year 2010, and $50.5 million in "deficiency" payments. This latter category consists of regular payments, or portions of payments, that were delayed during fiscal years 2003 through 2007 due to state budget shortfalls.[12] Assuming future annual appropriations of $15.2 million, the deficiency payments would be completed in fiscal year 2012.

These older plants also received other types of public assistance. Four plants received grants from the state Economic Recovery Grants Program, and at least three plants received low-interest state loans from the Minnesota Investment Fund. Some plants also received assistance from local communities using tax increment financing.

Most recently built ethanol plants and two biodiesel plants are receiving tax breaks from the JOBZ program.

All of the newer plants now operating that did not qualify for producer payments are receiving favorable tax treatment under the Job Opportunity Building Zone (JOBZ) program. In addition to these six plants that are currently in operation, three additional projects are JOBZ participants, including two plants that are not yet operational and one project that is on hold.[13] Two additional plants under construction and one in the planning stage are not participating in the JOBZ program.

Minnesota has also encouraged the consumption of E85—a blend of 85 percent ethanol and 15 percent gasoline—by taxing E85 at a lower rate than E10 or pure gasoline.[14] In addition, the state has provided grants to service station owners to install E85 dispensing pumps. State agencies have been directed to purchase flex-fuel vehicles that are capable of running on E85.

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[11] A twelfth plant was in the producer payment program until recently. This plant stopped producing ethanol in late 2008. It was a relatively small plant making ethanol from cheese whey and was only producing about 3 million gallons of ethanol annually.

[12] Payments were suspended during part of fiscal year 2003 due to the Governor's unallotment of funds. During fiscal years 2004 through 2007, ethanol producers received 13 cents, rather than 20 cents, per gallon of ethanol on the first 15 million gallons of production.

[13] The project on hold was required to conduct an Environmental Impact Statement by the Minnesota Pollution Control Agency. Due to that requirement and financial considerations, the developers have suspended their project.

[14] Currently, the state excise tax on E85 is 17.75 cents per gallon compared with 25 cents for either E10 or pure gasoline.

Minnesota's Next Generation Energy Board was established in 2007 to examine the future role for alternative fuels and develop programs and policies for legislative consideration.

Minnesota requires nearly all gasoline sold in the state to contain 10 percent ethanol and nearly all diesel fuel to contain 2 percent biodiesel.

Minnesota does not have any state financial incentives specifically directed at biodiesel producers. As mentioned earlier, the federal government provides a $1 per gallon tax credit for biodiesel blending and has a small biodiesel producer tax credit. However, two biodiesel plants in Minnesota are participating in the JOBZ program. The participants are the two largest plants—one of which has been idle since last March.

The 2007 Legislature also took steps to accelerate the development of renewable energy projects, including advanced biofuel production, by establishing the Next Generation Energy Board. The Board is responsible for developing next generation energy and biofuels policy, making recommendations for legislative consideration, and distributing $3 million for state grants to projects that accelerate the development of renewable energy projects and advanced biofuels. The $3 million for grants was a one-time appropriation from the 2007 Legislature.

In November 2008, the Next Generation Energy Board awarded eight grants totaling about $2.7 million. Two grants went to existing ethanol companies. One grant will assist Chippewa Valley Ethanol Company in introducing technology to use farm or woodland biomass to power ethanol plant operations and replace up to 90 percent of its natural gas use. The technology will also allow eventual transition from corn-based ethanol production to cellulosic ethanol production. Another grant will fund the final stage of a study to determine the feasibility of building a commercial scale cellulosic ethanol plant that would be co-located with the existing Central Minnesota Ethanol Co-op corn ethanol plant. In addition, three other grants provide funding for studies or demonstration projects that are relevant to the production of biomass for conversion to liquid biofuels. These three studies focus on best management practices for growing and harvesting cellulosic energy crops, pelletizing biomass materials for easy storage and transport, and assessing the sustainability of the state's forests and their potential use for woody biomass.[15]

Mandates

Minnesota has been a leader in the adoption of consumption mandates for both ethanol and biodiesel. The Legislature first mandated that ethanol be used to meet the EPA winter mandate for oxygenate use in the Twin Cities beginning in October 1992. Then, the Legislature extended the requirement for a 7.7 percent mixture of ethanol in gasoline year-round for motorists in the Twin Cities metropolitan area beginning in October 1995. The year-round requirement was expanded statewide in October 1997. Since 2003, state law has required that almost all of the gasoline sold in the state contain 10 percent ethanol (E10).[16]

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[15] The other three projects funded by the Next Generation Energy Board involve the use of biomass or waste materials to produce electricity or heat.

[16] Fuel used in certain vehicles or engines is exempt from the E10 requirement. Exemptions include collector vehicles, motorcycles, off-road vehicles, and small engines, as well as gas sold at marinas or airports.

State law requires future increases in ethanol and biodiesel use.

Current state law provides for a growing role for ethanol. It requires the ethanol content in motor fuel to be 20 percent by August 30, 2013, provided that the federal government approves the use of E20 by the end of 2010.[17] Furthermore, state law sets a goal of producing one-fourth of the ethanol consumed in Minnesota from cellulosic materials by 2015. The proposed growth in ethanol use would be one of the steps taken to achieve the state's broader goal of providing 25 percent of all energy consumed in the state from renewable resources by 2025.

In 2002, Minnesota became a national leader in biodiesel policy when the Legislature passed the first biodiesel mandate in the nation. Effective in late September of 2005, the biodiesel mandate required most diesel motor fuel sold in Minnesota to contain at least 2 percent biodiesel. During the 2008 legislative session, the Legislature increased the mandate to 5 percent biodiesel by May 1, 2009. In addition, the law passed in 2008 requires—during the months of April through October—a minimum percentage of 10 percent biodiesel effective May 1, 2012, and 20 percent effective May 1, 2015.[18]

BIOFUEL PRODUCTION

The ethanol and biodiesel industries in the United States have been growing at a significant pace in recent years. In this section, we first review the trends in ethanol production, and then we consider the trends for biodiesel.

Ethanol

Ethanol production in the United States doubled between 1992 and 2002 and then quadrupled between 2002 and 2008. As Figure 1.1 indicates, ethanol production grew from about 2.1 billion gallons in 2002 to 9.2 billion gallons in 2008. Even with this large growth, the 6.5 billion gallons of ethanol produced in 2007 represented only about 3 percent of the energy content in gasoline consumed by motorists in the United States. For 2008, this figure will likely grow to about 4.5 percent.

The tremendous growth in the last six years can be attributed primarily to several factors. First, ethanol increased its market share when MTBE was phased out as a fuel oxygenate in many states due to its adverse impact on groundwater quality. Second, favorable prices enabled ethanol producers to earn significant profits and spurred additional investment in the industry. Producers benefited from elevated oil prices and low corn prices relative to the price of ethanol. Finally, an increasing number of states enacted mandates for the use of ethanol.

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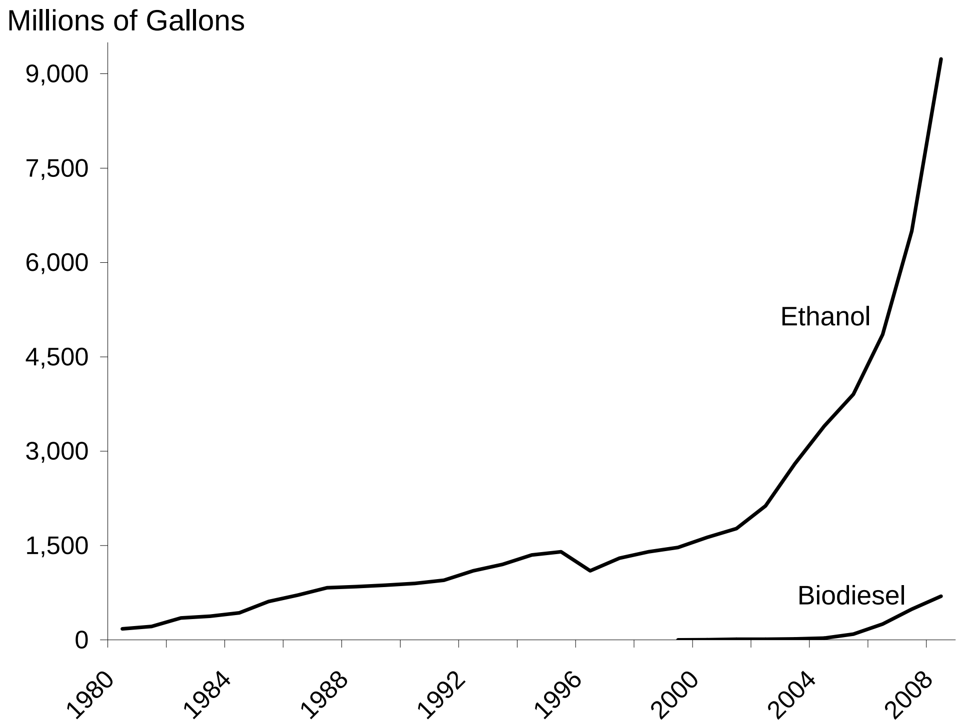
[17] Minnesota's production of ethanol was already high enough in 2006 (at 550 million gallons) to supply the ethanol needed to meet a 20 percent requirement. Because the current requirement was set at 10 percent, more than half the ethanol produced in 2006 (about 287 million gallons) was exported to markets outside the state.

[18] Fuel containing 2 percent biodiesel and 98 percent diesel fuel is called B2. Similarly, blends containing 5 percent biodiesel and 20 percent biodiesel are called B5 and B20, respectively.

Ethanol production in the United States has quadrupled since 2002.

Figure 1.1: Ethanol and Biodiesel Production in the United States, 1980-2008



SOURCES: Renewable Fuel Association, National Biodiesel Board, and the United States Department of Energy.

As a result, there are now 193 ethanol plants in the United States with a capacity of about 12.4 billion gallons per year. In addition, new construction and expansion is expected to add another 2.1 billion gallons of annual capacity. However, some of the existing capacity is idle due to bankruptcies and changing economic conditions.[19] The Renewable Fuels Association estimates that operating refineries have a capacity of 10.5 billion gallons per year, while refineries with a capacity of 1.9 billion gallons are idle.[20]

[19] Some of the idle capacity is due to bankruptcies brought on by large hedging losses incurred by ethanol producers. During 2008, both oil prices and agricultural commodity prices experienced dramatic swings, first increasing and then falling. Some ethanol producers took significant hedging positions both while corn prices were on their way up and while they were declining. Some of these producers incurred large hedging losses because their bets on the future direction of corn prices were incorrect. In addition, some of the idle capacity may include recently built plants that have contracted for corn at relatively high prices compared with the current price of ethanol.

[20] Renewable Fuels Association, "Biorefinery Locations," http://www.ethanolrfa.org/industry/locations, updated February 5, 2009, accessed February 9, 2009.

Currently, there are 18 ethanol plants operating in Minnesota with a total annual capacity of close to 850 million gallons.[21] Roughly 460 million gallons of additional capacity is under construction or has been constructed and has not yet begun operating. According to industry figures from November 2008, Minnesota ranks fourth in the nation in production capacity after Iowa, Nebraska, and Illinois.[22]

Actual ethanol production in Minnesota has grown from 35 million gallons in 1992 to 300 million gallons in 2002 and roughly 750 million gallons in 2008. Current production is more than double the amount used in Minnesota, so a majority of the ethanol produced in Minnesota is exported to other states.

Biodiesel

Biodiesel production has grown significantly but is still only about 1 percent of diesel consumption.

Like ethanol, biodiesel production in the United States has grown quickly in recent years. Between 2002 and 2007, biodiesel production grew from 10 million to 490 million gallons. Production for 2008 is estimated to be about 690 million gallons. Despite this growth, biodiesel production in 2008 represents only about 1.2 percent of the energy content in diesel fuel consumed in the transportation sector in the United States.

According to industry data, biodiesel production capacity has expanded even more than indicated by production data. Recent data suggest that there are 143 biodiesel plants with a combined annual capacity of close to 2.5 billion gallons. Another 32 plants are not currently producing any biodiesel but have a capacity of 0.3 billion gallons per year. In addition, plants and expansions now under construction will have an expected annual capacity of 0.3 billion gallons.

In Minnesota, there are two biodiesel plants currently operating with a combined annual capacity of 33 million gallons.[23] The total operating capacity in Minnesota is expected to increase to 36 million gallons per year in March 2009 when a third plant becomes operational. Minnesota has a fourth plant with an annual capacity of 30 million gallons, but it has been idle since mid-March 2008 due to high soybean oil costs relative to biodiesel prices.[24]

CORN AND SOYBEAN PRODUCTION

Because corn and soybeans are the primary feedstocks for ethanol and biodiesel in the United States, we examine both the long run and more recent trends in

[21] One of these 18 plants temporarily shut down production beginning in February 2009.

[22] The most up-to-date statistics available suggest that Minnesota also ranks high in the consumption of ethanol for highway transportation purposes. The data indicate that Minnesota was ranked third in the nation in 2003.

[23] One of the two operating plants has an annual capacity of 30 million gallons of biodiesel, while the other has a 3 million gallon capacity.

[24] Unlike Minnesota's other large plant which produces its own soy oil from soybeans provided by cooperative members, this plant purchases soy oil from outside suppliers.

their production.[25] We also examine how the amounts of corn and soybeans used for biofuels have changed in recent years.

Long Run Trends

The corn industry in the United States has experienced significant increases in production, fueled primarily by increases in yield per acre. From 1960 to 2008, corn production grew 210 percent.[26] Yield, measured in bushels per harvested acre, increased 193 percent, and the number of planted acres increased 6 percent.

Soybean production in the United States grew 433 percent from 1960 to 2008. Over this period, yield increased 72 percent, and the number of planted acres grew 210 percent. Much of the increase in acreage occurred, however, between 1960 and 1980, while most of the increase in yield came between 1980 and 2008. Since 1980, soybean production has grown 65 percent, compared with a 50 percent increase in yield and an 8 percent increase in planted acres.

Since 1960, the amount of land planted in either corn or soybeans increased by 53 percent. Most of this increase occurred between 1960 and 1980 due to the large expansion in the planted acres for soybeans. Between 1960 and 1980, combined acres planted increased 45 percent, but have increased by only 5 percent since 1980.

More Recent Trends

From 2001 to 2008, the percentage of corn used to produce ethanol in the United States has increased from 7 percent to an estimated 31 percent.

In examining more recent trends, we focused on the years from 2001 through 2008. Over this seven-year period, the percentage of the United States corn crop being used for ethanol has increased from about 7 percent to an estimated 31 percent. The percentage of soybeans used to make biodiesel has grown from less than 0.5 percent to an estimated 7 percent for 2008.

Corn

In the United States, corn production has grown 27 percent from 2001 to 2008. As Table 1.2 indicates, the increase in production has been due both to an 11 percent increase in yield and a 14 percent increase in planted acres.

Additional detail on the United States corn market is provided in Table 1.3. This table provides information on the sources and uses of corn in the United States. In particular, it shows how the uses of the United States corn crop have changed

[25] It is important to recognize that our summary of trends masks significant year-to-year variation in crop acreage, yields, and production. This variation occurs largely due to market conditions and weather conditions. Planted acreage depends on the perception of farmers about the profitability of various crops and on the weather conditions during the planting season. Year-to-year variation in yield, as opposed to long run trends, is largely due to weather conditions. Long run increases in yield have been a result of changes in farming practices and technology, improved seed characteristics, and increased or better use of fertilizers and pesticides.

[26] Figures for 2008 are based on the January estimates of production, yield, and acres from the United States Department of Agriculture.

during the recent surge in ethanol production. The figures are based on United States Department of Agriculture projections for the 2008-09 marketing year compared with actual figures for 2001-02.[27] The projections indicate that:

- **All of the increased corn production since 2001 has been used to increase the amounts of corn used to make ethanol.**

Other uses of corn such as animal feed, exports, and food are expected to decline modestly over this period.

These published figures are widely used but understate the amount of available animal feed. Distillers grains, a coproduct of the ethanol production process, can be used as a portion of the diets of certain livestock, including beef and dairy cattle, swine, and poultry. Distillers grains serve as a replacement for corn and soybean meal in animal feed.[28] The expansion of ethanol production in the

Since 2001, corn production has increased 27 percent due to both an increase in planted acres and growth in yields per acre.

Table 1.2: United States Corn and Soybean Production, Yield, and Acreage, 2001 and 2008

Corn and Soybean Statistics	2001	2008 (Estimated)	Percent Change, 2001-08
Corn			
Planted Acres	75,702,000	85,982,000	14%
Harvested Acres	68,768,000	78,640,000	14
Production (in bushels)	9,502,580,000	12,101,238,000	27
Yield per Harvested Acre (in bushels)	138.2	153.9	11
Soybeans			
Planted Acres	74,075,000	75,718,000	2%
Harvested Acres	72,975,000	74,641,000	2
Production (in bushels)	2,890,682,000	2,959,174,000	2
Yield per Harvested Acre (in bushels)	39.6	39.6	0

SOURCE: United States Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/QuickStats/PullData_US.jsp, accessed March 25, 2009.

[27] The 2008-09 marketing year for corn covers the period from September 2008 through August 2009. It captures the production from the corn crop planted in the spring of 2008 and harvested in the fall, as well as subsequent uses of the crop during the marketing year. The 2008-09 marketing year is best matched with ethanol production in calendar year 2009, although it technically covers corn used for ethanol production from September 2008 through August 2009. The period we examined is best matched with ethanol production from calendar year 2002 through 2009.

[28] For beef cattle, distillers grains are primarily a substitute for corn, but they can replace both corn and soybean meal in the diets of dairy cattle, swine, and poultry. The digestive systems of hogs and poultry are less suited for high levels of distillers grains in feed, and the portion of distillers grains in their diets must be more limited than for cattle.

All of the growth in corn production since 2001 has been used to produce ethanol.

United States has increased the production of distillers grains and their consumption both here and abroad.[29]

As a result, we adjusted the official statistics in Table 1.3 to reflect the additional corn feed and exports available as a result of the production of distillers grains.[30] However, as the last column in the table indicates, an adjustment for distillers grains production does not change the previously stated conclusion about the increase in ethanol production. Since 2001, all of the increase in corn production has gone to ethanol production. When the figures in Table 1.3 are adjusted, the corn used for ethanol has increased by more than 400 percent since 2001-02, while other uses of corn such as animal feed, exports, and food and other industrial uses have each decreased by 2 or 3 percent.

Table 1.3: Sources and Uses of United States Corn, in Millions of Bushels, 2001-02 and 2008-09

	Official Statistics			Statistics Adjusted for Distillers Grains Production		
Sources and Uses of Corn	2001-2002 Marketing Year	2008-2009 Marketing Year (Projected)	Percent Change, 2001-02 to 2008-09	2001-2002 Marketing Year	2008-2009 Marketing Year (Projected)	Percent Change, 2001-02 to 2008-09
Beginning Stocks	1,899	1,624	-14%	1,899	1,624	-14%
Imports	10	15	48	10	15	48
Production	9,503	12,101	27	9,503	12,101	27
Distillers Grains	NA	NA	NA	150	837	456
Total Supply	11,412	13,740	20%	11,562	14,577	26%
Ethanol	706	3,700	424%	706	3,700	424%
Other Food, Seed, and Industry	1,340	1,300	-3	1,340	1,300	-3
Feed and Residual	5,864	5,300	-10	6,002	5,995	0
Exports	1,905	1,700	-11	1,917	1,842	-4
Total Use	9,815	12,000	22%	9,965	12,837	29%
Ending Stocks	1,596	1,740	9%	1,597	1,740	9%

NOTE: Official statistics were adjusted to reflect the impact of distillers grains production as a coproduct of ethanol production. The adjustments were based on adjustments made to the marketing year 2008-09 by Robert Wisner of Iowa State University.

SOURCE: United States Department of Agriculture, as adjusted by the Office of the Legislative Auditor. Official projections for 2008-09 are from the World Agricultural Supply and Demand Estimates, United States Department of Agriculture, March 11, 2009.

[29] The Renewable Fuels Association estimates that the ethanol industry produced 14.6 million metric tons of distillers grains in 2007.

[30] We used estimates made by Robert Wisner, an economist at Iowa State University, to make these adjustments. We had to prorate his figures since they were based on an earlier and slightly different estimate of the amount of corn to be used for ethanol production. In addition, we adjusted the 2001-02 figures to reflect the impact of distillers grains production. Wisner estimates that, after adjusting for distillers grains production, the ethanol industry used about 25 percent, rather than 30 percent, of the acres of corn harvested in 2008. For Wisner's estimates, see http://www.extension.iastate.edu/agdm/crops/outlook/dgsbalancesheet.pdf; accessed February 2, 2009.

Soybeans

From 2001 to 2008, soybean production in the United States has grown only 2 percent. The number of acres planted in soybeans has increased by 2 percent, but the yield per harvested acre has been unchanged.[31] The increase in production of biodiesel has not affected exports of soybeans and soybean meal, which increased 3 percent and 5 percent, respectively, over this period. However, exports of soybean oil have declined 31 percent, and domestic use of soy oil—other than for biodiesel—has declined about 12 percent.

These trends reflect the fact that soybeans are used to make both soybean meal and soybean oil. Only the soybean oil is used to make biodiesel. Less than 20 percent of the weight of a soybean is oil, while close to 80 percent can be made into soybean meal. As a result, the significant expansion in biodiesel over the last seven years has not resulted in reductions in soybean or soybean meal exports but has reduced the amount of soybean oil available for exports or domestic use other than biodiesel.

Ethanol plants produce distillers grains, which are used to replace some of the corn and soybean meal fed to livestock.

These statistics from the United States Department of Agriculture do not reflect, however, the impact of distillers grains on soybean meal markets. As we discussed earlier, distillers grains can replace some of the soybean meal in the diets of certain livestock. The increase in their production expands the available soybean meal for animal feed use. An estimate from Iowa State University for the 2008-09 marketing year suggests that distillers grains will provide the equivalent of the soybean meal produced from 5 million acres of soybeans. Those 5 million acres represent about 42 percent of the acres of soybeans expected to be used for biodiesel. The extra animal feed from distillers grains will not, however, reduce the need for acres to produce biodiesel because soy oil—not soybean meal—is used to make biodiesel.

[31] Since 2001, the combined acres planted with corn or soybeans have increased 8 percent.

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Energy Issues

According to supporters of biofuels, one of the primary reasons for using biofuels is to reduce imports of foreign oil. Imports have grown from about one-third of United States oil consumption in 1973 to close to two-thirds in 2007. Proponents believe that producing biofuels domestically is preferable to a growing reliance on imports from nations with unfriendly or unstable governments.

In this chapter, we focus much of our attention on the potential impact of biofuels on petroleum consumption. We first provide some background information on the source of crude oil supplies in the United States. Second, we consider whether biofuels such as corn-based ethanol and soy-based biodiesel contain more energy than is used in their production. Third, we use the results from various scientific studies to calculate how much fossil fuel energy in general, and petroleum energy in particular, can be saved for each gallon of biofuel production. Finally, we consider the extent to which the United States can rely on crop-based feedstocks like corn and soybeans, or other alternative fuels such as cellulosic ethanol, to reduce its dependence on petroleum. Among the issues we consider are the amount of corn ethanol and soy biodiesel that can be produced on existing cropland and the amount of additional land that would be needed to achieve various levels of petroleum savings.

SOURCES OF OIL SUPPLY

Imports account for nearly two-thirds of petroleum consumption in the United States.

In 2007, supplies of petroleum products in the United States averaged about 20.7 million barrels per day. The total amount supplied for the year was about 317 billion gallons. Imports of oil and refined petroleum products were about 65 percent of the total amount supplied in the United States in 2007.[1]

Imports of oil and petroleum products come from a number of countries. In 2007, Canada and Mexico topped the list of countries from which the United States imported oil. Canada alone was the source of 18 percent of imports and 12 percent of total petroleum supplies in the United States. Other large sources of oil for the United States included Saudi Arabia, Venezuela, and Nigeria.

The Organization of the Petroleum Exporting Countries (OPEC) accounted for 44 percent of imports into the United States and 29 percent of total supply, while non-OPEC countries like Canada and Mexico accounted for 56 percent of imports and 36 percent of overall supply. The percentage of the nation's oil supply that came from Persian Gulf nations was relatively small. Only 16

[1] The United States also exports some oil and petroleum products. Net imports—or total imports less exports—were 58 percent of the nation's supply of petroleum.

Imports from Canada account for roughly three-fourths of Minnesota's petroleum consumption.

percent of imports and 10 percent of total supply were from Persian Gulf nations.[2]

Less information is available on the sources of Minnesota's oil and petroleum supplies. However, using data from the United States Department of Energy, we estimate that about three-fourths of Minnesota's supply came from Canada in 2006.

NET ENERGY FROM BIOFUELS

Some critics have long maintained that more fossil fuel energy is consumed in producing corn-based ethanol than is contained in ethanol. In this section, we consider that claim and examine the net energy balance from other biofuels such as soy-based biodiesel and cellulosic ethanol. The results reported in this section and the following section are based on life-cycle analyses reported in the scientific literature. These analyses consider the full implications of biofuel use including energy used to produce and transport corn and to produce and distribute ethanol.

Corn-Based Ethanol

Corn-based ethanol provides at least 25 percent more energy than is contained in the fossil fuel consumed in its production.

Despite the claims of some critics, the general scientific consensus today is that:

- **Corn-based ethanol provides more energy than the fossil fuel energy consumed in producing it.**

Estimates of corn ethanol's "net energy balance" vary, but most studies confirm that it provides more energy than contained in the fossil fuels consumed in the production of corn and ethanol. For example, a 2006 study from the University of Minnesota concluded that corn-based ethanol yields 25 percent more energy than is consumed in its production.[3] Data from a 2006 study from the University of California, Berkeley show the net energy gain to be about 27 percent.[4] A recently released study from the University of Nebraska-Lincoln estimates the net energy gain to be much higher based on more recent data on corn yields and

[2] The major Persian Gulf sources of oil and petroleum products for the United States included Saudi Arabia, Iraq, and Kuwait. Saudi Arabia supplied about two-thirds of the imports from the Persian Gulf.

[3] Jason Hill, Erik Nelson, David Tilman, Stephen Polasky, and Douglas Tiffany, "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103 (July 25, 2006): 11206-11210.

[4] See Alexander Farrell, Richard Plevin, Brian Turner, Andrew Jones, Michael O'Hare, and Daniel Kammen, "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311 (January 27, 2006): 506-508. We derived the 27 percent figure from the data in Figure 2 of the article.

energy use on farms and by ethanol plants.[5] The Nebraska study finds an energy gain of 61 percent for a dry mill ethanol plant in the Midwest powered by natural gas.[6]

Recent studies have discredited those analyses that said corn-based ethanol contained less energy than the fossil fuel energy consumed in its production.[7] The analyses critical of corn ethanol failed to consider the coproducts such as distillers grains that are made during the production of ethanol.[8] In addition, the analyses either used out-of-date information or were poorly documented.

A 2007 Argonne National Laboratory study further shows that:

- **The net energy gain from corn-based ethanol varies depending on the fuel used in the ethanol production process.**

Some Minnesota plants have installed technology and equipment that reduces their fossil fuel use and increases the net energy gain from ethanol.

The results from the Argonne study appear to indicate that the current net energy gain from the average corn-based ethanol plant is roughly 30 percent.[9] But a new ethanol plant fueled by coal would have only about a 20 percent gain, while a new plant powered by biomass would have an energy gain of close to 190 percent. A new plant powered by natural gas and corn syrup would have an energy gain of about 67 percent.

We found no source of data on the net energy gain for Minnesota's ethanol plants. It is possible that the net energy gain for the average ethanol plant in Minnesota is greater than the gain for the average plant in the Argonne study. Minnesota has three ethanol plants that are using or converting to an alternative energy source, and those plants may have a net energy gain well in excess of the

[5] Adam Liska, Haishun Yang, Virgil Bremer, Terry Klopfenstein, Daniel Walters, Galen Erickson, and Kenneth Cassman, "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol," *Journal of Industrial Ecology*, published online on January 21, 2009; http://www3.interscience.wiley.com/cgi-bin/fulltext/121647166/PDFSTART, accessed January 26, 2009.

[6] The study also estimates that corn-based ethanol in Minnesota has the third highest net energy yield per unit of land among 19 ethanol-producing states. Whether this ranking is appropriate is unclear. The study uses state-by-state data on corn yield, fertilizer and insecticide use, and farm energy use. However, the study uses the same survey data on ethanol plant conversion yield and energy use for all states. The survey data are based on a small number of dry mill plants, two-thirds of which were built after 2001. In Minnesota, only one-third of the currently operating plants were built after 2001.

[7] Farrell et al., 506.

[8] Ethanol plants produce ethanol and other products such as distillers grains. Analyses critical of ethanol assigned all the energy use at the plant to the production of ethanol and none to coproducts like distillers grains. Such an assumption is not reasonable, since the production process results in more than one marketable product. For every bushel (or 56 pounds) of corn, up to 2.8 gallons of ethanol and 18 pounds of distillers grains may be produced. In addition, some of the energy used in dry mill ethanol plants is specifically directed at drying distillers grains often with natural gas.

[9] See Michael Wang, May Wu, and Hong Huo, "Life-Cycle Energy and Greenhouse Gas Emissions of Different Corn Ethanol Plant Types," *Environmental Research Letters* 2: 024001 (May 22, 2007), http://www.iop.org/EJ/article/1748-9326/2/2/024001/erl7_2_024001.pdf?request-id =c4950a50-935f-4a1b-8cf9-5191c27271c0, accessed September 9, 2008. The 30 percent number is based on our reading of Figure 6.

industry average.[10] However, additional data would need to be collected on all of Minnesota's ethanol plants in order to calculate an average net energy gain for Minnesota's ethanol industry. We did not attempt to complete such a task due to limits on our time and resources.

Soy-Based Biodiesel

In general, we found that:

- **Soybean-derived biodiesel provides significantly more energy than is contained in the fossil fuels used in its production.**

For example, the 2006 University of Minnesota study cited above found that soybean biodiesel contains 93 percent more energy than the fossil fuels used in its production.[11]

Cellulosic Ethanol

In the scientific literature:

Studies suggest that cellulosic ethanol would provide a much larger energy gain than corn-based ethanol.

- **Cellulosic ethanol is believed to have a much more favorable energy ratio than corn-based ethanol.**

A 2006 study found that ethanol produced from grassland biomass would provide energy that was 444 percent greater than the fossil fuel energy used to produce it.[12] Data from another study suggest an even higher net energy gain, close to 900 percent.[13]

While these results are encouraging, some caution should be used in applying these preliminary results to public policy. Because cellulosic ethanol is not being widely produced, only rough estimates of the energy used in growing, harvesting, and transporting cellulosic feedstock and converting it to ethanol are available. More precise information is needed to produce an accurate life-cycle analysis.

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[10] Corn Plus in Winnebago is burning leftover corn syrup from the ethanol production process in a fluidized bed reactor in order to reduce its natural gas usage by more than 50 percent. In addition, Corn Plus uses two wind turbines to provide a portion of its ethanol plant's electricity. Chippewa Valley Ethanol Company in Benson has installed technology that will burn corn cobs and provide energy for its plant. The biomass energy would replace up to 90 percent of its natural gas use. In addition, the new technology may eventually facilitate the production of cellulosic ethanol. Central Minnesota Ethanol Cooperative (CMEC) in Little Falls has installed technology to burn wood waste to reduce or eliminate its natural gas and electricity needs. There have been some problems with the CMEC plant's new power system that have prevented it from becoming operational. These three plants produce about 14 percent of the ethanol produced in Minnesota.

[11] Hill et al., 11207.

[12] See David Tilman, Jason Hill, and Clarence Lehman, "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science* 314 (December 8, 2006): 1598-1600. Their results are based on low-input high-diversity native grassland perennials grown on test plots in Minnesota.

[13] See Farrell et al., 507. We derived this percentage from the data in Figure 2 of the article.

For example, a recent report points out that most life-cycle analyses have not adequately considered the impact of process chemicals and enzymes that will be needed for biochemical production of cellulosic ethanol.[14] Current life-cycle analyses are thus very preliminary in nature and will need to be refined as cellulosic ethanol production increases.

PETROLEUM AND FOSSIL FUEL SAVINGS

Another issue often raised is how much petroleum and fossil fuel consumption in the United States can be reduced by using biofuels.[15] Fossil fuels include natural gas and coal, as well as petroleum products. We first examine how much biofuels can reduce fossil fuel consumption, particularly petroleum consumption. For ease of understanding, we translate the results from the scientific literature, which are figured on an energy equivalent basis, into savings per gallon of biofuel. Then, we consider how many gallons of various biofuels can reasonably be produced in the foreseeable future, given land and other constraints. We examine these questions for corn-based ethanol, biodiesel, and cellulosic ethanol.

Corn-Based Ethanol

A primary benefit of corn-based ethanol is reduced consumption of petroleum and other fossil fuels.

In general:

- **Corn-based ethanol provides fossil fuel savings, and even larger petroleum savings on an energy unit basis.**

Data from several studies suggest that using ethanol rather than gasoline reduces fossil fuel energy use by at least one-third to create the same amount of energy.[16] In other words, if ethanol containing 1 million British thermal units (BTUs) is substituted for 1 million BTUs of gasoline, then fossil fuel consumption is reduced by at least 333,333 BTUs. The reduction in fossil fuel use is closer to three-fourths if biomass is used to fuel the corn ethanol plant.[17]

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[14] See Heather MacLean and Sabrina Spatari, "The Contribution of Enzymes and Process Chemicals to the Life Cycle of Ethanol," *Environmental Research Letters* 4: 014001 (January 13, 2009), http://www.iop.org/EJ/article/1748-9326/4/1/014001/erl9_1_014001.pdf?request-id=d6df0be9-c4a5-4405-bd83-c35c75580092, accessed February 12, 2009. This study concludes that, even with considerable improvement over current performance, process chemicals and enzymes will be responsible for 30 to 40 percent of the fossil fuel use for cellulosic ethanol. This compares with only about 3 percent for corn ethanol.

[15] The issue of how much fossil fuel consumption can be saved by various biofuels is closely related to the issue of net energy balance discussed above. If a biofuel produces more energy than contained in the fossil fuels used in its production, then its use in motor vehicles will reduce fossil fuel consumption. To make the latter calculation, one must also consider the fossil fuel used to produce petroleum-based fuels like gasoline or diesel. Studies generally assume that it takes roughly 1.2 million British thermal units (BTUs) of fossil fuel to produce 1.0 million BTUs of gasoline or diesel.

[16] This estimate is based on data in Farrell et al., 507, and Wang et al., 9.

[17] See Figure 6 in Wang et al., 9.

The savings in petroleum use from corn-based ethanol are even greater since natural gas and coal are used more than petroleum in making corn ethanol. Data from several studies suggest a petroleum savings of 90 to 95 percent when using corn ethanol rather than gasoline. At the 95 percent level, this means that:

- **One gallon of 100 percent corn-based ethanol replaces about 0.69 gallons of gasoline.**

As Table 2.1 illustrates, a gallon of E100 saves less than one gallon of gasoline because ethanol has about 66 percent of the energy or heat content of gasoline.[18] Motor vehicles currently on the road, including flex-fuel vehicles that can use E85, are optimized for gasoline use. As a result, their fuel mileage declines in rough proportion to the energy content of the fuel. Simply put, ethanol blends can be expected to get lower mileage than pure gasoline in today's motor vehicles. Consequently, the savings from a gallon of E100 must be adjusted to reflect its lower gas mileage compared with gasoline.

Table 2.1: Petroleum Savings from Corn-Based Ethanol

Fuel Production and Petroleum Use	Ethanol	Gasoline	Petroleum Saved by Ethanol	Percent Reduction in Petroleum Use
Amount Produced (BTUs)	1,000,000	1,000,000		
Amount of Petroleum Used in Production[a]	50,000	1,100,000	1,050,000	95%

Petroleum Savings Relative to Ethanol Production	Ethanol	Petroleum Savings in Gasoline Equivalent Units[b]	Gallons of Gasoline Saved per Gallon of Ethanol Produced
Ethanol Produced and Petroleum Saved (BTUs)	1,000,000	1,050,000	
Energy Content (BTUs per Gallon)	75.670	115,400	
Ethanol Produced and Petroleum Saved (Gallons)	13.2	9.1	0.69

[a] The petroleum savings were estimated using the results from Figure 2 in Alexander Farrell, Richard Plevin, Brian Turner, Andrew Jones, Michael O'Hare, and Daniel Kammen, "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311 (January 27, 2006): 507. The data in Farrell et al. were converted from megajoules of energy to British Thermal Units (BTUs).

[b] The petroleum savings were converted to gasoline equivalent gallons to allow a comparison of the volume of gasoline saved per gallon of ethanol production.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

[18] Table 2.1 shows that producing 1,000,000 BTUs of corn-based ethanol (or 13.2 gallons) requires 1,050,000 fewer BTUs of petroleum than producing 1,000,000 BTUs of gasoline (or 8.7 gallons). This difference is largely due to the fact that gasoline is made from petroleum and ethanol is made from corn, although there is also a small difference in the amount of petroleum used in the production and distribution processes for the two fuels. The petroleum savings from 13.2 gallons of ethanol involve 1,050,000 BTUs, or about 9.1 gallons of petroleum in gasoline-equivalent units. The volume of gasoline saved per gallon of ethanol produced is thus 0.69 gallons, or 9.1 divided by 13.2.

Ethanol does have some advantages over gasoline in that ethanol has a higher octane rating and vaporizes at higher temperatures than gasoline. If an engine is developed that is optimized for ethanol use, the mileage disadvantage for ethanol could be reduced.[19]

Each gallon of corn-based ethanol can reduce petroleum consumption by the equivalent of about 0.7 gallons of gasoline.

The reductions in gasoline use per gallon of blended fuel are proportionately less when lower percentages of ethanol are blended with gasoline. While one gallon E100 reduces gasoline consumption by about 0.69 gallons, one gallon of E10 reduces gasoline consumption by about 0.07 gallons. As indicated in Table 2.2, a gallon of E20 reduces gasoline use by about 0.14 gallons, and a gallon of E85 reduces gasoline use by about 0.59 gallons. Table 2.2 also provides information on the fossil fuel savings for corn ethanol and soy-based biodiesel blends and converts those energy savings to a petroleum-based equivalent.

Table 2.2: Petroleum and Fossil Fuel Savings per Gallon of Blended Fuel

Biofuel Blends	Number of Gallons of Petroleum Fuel Saved per Gallon of Blended Fuel	Fossil Fuel Savings per Gallon of Blended Fuel (converted to gallons of gasoline or diesel fuel)
Corn Ethanol	Gasoline	Gasoline
E100	0.69	0.26 to 0.37
E85	0.59	0.22 to 0.32
E20	0.14	0.05 to 0.07
E10	0.07	0.03 to 0.04
Soy Biodiesel	Diesel Fuel	Diesel Fuel
B100	0.96	0.83
B20	0.19	0.17
B5	0.05	0.04
B2	0.02	0.02

NOTE: The range in fossil fuel savings for ethanol blends reflects the difference in results for ethanol in the Farrell et al. and Liska et al. studies.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

Soy-Based Biodiesel

Available data indicate that:

[19] Recent press reports say that Ricardo, an engineering research firm based in Detroit, has developed a concept engine that is designed to take advantage of ethanol's higher octane rating and lower combustion temperatures. The engine, which has only been tested in a laboratory, would reportedly improve fuel mileage for ethanol blends. See Duncan Graham-Rowe, "A More Efficient Ethanol Engine," *Technology Review* (February 19, 2009), http://www.technologyreview.com/energy/22198/?a=f, accessed February 20, 2009.

- **Soybean-based biodiesel provides significant fossil fuel savings, and large petroleum savings on an energy unit basis.**

A 2009 study concluded that using the same amount of energy from soybean-based biodiesel rather than diesel fuel reduces fossil fuel energy use by roughly 66 to 84 percent.[20] In other words, if biodiesel containing 1 million BTUs is substituted for diesel fuel, then fossil fuel consumption is reduced by 666,667 to 840,000 BTUs.

As was the case for corn ethanol, the savings in petroleum use from biodiesel are even greater than the fossil fuel savings. The recent study cited above suggests a petroleum savings from about 90 to slightly more than 100 percent when using biodiesel rather than diesel fuel.[21] At the 95 percent level, this means that:[22]

- **One gallon of 100 percent soy-based biodiesel replaces about 0.96 gallons of diesel fuel.**

A gallon of soy biodiesel reduces petroleum consumption by more than a gallon of corn-based ethanol, but significantly more ethanol can be made from an acre of land.

The reductions in diesel use are proportionately less per gallon of blended fuel when lower percentages of biodiesel are used. For example, the use of one gallon of B2 reduces diesel consumption by about 0.02 gallons, while a gallon of B5 reduces diesel use by 0.05 gallons.

A gallon of pure biodiesel replaces about 55 percent more petroleum energy than is replaced by a gallon of ethanol. However, it should be pointed out that an acre of corn used for ethanol can reduce petroleum energy use by more than four times as much as an acre of soybeans used for biodiesel. The advantage for corn in reducing fossil fuel energy use is less than for petroleum, but still double that of biodiesel. The advantage for corn results from its higher crop yields—153.9 bushels per acre versus 39.3 bushels per acre—and the larger amounts of biofuel that can be produced per bushel.

Cellulosic Ethanol

As mentioned earlier, estimates of fossil fuel and petroleum savings from cellulosic ethanol are tentative at this point. Better estimates will be possible once the primary feedstock and production process are established. Nevertheless, preliminary estimates suggest that:

- **Cellulosic ethanol is expected to provide large fossil fuel and petroleum savings on an energy unit basis.**

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[20] Hong Huo, Michael Wang, Cary Bloyd, and Vicky Putsche, "Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels," *Environmental Science & Technology* 43 (February 1, 2009): 750-756. The numbers cited above are based on Figure 3 in the Huo et al. article. The range in the results is due to different methods used to allocate energy use to the coproducts of biodiesel production.

[21] See Figure 4 in Huo et al., 755.

[22] The savings are less than one gallon of diesel fuel because a gallon of biodiesel has an energy content that is about 9 percent less than that in the average gallon of diesel fuel.

For example, the data from one study suggest that using the same amount of energy from cellulosic ethanol rather than gasoline reduces both fossil fuel and petroleum consumption by between 90 and 95 percent.[23] Compared with corn-based ethanol, the fossil fuel savings for cellulosic ethanol are greater and the petroleum savings are similar.

REDUCING PETROLEUM DEPENDENCE

As discussed above, existing studies show that the use of corn-based ethanol and soybean-based biodiesel reduces the nation's reliance on petroleum-based fuels. However, an equally important issue is how much the nation can reduce petroleum dependence through a reliance on biofuels produced from agricultural crops or other biomass. In this section, we first discuss the ability of corn and soybeans to reduce petroleum dependence. Then, we briefly discuss cellulosic ethanol and algae-based biodiesel.

Land availability limits the overall ability of corn-based ethanol and soy biodiesel to replace petroleum-based fuels.

Corn-Based Ethanol and Soy Biodiesel

In general, we found that:

- **Land resource constraints limit the ability of corn ethanol and soy biodiesel to replace petroleum-based fuels.**

The impact of land resource constraints is illustrated below in two ways. First, we examine the percentage of corn and soybean cropland currently being used to produce ethanol and biodiesel and the reduction in gasoline and diesel use expected to result from the production of these biofuels. We also estimate how large the reduction in gasoline and diesel use would be if all the current corn and soybean production was used to make ethanol and biodiesel. Second, we estimate how much land would need to be used for corn production in order to achieve ethanol usage equivalent to nationwide use of E10, E20, or E85. We also estimate how much nationwide use of E10, E20, or E85 would reduce the use of gasoline. Similarly, we consider the land and petroleum implications of nationwide use of B2, B5, or B20.

Regarding this first point, we concluded that:

- **Using all current corn and soybean production in the United States to produce ethanol and biodiesel would replace only about 17 percent of gasoline use and less than 9 percent of diesel fuel use and would have significant economic and environmental implications.**

Table 2.3 shows that about 31 percent of the land planted with corn in the United States in 2008 is expected to be used to produce ethanol. The ethanol from that

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[23] See Figure 2 in Farrell et al., 507.

corn will replace about 5.2 percent of the nation's gasoline use.[24] In addition, about 6.5 percent of the land planted with soybeans in 2008 is expected to be used to produce biodiesel. The resulting biodiesel will replace about 0.6 percent of the nation's diesel fuel use in motor vehicles.

If all of the land planted with corn and soybeans in 2008 had instead been used for biofuels, the ethanol and biodiesel produced would have replaced about 17 percent of the nation's gasoline use and 8.7 percent of the nation's diesel fuel use. These figures are higher than the 12 percent and 6 percent figures estimated in a 2006 University of Minnesota study.[25] The increase in the potential gasoline

Using all the U.S. acres planted with corn or soybeans in 2008 for biofuel production would only replace 17 percent of gasoline use and 9 percent of diesel consumption.

Table 2.3: Acres in the United States Used for Corn Ethanol and Soy Biodiesel and Estimated Petroleum Savings, 2008-09

	Corn Ethanol and Gasoline	Soy Biodiesel and Diesel Fuel
Estimated Use		
Percentage of Corn or Soybean Acres Used for Biofuel, 2008-09[a]	30.6%	6.5%
Percentage of Gasoline or Diesel Use Replaced, 2009	5.2	0.6
Hypothetical Scenario: All Planted Acres Used for Biofuels[b]		
Percentage of Corn or Soybean Acres Used for Biofuel, 2008-09	100.0%	100.0%
Percentage of Gasoline or Diesel Use Replaced, 2009	16.9	8.7

NOTE: This table compares the projected use of corn and soybeans for biofuels during the 2008-09 marketing year with fuel consumption in 2009. Overall fuel consumption for 2009 is assumed to be the same as in 2008. Ethanol and biodiesel made from other feedstocks than corn and soybeans are not included in the table.

[a] We estimated the percentages of crops used for biofuels using data in the World Agricultural Demand and Supply Estimates from the United States Department of Agriculture as of March 11, 2009. The estimated use of soybeans for biodiesel during the 2008-09 marketing year is much lower than during the previous year. During the 2007-08 marketing year, about 9.8 percent of the oil from the soybean crop was used for biodiesel. The Department is projecting significantly lower biodiesel production from the current year's crop due to deteriorated market conditions for biodiesel producers.

[b] The hypothetical scenario assumes all United States corn production in 2008 is used for corn ethanol and all soybean production is used for biodiesel.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

[24] Figures on estimated savings in gasoline or diesel fuel use have been adjusted to reflect: (1) the amount of petroleum used to produce ethanol and biodiesel, and (2) the energy content of those biofuels relative to gasoline and diesel fuel.

[25] See Hill et al., 11208. The authors also concluded that devoting all 2005 corn and soybean production to biofuels would only have provided a net energy savings equivalent to just 2.4 percent of gasoline consumption and 2.9 percent of diesel consumption. This result reflects the total amount of fossil fuel, including natural gas and coal as well as petroleum, used in the production of ethanol and biodiesel.

and biodiesel savings reflect changes in the amount of land used for corn and soybeans, increases in crop yields and biofuel conversion yields per bushel, and a reduction in the nation's use of gasoline and diesel fuel.

But using the entire U.S. corn and soybean crops for biofuels would have adverse economic and environmental impacts.

However, the implications of using that much land exclusively for biofuels would be significant. First, corn could no longer be used for exports and the domestic food industry. In addition, soy oil for domestic food use and exports would be eliminated. Second, less corn would be available for animal feed even though ethanol production would produce distillers grains that could be used as animal feed. Finally, using all corn and soybean production for biofuels would put considerable pressure for converting land in the United States and other countries to corn and soybean production to replace the corn and soybeans no longer available for non-biofuel uses. As we will discuss in Chapter 3, the land use implications could potentially increase greenhouse gas emissions.

Table 2.3 is useful in illustrating the land use constraints facing biofuels, but no one, including advocates of biofuels, is suggesting that all corn and soybean production be used for biofuels. Instead, the arguments are usually about the land use and petroleum implications of various biofuel mandates or the federal Renewable Fuel Standard (RFS). In addition, it is appropriate to consider the ability of the agricultural sector to meet these various mandates or standards in the future, since crop yields have historically increased over time.

Nationwide use of E10 is achievable by 2015 with only a modest increase in the land dedicated to corn-based ethanol.

Consequently, we also looked at the land and petroleum implications of various biofuel usage levels. In these analyses, we assumed that corn-based ethanol and soy-based biodiesel were the only biofuels produced. We made this assumption to see how much the nation can rely on these two fuels to reduce gasoline and diesel consumption. The results help illustrate how much these two fuels may reduce petroleum consumption over the next decade and the extent to which other biofuels such as cellulosic ethanol would be needed to supplement current biofuels. We found that:

- **Nationwide use of E10 could probably be achieved by 2015 with only a modest increase in the share of corn production dedicated to ethanol.**

- **But E20 would likely require a significant increase in the amount of land used for corn-based ethanol, and nationwide E85 use cannot be accomplished by 2020 even using all available corn production.**

Currently, about 31 percent of 2008 corn production is expected to be used for ethanol. As shown in Table 2.4, we estimated about 37 percent of the corn produced in 2015 would be needed in order to produce 14.2 billion gallons of ethanol. That amount of ethanol is equivalent to the amount needed to have E10 used nationwide and is a little smaller than the 15 billion gallons of conventional biofuel allowed under the federal RFS in 2015.[26] An E10 equivalent level of usage would replace about 7 percent of the nation's gasoline use. Figure 2.1 illustrates the land use implications of E10 and other ethanol blends in 2020.

Nationwide usage of E20 would reduce gasoline use by 14 percent, but would require 73 percent of the corn crop in 2015 and 65 percent in 2020. Nationwide E85 usage would reduce gasoline use by 59 percent, but is not possible without a dramatic increase in the amount of land dedicated to corn ethanol production. Even by 2020, nationwide E85 usage would require almost 2.8 times the total acres that were planted with corn in 2008.

Table 2.4: Acres in the United States Needed for Corn Ethanol in 2015 and 2020 as a Percentage of Acres Planted in 2008

Corn and Ethanol Yield Scenario[a]	2015 E10	2015 E20	2015 E85	2020 E10	2020 E20	2020 E85
Very Optimistic Growth	29%	58%	245%	22%	44%	186%
Optimistic Growth	31	62	263	28	55	235
Average Growth	37	73	312	32	65	276
Less Than Average Growth	40	81	343	38	75	321
No Growth	45	89	378	44	89	377
Billions of Gallons of Ethanol	14.2	28.4	120.5	14.1	28.2	120.0
Percentage of Gasoline Use Replaced	7%	14%	59%	7%	14%	59%

NOTE: This analysis assumes that the total number of acres planted with corn does not change from 2008 through 2020. About 31 percent of 2008 corn production is expected to be used for ethanol production. A percentage higher than 31 percent in this table indicates that the percentage of acres used for ethanol production would need to be higher than in 2008. A percentage less than 31 percent indicates that the percentage of acres used for ethanol production would decrease. A percentage higher than 100 percent means that the amount of land used for ethanol would have to be greater than all the land planted with corn in 2008. It should be noted that the figure of 31 percent is based on a March 2009 estimate from the United States Department of Agriculture. That estimate may change as the department receives new information.

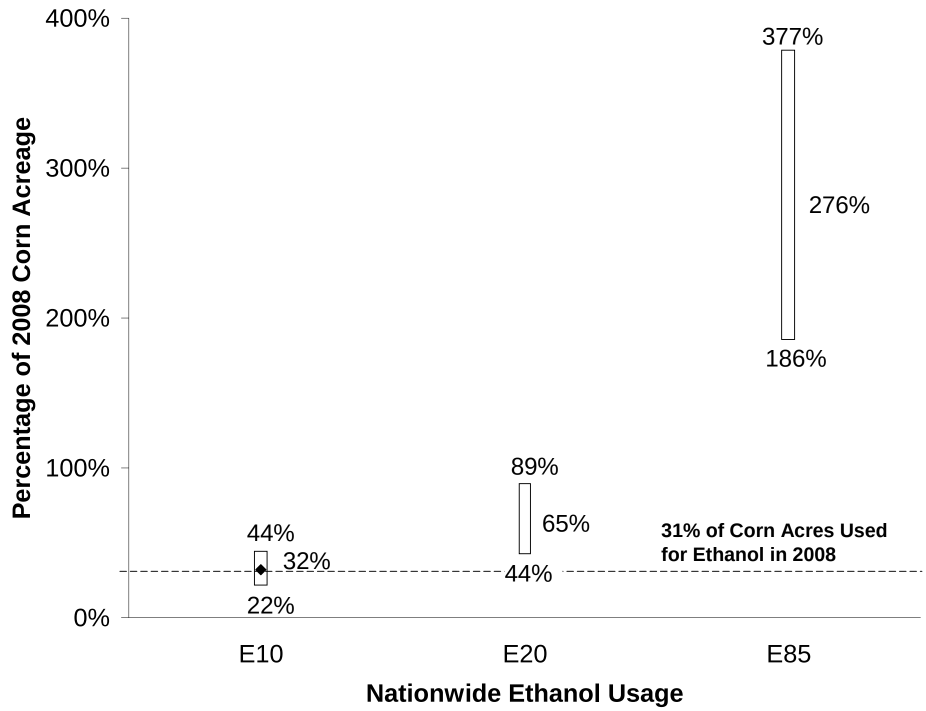
[a] The very optimistic scenario assumes corn yield per acre increases 3.53 percent annually, starting with a 2007 value of 151.1 bushels per acre. Ethanol yield per bushel increases 2 percent annually, starting with a 2007 yield of 2.68 gallons of ethanol per bushel of corn. The optimistic scenario assumes corn yield increases an average of 2.18 percent annually but increases are faster in early years. Similarly, ethanol yield increases 1.49 percent annually, but the increases are higher in earlier years than later years. The average growth scenario assumes corn yield increases 1.67 percent annually and ethanol yield increases 0.75 percent annually. Under the less than average growth scenario, corn yield increases 1 percent annually and ethanol yield increases 0.25 percent annually. Under the no growth scenario, corn and ethanol yields are fixed at 2007 levels.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

[26] Our estimates assume that all motor vehicles powered by gasoline are using E10, or alternatively E20 or E85. This assumption should not be confused with the blending rate set by the Environmental Protection Agency (EPA). The 2009 blending rate is 10.21 percent, which is the rate at which ethanol must be blended with gasoline in order to achieve the required 11.1 billion gallons of biofuel use. While the blending rate is slightly above 10 percent, this does not mean that 10 percent of all motor vehicle fuel consumption would be from ethanol. About 14 percent of gasoline consumption is exempted from blending requirements because it comes from small refineries. In addition, the state of Alaska has an exemption.

These estimates were based on an annual growth rate of 1.67 percent in corn yield, which is the average rate of growth over the last 40 years. In addition, we assumed that the amount of ethanol produced per bushel of corn would increase 0.75 percent annually. The amount of land planted with corn was held constant over time in order to isolate the land use implications of increasing yields and various levels of ethanol production.

Figure 2.1: Percentage of Corn Acres in the United States Needed for Ethanol in 2020



NOTE: We assume that the total number of acres planted in corn do not change from 2008 to 2020. We then estimate the percentage of 2008 corn acres that will be needed to meet certain national ethanol usage levels in 2020. Any percentage greater than 31 percent indicates that more acres will need to be devoted to ethanol production than were used in 2008. The percentage in the middle of each bar represents an estimate based on average past growth in corn yields. The bottom percentages on each bar represent very optimistic estimates of future growth, while the top percentages represent a no growth scenario. See Table 2.4 for more details.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

We think our assumptions are reasonable.[27] However, to test the sensitivity of our conclusions, we used alternative assumptions about crop and ethanol yields, including a very optimistic scenario and a no growth scenario. The former scenario assumed that corn yields increase at an annual rate of 3.53 percent—a rate that would double corn yields in 20 years.[28] Ethanol yields per bushel were assumed to increase by 2 percent annually. Under the very optimistic scenario, E10 use can be accomplished by 2015 with a slightly smaller share of corn production (29 percent) than was used in 2008. By 2020, E20 use can be accomplished with 44 percent of the corn crop. Nationwide E85 use is not practical since it would require total dedication to ethanol of nearly 1.9 times the overall acres that were planted with corn in 2008. Under the no growth scenario, 44 to 45 percent of the acres currently planted with corn would be required in either 2015 or 2020 to implement E10 usage nationwide. This is a significant increase from the current figure of 31 percent. E20 would require 89 percent of the current corn acres, and E85 would require almost 3.8 times the total acres planted with corn in 2008.

Even considering the impact of distillers grains production, nationwide E20 use in 2015 would require a significant increase in the amount of land used for ethanol.

The above estimates do not, however, examine the impact of distillers grains production by ethanol producers. Since distillers grains can substitute for a portion of the corn and soybean meal intake by livestock, the growth in production of distillers grains can partially offset the land needed for corn used for ethanol production. For example, while about 31 percent of the 2008 corn acreage is expected to be used for ethanol, we estimate that the net land impact of ethanol production is only about 19 percent of 2008 corn acreage. Distillers grains fed to animals offsets more than a third of the land used by ethanol.

Adjusting our estimates for distillers grains does not, however, modify the conclusions we discussed above. Under the average growth scenario, the net land needed for nationwide E10 consumption in 2015 would be 23 percent of 2008 corn acreage—a modest increase from the current figure of 19 percent. Nationwide E20 consumption in 2015 would require 46 percent of 2008 corn acreage, which represents a substantial increase over the current level. Furthermore, even after adjusting for the impact of distillers grains, nationwide E20 consumption would result in a 36 percent reduction in the overall corn

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[27] Some observers have argued that crop yields have increased since the mid-1990s. While we found that the annual increase is greater in terms of the numbers of bushels per acre, this is misleading since the annual growth rate has declined in percentage terms. In addition, some analysts have concluded that favorable weather has resulted in increased yields since the mid-1990s. A return to more average weather conditions could result in a period of slower yield increases. See Mike Tannura, Scott Irwin, and Darrel Good, "Are Corn Trend Yields Increasing at a Faster Rate?" Marketing and Outlook Briefs, University of Illinois at Urbana-Champaign (February 20, 2008).

[28] Some ethanol advocates have argued that corn yields will grow at significantly higher rates than in the past. They expect advances in seed and other technology to occur in the near future. Our two more optimistic scenarios are based in large part on those assumptions. For example, our "very optimistic" scenario is based on the statement from Jeff Broin of POET Ethanol that corn yields will double in 20 years. Our "optimistic" scenario is based on corn and ethanol assumptions used in an article by Martha Schlicher of GTL Resources, an ethanol production and project management company. See Martha A. Schlicher, "Biofuels in the US: Today and in the Future," *AgBioForum* 11 (2008): 1-7.

available for uses other than ethanol.[29] In 2015, nationwide E85 consumption would require almost three times the total amount of land used for corn production in 2008.

Nationwide use of B2 would be difficult to achieve in the next decade using only soybeans to produce biodiesel.

Compared with corn ethanol, soy biodiesel would require a greater expansion of the cropland dedicated to biofuels and would replace less petroleum. We found that:

- **If soybeans were the only feedstock used to produce biodiesel, nationwide use of B2 would require a significant increase in the share of soybean production dedicated to biodiesel.**

- **Under the same assumptions, B5 would likely require about half of the amount of land planted with soybeans, and nationwide B20 use could not be accomplished by 2020 even using all available soybean production.**

As mentioned earlier, about 7 percent of soybean production in 2008 is expected to be used for biodiesel. As shown in Table 2.5, we estimated that achieving nationwide use of B2 by 2015 would require about 22 percent of the acres planted in soybeans in 2008. Nationwide use of B2 would involve production of about 1.2 billion gallons of biodiesel in 2015 and would replace about 1.9 percent of the diesel fuel used in the United States. Figure 2.2 shows the land use implications of B2 and other biodiesel blends in 2020.

In contrast, year-round nationwide use of B5 by 2015 would require 54 percent of the acres planted in soybeans in 2008. Alternatively, it would require 52 percent of the acres in 2020, but would only replace about 4.8 percent of diesel fuel use. In any case, the use of B5 nationwide would require a substantial increase in the acres used for biodiesel production. Year-round nationwide use of B20 by 2020 would replace 19.1 percent of diesel fuel, but would require more than twice the total acres planted in soybeans in 2008.

Our estimates provide a rationale for the federal RFS, which calls for 15 billion gallons of conventional biofuels like corn ethanol for the years 2015 through 2022. Producing that amount is probably achievable without a significant increase in the land dedicated to corn ethanol. But according to our estimates, producing more than that amount may result in more than a modest increase in the amount of land dedicated to corn ethanol.

[29] Nationwide E20 consumption is achievable with a modest growth in the net land used for ethanol if we extend the timeframe to 2020 and use the most optimistic scenario in Table 2.4. In that case, ethanol's net use of corn acreage would increase from 19 percent in 2008 to 26 percent in 2020. However, in our view, the assumptions used in that scenario are very optimistic and cannot be relied upon in making a realistic estimate of the land use implications of corn-based ethanol.

Table 2.5: Acres in the United States Needed for Soy Biodiesel in 2015 and 2020 as a Percentage of Acres Planted in 2008

	2015			2020		
Soybean and Biodiesel Yield Scenario[a]	B2	B5	B20	B2	B5	B20
Optimistic Growth	19%	46%	186%	16%	40%	159%
Average Growth	22	54	217	21	52	206
Less Than Average Growth	24	59	235	23	59	234
No Growth	26	64	255	27	67	267
Billions of Gallons of Biodiesel[b]	1.2	3.0	11.9	1.2	3.1	12.4
Percentage of Diesel Use Replaced	1.9%	4.8%	19.1%	1.9%	4.8%	19.1%

NOTES: This analysis assumes that the total number of acres planted with soybeans does not change from 2008 through 2020. Close to 7 percent of oil contained in the 2008 soybean crop in the United States is expected to be used for biodiesel production. A percentage higher than 7 percent in this table indicates that the percentage of acres used for biodiesel production would need to be higher than in 2008. A percentage less than 7 percent indicates that the percentage of acres used for biodiesel production would decrease. A percentage higher than 100 percent means that the amount of land used for biodiesel would have to be greater than all the land planted with soybeans in 2008. It should be noted that the percentage of the oil from the 2008 soybean crop that is expected to be used for biodiesel is based on a March 2009 estimate from the United States Department of Agriculture. That estimate may change as the department receives new information. The estimate of 7 percent for 2008 is also lower than the estimate of 10 percent for the 2007 soybean crop, although the 2007 crop was smaller than the 2008 crop.

This analysis measures the number of acres needed for soybean production if only soybeans are used to meet certain national targets for biodiesel consumption. As such, it measures the limitations of soybeans in achieving these targets. However, other feedstocks such as yellow grease and algae may be used to assist soybeans in achieving the targets.

[a] The optimistic scenario assumes soybean yield per acre increases 2 percent annually starting with a 2007 value of 41.7 bushels per acre. Biodiesel yield per bushel increases 2 percent annually, starting with a 2007 yield of 1.5 gallons of biodiesel per bushel of soybeans. The average growth scenario assumes soybean yield increases 1 percent annually and biodiesel yield increases 1 percent annually. Under the less than average growth scenario, soybean yield increases 0.5 percent annually, and biodiesel yield increases 0.5 percent annually. Under the no growth scenario, soybean and biodiesel yields are fixed at 2007 levels.

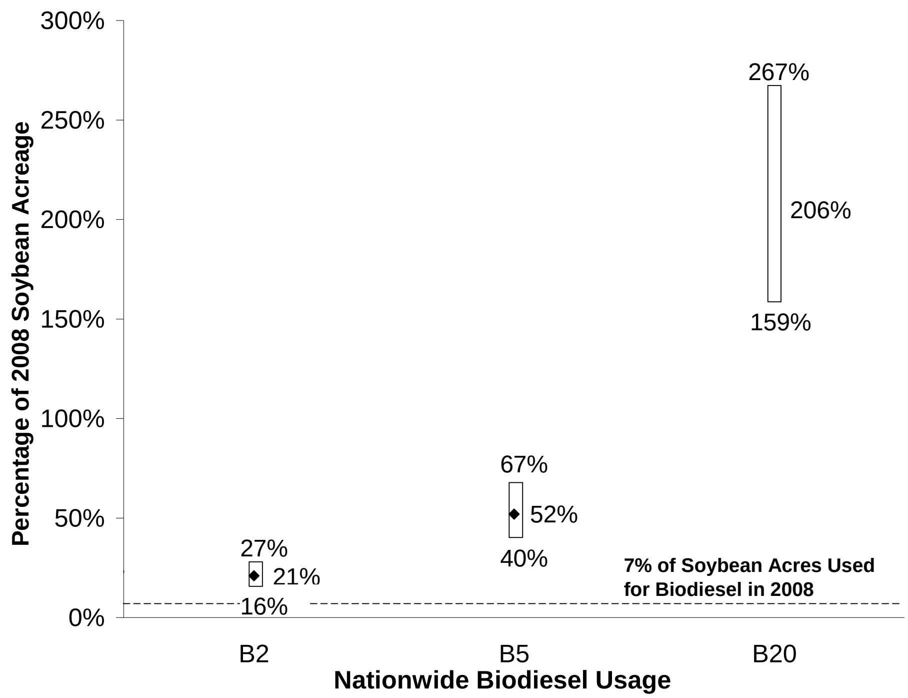
[b] Soybeans are used to produce both soy meal and soy oil. Biodiesel is produced from soy oil. As a result, biodiesel production does not use the entire soybean, just the oil from the soybean crop.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

Our estimates also indicate that soy-based biodiesel will need to be supplemented with biodiesel from other feedstocks to achieve a nationwide average blending rate of 2 percent biodiesel in diesel fuel. There is some evidence that other feedstocks, such as scrap greases from various sources, are being increasingly used to produce biodiesel. A recent news story suggests that the percentage of biodiesel produced in the United States from soy oil has declined from almost 90 percent two years ago to less than 50 percent in January 2009.[30] The overall ability of these other feedstocks, as well as that of algae, to supplement the biodiesel produced from soy oil is unclear.

[30] Andrew Johnson Jr. and Bill Tomson, "Biodiesel Industry Needs Government Mandates to Survive," Dow Jones Newswires (March 26, 2009), http://www.agriculture.com/ag/futuresource/FutureSourceStoryIndex.jhtml?storyId=149300470, accessed March 27, 2009. The news story attributes the information on recent trends in biodiesel production to JP Morgan Research.

Figure 2.2: Percentage of Soybean Acres in the United States Needed for Biodiesel in 2020



NOTE: We assume that the total number of acres planted in soybeans do not change from 2008 to 2020. We then estimate the percentage of 2008 soybean acres that will be needed to meet certain national biodiesel usage levels in 2020. Any percentage greater than 7 percent indicates that more acres will need to be devoted to biodiesel production than were used in 2008. The percentage in the middle of each bar represents an estimate based on average past growth in soybean yields. The bottom percentages on each bar represent very optimistic estimates of future growth, while the top percentages represent a no growth scenario. See Table 2.5 for more details.

SOURCE: Office of the Legislative Auditor, analysis of data from various sources.

Despite some limitations, corn-based ethanol and soy biodiesel have been, and will continue to be, useful renewable fuels.

It is important to note that these results do not diminish the importance of corn ethanol and soy biodiesel as important steps in the overall process of reducing energy dependence. These “first generation” biofuels have helped reduce energy use, but will need to be supplemented by “second generation” biofuels, energy conservation, and other methods in order to reduce the nation’s dependence on petroleum.

In addition, we think it is important to recognize that the land and other limitations of corn ethanol and soy biodiesel on a national level do not necessarily preclude an individual state from achieving higher levels of biofuel blending such as E20. Minnesota already has enough corn ethanol production to meet that goal. However, if enough ethanol-producing states mandate E20, it would mean other states would not be able to achieve E10 blending mandates without a significant expansion of land devoted to corn ethanol or the development of cellulosic ethanol alternatives.

Other Biofuels

But to replace a greater share of petroleum-based fuels, advanced biofuels like cellulosic ethanol will be needed.

In order for biofuels to replace a more significant share of gasoline and diesel fuel than can be replaced by corn ethanol and soy biodiesel, other biofuels will need to make a significant contribution. Recognizing the need for other biofuels, the federal Renewable Fuel Standard requires 16 million gallons of cellulosic ethanol and 5 million gallons of other advanced biofuels by 2022.

However, whether cellulosic and other advanced biofuels will be able to meet that challenge remains to be seen. A 2005 study found that there will be adequate biomass by 2030 to replace 30 percent of the nation's petroleum use.[31] The reductions in petroleum use would include a 20 percent reduction in petroleum-based transportation fuels, a 25 percent reduction in petroleum used for chemical production, and the use of biomass to supply 5 percent of the nation's power.

This study, cosponsored by the United States Department of Energy and the United States Department of Agriculture, claims that adequate biomass from perennial grass or woody crops, crop and other residues, and manures could be available by 2030. The study's reliance on conventional biofuels from corn, soybeans, and other crops appears to be significantly less than in the estimates we presented earlier. This is, in part, due to when the report was prepared and, in part, because the authors constrained the growth in ethanol so that projected growth in world demand for other uses of corn would be met. The 2005 study relies significantly, however, on corn stover—or cornstalks, cobs, and other portions of the plant—to supply the needed biomass. The results of the study also require the conversion of 40 to 60 million acres of pasture, Conservation Reserve Program land, and existing cropland to meet the desired level of petroleum savings.

A recent study by Sandia National Laboratories and General Motors Corporation claims that the United States could replace nearly a third of its gasoline use by the year 2030.[32] The study anticipates the production of 15 billion gallons of corn-based ethanol and 75 billion gallons of cellulosic ethanol. The cellulosic feedstocks would include crop residues like corn stover and wheat straw; forest residue; dedicated energy crops such as switchgrass; and short rotation woody crops like willow and poplar trees. The 90 billion total gallons of ethanol would replace the energy equivalent of 60 billion gallons of gasoline.

In our view:

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[31] Oak Ridge National Laboratory, a report prepared for the United States Department of Energy and the United States Department of Agriculture, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge, TN, April 2005).

[32] Sandia Laboratories and General Motors Corporation, 90-Billion Gallon Biofuel Deployment Study (Livermore, CA, February 2009); executive summary found at http://hitectransportation.org/news/2009/Exec_Summary02-2009.pdf, accessed February 11, 2009.

Cellulosic ethanol shows promise, but significant questions remain about its economic viability and production process.

- **Cellulosic ethanol has promise, but its ability to replace a substantial share of the nation's gasoline use is still unclear.**

Cellulosic ethanol is still in the developmental stage and is not yet being commercially produced on a large scale. A new federal tax credit in 2009 will give cellulosic ethanol an added tax incentive over corn ethanol for the first time. However, at this point, it is unclear exactly what feedstocks would be grown and how they would be harvested, transported, stored, and converted into cellulosic ethanol. Given those uncertainties, it is unclear what it will cost to grow feedstock and harvest, transport, store, and convert it to ethanol. The executive summary of the recent Sandia Laboratories report says that cellulosic ethanol would be competitive at oil prices of $90 or more per barrel. However, details supporting this conclusion are not yet available.[33]

Algae-based biodiesel is still in the research and development stage.

Algae-based biodiesel has been touted as being a better alternative than soy biodiesel for replacing diesel fuel. Advocates say that algae-based biodiesel can be produced on infertile land like deserts and would have the energy benefits of soy biodiesel without negative impacts on land use and food markets. However, algae-based biodiesel is still being researched and is in the early stages of development. As a result, the precise impacts of this product have not been thoroughly examined in the scientific literature. In addition, it is unclear whether algae-based biodiesel would be competitive on a cost basis with soy biodiesel or diesel fuel.

[33] As of February 15, 2009, only an executive summary of the Sandia Laboratories report was available.

3

Environmental Issues

The environmental impacts of conventional biofuels are widely disputed. Ethanol proponents claim that ethanol reduces greenhouse gas emissions and emissions of various air pollutants such as carbon monoxide. Critics say that ethanol and other biofuels may increase greenhouse gas emissions despite the lower carbon emissions in ethanol compared with gasoline. Some critics have argued that the overall health impacts from air pollution due to ethanol are no better, and perhaps worse, than from gasoline. In addition, critics charge that expanding corn production to produce more ethanol increases water pollution problems and uses valuable water supplies. Finally, critics have raised concerns about the impact of expanding corn production on sensitive wildlife habitats.

This chapter examines the environmental impacts of biofuels, particularly corn-based ethanol, soy-based biodiesel, and cellulosic ethanol. We review in detail the controversy over greenhouse gas emissions and, to a lesser extent, consider the impacts on various air pollutants. We also examine the impacts of biofuels on water quality and water supply. Finally, we review the potential impacts of biofuel expansion on the lands set aside under the federal Conservation Reserve Program. This program encourages farmers to protect land that is environmentally sensitive or highly erodible.

We rely significantly on scientific studies from universities and other research institutions. Because there is more extensive research on corn-based ethanol, this chapter provides more details on the impacts of corn ethanol than on the impacts of other biofuels. In addition, some issues—like greenhouse gas emissions—have received far more research attention than others. As a result, we have more information on some environmental issues than others.

GREENHOUSE GAS EMISSIONS

In measuring environmental impacts, it is important to consider the full life-cycle impacts of both biofuels and petroleum-based fuels when possible.

As we saw with energy issues, it is extremely important when evaluating the environmental impacts of biofuels to consider the full life-cycle impacts of biofuels and petroleum-based fuels. To estimate greenhouse gas or other emissions, analysts must consider not only the emissions from vehicles but also emissions that occur in fuel production and distribution. For biofuels, this includes emissions at farms during production of corn, soybeans, or other feedstocks, as well as emissions during production of ethanol or biodiesel. For petroleum-based fuels, this includes emissions during oil production and refining.

In this part of the chapter, we first review the findings of various life-cycle analyses of the greenhouse emissions from biofuels and their petroleum-based counterparts. Then, we discuss some of the concerns raised about the assumptions used in those analyses. The failure of most analyses to consider the land use impacts of biofuel production is one of the most important concerns, since it has the potential to change the conclusion that most analyses reach about the effect biofuels have on greenhouse gas emissions.

Life-Cycle Analyses

In this section, we examine impacts of biofuels on greenhouse gas emissions as measured by life-cycle analyses. First, we examine the impact of pure biofuels such as E100 or B100 relative to gas or diesel fuel. We measure the emission impact using equal amounts of energy from the biofuel and petroleum-based fuel being compared. Second, we consider the impacts of various ethanol and biodiesel blends. Finally, we examine the relative greenhouse gas reductions of various biofuels grown on a fixed amount of land. Since crop yields of the feedstocks used to produce biofuels vary, the results from this last analysis do not necessarily agree with the previous analyses.

Pure Biofuels

Recent life-cycle analyses indicate that, on average, pure corn-based ethanol reduces greenhouse gas emissions by at least 12 to 19 percent when compared with gasoline.

Overall, we found that:

- **Life-cycle analyses have concluded that biofuels reduce greenhouse gas emissions.[1]**

A number of recent studies that have looked at corn-based ethanol have found that E100 lowers greenhouse gas emissions by 12 to 19 percent.[2] For example, a 2006 University of Minnesota study found a 12 percent reduction, while a 2006 University of California, Berkeley study cited a 13 percent reduction.[3] A 2007 study from Argonne National Laboratory concluded that corn ethanol currently reduced greenhouse gas emissions by 19 percent and would reduce them by 21 percent by 2010.[4]

The Argonne study also concluded that, depending on the fuel used to power an ethanol plant, the impact on greenhouse gas emissions from a new plant could range from a 3 percent increase to a 52 percent decrease. The use of coal would increase emissions by 3 percent, while the use of biomass—like wood waste, corn cobs, or other plant matter—would reduce emissions by 52 percent. For the most common fuel, natural gas, E100 produced by a new plant would reduce

[1] It should be pointed out that the percentage reductions in emissions reported in this section and in the section on air pollutants only reflect the reductions in emissions from vehicles that use the biofuel in question. They do not represent a total reduction in emissions for a geographic area, because there are other sources of emissions besides motor vehicles. In addition, they do not represent the total reduction in emissions from motor vehicles in an area, unless all vehicles are using the biofuel.

[2] These analyses all use an energy-equivalent basis to calculate the impact of biofuels on greenhouse gas emissions. In other words, they adjust for the difference in the energy or heat content of biofuels and petroleum-based products.

[3] See Hill et al. (2006), 11206, and Farrell et al. (2006), 506.

[4] Wang et al. (2007), 11-12.

greenhouse gas emissions by 28 percent.[5] The combined use of natural gas and corn syrup would reduce emissions by 36 percent.

Three Minnesota ethanol plants are using or installing technology that will reduce the greenhouse gas emissions from their ethanol by much more than the average corn-based ethanol plant.

As we noted in Chapter 2, three plants in Minnesota are using or planning to use alternative fuels. One plant is currently using both natural gas and corn syrup as a fuel source and has installed wind generators to provide some of its electrical power. Two plants are preparing to use biomass. One of the two is planning to use wood waste, while the other is going to use corn cobs, other agricultural residues, grasses, and wood. The results from the Argonne study suggest that ethanol produced by these three plants will likely reduce greenhouse gas emissions by significantly more than the average reduction of 19 percent cited in the Argonne study.[6]

A more recent study from the University of Nebraska-Lincoln concludes that the most common corn ethanol plants—those that use natural gas—reduce greenhouse gas emissions by 48 to 59 percent.[7] More specifically, the study estimated that Midwest ethanol plants reduce emissions by 51 percent.[8] In addition, the study estimated a 53 percent reduction in emissions from corn ethanol plants in Minnesota.[9]

The Nebraska study has the clear advantage over previous studies of using more up-to-date information on corn yields and fossil fuel energy use. However, unlike previous studies, this study looked at specific types and sizes of ethanol plants. Consequently, the results may not be directly applicable to the average plant either in the United States or in Minnesota.[10] Nevertheless, the results may be more indicative of newer and larger plants using natural gas as a fuel.

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[5] *Ibid*., 12.

[6] We are somewhat reluctant to calculate an average greenhouse gas emission reduction for Minnesota ethanol production. Calculating such an average would require detailed information on each plant operating in Minnesota, as well as detailed information on Minnesota corn production. However, if one assumes that ethanol produced at Minnesota's 15 other ethanol plants reduces greenhouse gas emissions by 19 percent (or the national average), then the average for Minnesota would be close to 23 percent once the improvements at all three of these plants are operational.

[7] Liska et al. (2009), 6 and 9.

[8] Some of the results apply only to certain plants in Nebraska or Iowa. The 51 percent reduction applies to two different groups of ethanol plants, both of which use natural gas as a fuel. The first group consists of the dry mill plants in a group of 22 Midwest ethanol plants with an average capacity of about 82 million gallons per year, while the second group includes eight ethanol plants with an average annual capacity of about 52 million gallons. All the plants in this second group began operations in January 2005 or later.

[9] Liska et al. (2009), 13.

[10] The Nebraska study uses updated information on corn yields and farm energy use specific to Minnesota, but does not use information specific to Minnesota's ethanol plants. Furthermore, Minnesota's plants are smaller than the plants in one of the Midwest groups examined in the Nebraska study and are older than the plants in the second Midwest group. In Minnesota, the average annual capacity of the 18 ethanol plants in operation is 47 million gallons compared with 82 million gallons for the first Midwest group. In addition, only one-third of Minnesota's ethanol plants opened in 2005 or later, while all of the plants in the second Midwest group were opened in that timeframe.

Available life-cycle analyses also indicate that:

- **Soy biodiesel provides greater reductions in greenhouse gas emissions than corn ethanol when measured in percentage terms on an energy equivalent basis.**

Compared with diesel fuel, pure soy biodiesel reduces greenhouse gas emissions by 41 to 94 percent.

A 2006 University of Minnesota study concluded that soy biodiesel reduces greenhouse gas emissions by 41 percent over diesel fuel, compared with a 12 percent reduction for corn ethanol in comparison with gasoline.[11] A 2009 study from Argonne National Laboratory found that B100, or pure biodiesel, reduces emissions by 66 to 94 percent.[12] The range in the Argonne results reflects the use of different methods to account for the coproducts of soy biodiesel production.

In addition, some studies have estimated the greenhouse gas impacts of cellulosic ethanol. The studies indicate that:

- **Cellulosic ethanol may provide significantly greater reductions in greenhouse gas emissions than corn ethanol.**

Estimates of the greenhouse gas reductions from pure cellulosic ethanol range from 65 to 90 percent.

For example, an Argonne Laboratory study estimates that cellulosic ethanol (E100) would reduce greenhouse gas emissions by 86 percent over gasoline.[13] Similarly, data from a University of California, Berkeley study suggest a reduction of about 88 percent.[14] A recent report found that most life-cycle studies of biofuels have not adequately examined the impact of process chemicals and enzymes that will be needed for biochemical production of cellulosic ethanol.[15] Using better estimates of the chemicals and enzymes needed for near-term and mature cellulosic technologies, the study estimated that cellulosic ethanol would reduce greenhouse gas emissions by 65 to 85 percent.[16] In general, all estimates for cellulosic ethanol should be considered preliminary and will need to be revisited once it is clear how cellulosic ethanol will be produced commercially.

Ethanol produced from sugarcane should also be mentioned, since it is produced extensively in Brazil and could be produced in certain southern states like Louisiana and Texas. In addition, more sugar ethanol would be exported to the United States if the 54 cent tariff imposed on it were lifted. In general, ethanol produced from sugarcane reduces greenhouse gas emissions by a significant

[11] Hill et al. (2006), 11206.

[12] Huo et al., 753. Also, see Hong Huo, Michael Wang, Cary Bloyd, and Vicky Putsche, *Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels* (Argonne, IL: Argonne National Laboratory, March 2008), 40.

[13] Wang et al. (2007), 12.

[14] See data in Figure 2 in Farrell et al. (2006), 507.

[15] See MacLean and Spatari (2009). This study concludes that, even with considerable improvement over current performance, process chemicals and enzymes will be responsible for 30 to 35 percent of the greenhouse gas emissions for cellulosic ethanol. This compares with only about 3 percent for corn ethanol.

[16] *Ibid.*, 8.

amount. The Environmental Protection Agency (EPA) has estimated a reduction of about 56 percent, compared with reductions of 91 percent for cellulosic ethanol, 68 percent for biodiesel, and 22 percent for corn ethanol.[17]

Biofuel Blends

The greenhouse gas emissions are relatively modest for lower blends of corn-based ethanol and soy biodiesel.

All of the above reductions are calculated in percentage terms on an energy equivalent basis for pure ethanol (E100) or pure biodiesel (B100). However, as we found in Chapter 2, certain levels of corn ethanol and soy biodiesel use are not achievable nationwide given land constraints. E85 and B20, for example, would take far more corn and soybean land than is currently planted for all uses, not just for biofuels. E20 and B5, while potentially achievable for an individual state, would require considerably more land devoted to ethanol and biodiesel on a national basis than is currently the case. As a result, it is important to ask what the greenhouse gas reductions would be for lower blends of ethanol than E85 and E100 and lower blends of biodiesel than B20 and B100. Table 3.1 provides this information and shows that:

- **Lower blend levels of corn ethanol such as E10 and E20—as well as lower blend levels of soy biodiesel such as B2 and B5—provide relatively modest levels of greenhouse gas reductions.**

Using the Argonne Laboratory estimate of emission reductions for an average corn ethanol plant, we calculated that an E10 blend would reduce emissions by about 2 percent for each gallon of gasoline saved.[18] An E20 blend would reduce emissions by 4 percent, while E85 would reduce them by 16 percent. For a corn ethanol plant powered by biomass, the emission reductions would be about 5 percent for E10, 10 percent for E20, and 42 percent for E85.[19] Similarly, assuming a 68 percent reduction in greenhouse gas emissions for B100, the reduction is about 1 percent for B2, 3 percent for B5, and 14 percent for B20.

The reductions for lower blend levels of corn ethanol and soy biodiesel are meaningful although modest. To achieve greater levels of greenhouse gas emissions, the United States would have to supplement corn-based ethanol with cellulosic ethanol. In addition, the nation would need more flex-fuel vehicles on the road that could accommodate a blend of ethanol greater than E20. Currently, the percentage of flex-fuel vehicles, while growing, is still relatively small.

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[17] Office of Transportation and Air Quality, *Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use* (Washington, DC: Environmental Protection Agency, April 2007), http://www.epa.gov/otaq/renewablefuels/420f07035.pdf, accessed January 15, 2009.

[18] Wang et al. (2007), 12.

[19] Similar reductions would apply as well to the large or relatively new Midwest ethanol plants for which Liska et al. estimated a 51 percent reduction in greenhouse gas emissions.

Table 3.1: Greenhouse Gas Emission Changes from Various Corn Ethanol, Cellulosic Ethanol, and Soy Biodiesel Blends

Ethanol Blends	Reductions for Corn Ethanol[a]	Reductions for Cellulosic Ethanol[b]	Biodiesel Blends	Reductions for Biodiesel[c]
E10	-2%	-9%	B2	-1%
E20	-4	-17	B5	-3
E85	-16	-73	B20	-14
E100	-19	-86	B100	-68

NOTE: For ethanol, reductions in greenhouse gas emissions were calculated relative to gasoline. For biodiesel, they were calculated relative to diesel fuel. For the most part, the reductions do not include land use impacts on greenhouse gas emissions, which may significantly change the results.

[a] We calculated the results for corn ethanol using the E100 estimate in Wang et al. for the average ethanol plant. Results for particular types of plants may vary from the average. Also, the reductions for newer plants tend to be larger than the average reduction.

[b] We calculated the results for cellulosic ethanol using the E100 estimate in Wang et al. for cellulosic ethanol. Estimates for cellulosic ethanol should be considered to be preliminary, since very little cellulosic ethanol is being sold commercially.

[c] We calculated the results for biodiesel using the estimate of a 68-percent reduction for B100 in Huo et al. based on an energy allocation method to account for coproducts. This study also estimates the reduction for B100 to be 66 percent for a market value allocation method and 94 percent for a displacement allocation method. We used the 68-percent figure because, in our view, either the energy or market value approaches are preferable to the displacement method. Also, Hill et al. estimate the greenhouse gas reductions from B100 to be considerably lower (41 percent) than the Huo et al. figures. As a result, it would not be appropriate to use the highest estimate of 94 percent.

SOURCES: Office of the Legislative Auditor, analysis of data from Michael Wang, May Wu, and Hong Huo, "Life-Cycle Energy and Greenhouse Gas Emissions of Different Corn Ethanol Plant Types," *Environmental Research Letters 2* (May 22, 2007): 12; and Hong Huo, Michael Wang, Cary Bloyd, and Vicky Putsche, *Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels* (Argonne, IL: Argonne National Laboratory, March 2008), 40.

Impacts per Acre

It should also be pointed out that the percentage reductions in greenhouse gas emissions can be somewhat misleading. Biofuels differ not only in the percentage reduction in emissions per unit of energy produced but also in the number of gallons and units of energy that can be produced per acre of land. For example, we conclude that:

- **Although soy biodiesel offers greater greenhouse gas reductions than corn ethanol on an energy equivalent basis, corn ethanol probably provides greater emission reductions per acre of land.[20]**

[20] See Figure 3 in Eric D. Larson, "A Review of Life-Cycle Analysis Studies on Liquid Biofuel Systems for the Transport Sector," *Energy for Sustainable Development* X, no. 2 (June 2006), 112.

Corn ethanol is capable of greater greenhouse gas reductions per acre because more than seven times as many gallons—and more than four and a half times as many BTUs—can be produced from an acre of land compared with soy biodiesel. Using the EPA figures cited above, we estimate that the ethanol produced from an acre of corn reduces greenhouse gas emissions by nearly 50 percent more than the biodiesel produced from an acre of soybeans. However:

- **Both cellulosic ethanol and sugarcane ethanol would likely provide greater greenhouse gas reductions per acre than corn ethanol.**

For example, a 2006 review of life-cycle studies found greenhouse gas reductions for sugarcane ethanol to be roughly five times those for corn ethanol per hectare.[21] In addition, a 2006 University of Minnesota study found that greenhouse gas reductions per hectare from ethanol produced with low-input high-diversity grassland biomass would be about 6 to 16 times greater than those from the use of corn ethanol or soy biodiesel.[22] For cellulosic ethanol, these figures should be considered preliminary since cellulosic ethanol is not yet in commercial production. In addition, the figures will likely vary depending on the biomass used to produce ethanol.

Criticisms of Life-Cycle Analyses

Life-cycle analyses have been criticized for a number of reasons, including their failure to fully consider land use impacts.

While life-cycle studies have provided a fairly comprehensive analysis of greenhouse gas emissions, they have also been criticized for a number of reasons. Among the reasons are: (1) a failure to consider the land use impacts of biofuels; (2) the lack of accounting for indirect greenhouse gas emissions; (3) the use of an assumption about nitrous oxide emissions from fertilizers that may be too low; (4) the lack of recognition that the value of some coproducts of biofuel production may decline as their production increases; (5) the failure to consider the greenhouse gas emissions from unconventional sources of gasoline such as Canadian oil sands; and (6) the failure to consider indirect greenhouse gas emissions from military operations designed to protect world supplies of oil.[23] The first four of these concerns raise greenhouse emissions for biofuels relative to the level estimated in most life-cycle analyses. The last two raise the estimated emissions for petroleum-based fuels. We discuss each of these concerns below.

Land Use Impacts

As we saw in Chapter 1, the increasing use of corn for ethanol in the United States since 2001 has resulted in modest declines in the availability of corn for other uses. As world demand for corn has grown, the United States—the top exporter of corn in the world—has supplied less corn for exports, domestic

[21] See Figure 3 in Larson (2006), 112. A hectare is a unit of land that is 10,000 square meters, or about 2.471 acres.

[22] Tilman et al. (2006), 1600.

[23] See Larson (2006) for a discussion of the second, third, and fourth issues on this list of concerns about life-cycle analyses.

Growth in crop-based biofuel production may cause land use changes that release significant amounts of greenhouse gases into the atmosphere.

animal feed, and industrial uses other than ethanol. For this reason as well as other factors we will discuss in Chapter 4, the prices of corn and other agricultural crops have increased.[24] As a result, farmers in the United States and worldwide have planted more corn. In the United States, corn acreage has increased 14 percent since 2001 and soybean acreage is up 2 percent.

Increased plantings of corn on non-cropland due to greater ethanol production are considered direct land use changes. These changes can happen on abandoned or marginal cropland, grassland, or other land that is brought into corn production. Alternatively, the land use change can be indirect. For example, land in the United States which was devoted to soybeans could be converted to corn, causing pasture or grassland in other parts of the world to be converted to soybean production and wooded property or rainforests to be converted to pasture. Because distillers grains for animal feed can be produced during the production of ethanol, the amount of land needed to replace that used for ethanol could be as low as two-thirds of the land used to grow corn for ethanol.

Several studies released in the last year highlighted the fact that:

- **Life-cycle analyses of biofuels have not adequately analyzed the impact of land use changes on greenhouse gas emissions, which may offset the reductions from biofuel use.[25]**

A 2008 study from Minnesota researchers found that converting grassland in the central United States to corn production would release greenhouse gases into the atmosphere.[26] The study estimated that it would take 93 years of using ethanol produced from corn grown on converted grassland before these emissions were offset. Converting abandoned cropland to corn in the United States would take 48 years of ethanol use to offset. Alternatively, a 2009 study found that converting grassland to corn production takes 12 years of ethanol use to pay back the emissions caused by the conversion.[27] The study also concluded that management practices like no-till or no-till plus winter cover crops reduce that payback period to 3 years. However, other research calls into question this favorable finding for no-till practices. A 2007 study found, contrary to conventional wisdom, that tilling has no effect on overall soil organic carbon

[24] As we will discuss in Chapter 4, the prices of corn and other agricultural commodities have increased for a variety of reasons in recent years. Ethanol expansion is just one of those factors. Consequently, increases in corn acreage in the United States and other countries can be attributed to a variety of factors, not just ethanol.

[25] The GREET model used by Argonne National Laboratory had a limited capacity to analyze land use impacts. However, its capacity was relevant only up to about 4 billion gallons of annual corn ethanol production.

[26] Joseph Fargione, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne, "Land Clearing and the Biofuel Carbon Debt," *Science* 319 (February 29, 2008): 1235-1237.

[27] Hyungtae Kim, Seungdo Kim, and Bruce Dale, "Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables," *Environmental Science & Technology* 43, no. 3 (January 6, 2009).

levels.[28] Instead, tilling redistributes organic carbon to deeper locations in the soil. Consequently, no-till practices, though desirable for other reasons, may not affect carbon levels in the soil or carbon emissions to the atmosphere.

Another 2008 study estimated the land use effects of increasing the 2015 goal for corn ethanol production from 14.8 billion gallons to 29.5 billion gallons.[29] By amortizing the effects over a 30-year period, the study found that greenhouse gas emissions would increase 93 percent for ethanol compared with gasoline, as opposed to a 20 percent decline using traditional life-cycle analysis.

This study undoubtedly overstates the land use impacts of corn ethanol because it modeled an extremely large increase in ethanol production on top of the large increase already contemplated under the federal Renewable Fuels Standard. While the acres devoted to corn ethanol may need to increase modestly to achieve a 14.8 billion gallon production level by 2015, they would need to increase much more significantly to achieve a 29.5 billion gallon level. Increased corn and ethanol yields can help achieve the former goal, but significantly greater growth in yields would be needed to achieve the latter goal.

Proponents of biofuels, and corn ethanol in particular, claim that future growth in crop yields will keep up with the growth in the use of corn for ethanol. In their view, corn yields per acre will grow faster in the near future than in recent decades due to scientific advances spurred in part by the growth in ethanol and increased corn prices. As a result, they believe the land impacts will be minimal.

The land use impacts of biofuels depend on how fast biofuel growth occurs relative to increases in crop and biofuel yields.

While we cannot endorse their view of future corn yields, our analysis in the previous chapter suggests that, even at past average growth rates for corn and ethanol yields, the United States may be able to increase corn ethanol production to a level anticipated by the federal Renewable Fuels Standard with a relatively modest growth in acres devoted to corn ethanol.[30] Thus, it is clear that growth in agricultural productivity can mitigate a part or all of the need for additional land. But the extent to which mitigation is possible depends on how fast ethanol expansion is occurring relative to the growth in productivity.

It is also reasonable to say that some future growth in corn yields would occur anyway as it did prior to the expansion of ethanol. To the extent that yield increases would occur anyway, ethanol should not receive credit for that

[28] John Baker, Tyson Ochsner, Rodney Venterea, and Timothy Griffis, "Tillage and Soil Carbon Sequestration—What Do We Really Know?" *Agriculture, Ecosystems and Environment* 118 (2007): 1-5.

[29] Timothy Searchinger, Ralph Heimlich, R.A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu, "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," *Science* 319 (February 29, 2008): 1238-1240.

[30] More specifically, we concluded that the number of corn acres devoted to ethanol would increase from 30 percent of the corn acres planted in 2008 to 37 percent in 2020 under an average growth scenario. That scenario assumed an annual rate of growth in corn yield of 1.67 percent, or the average rate during the last 40 years, and an annual increase in ethanol produced per bushel of corn of 0.75 percent. We also assumed that the total land planted with corn in the United States did not change over that time period.

increase. In other words, yield increases that would have occurred anyway would reduce the need for cropland and reduce greenhouse gas emissions by idling some cropland. If ethanol production increases and corn production uses land that would be otherwise idled, then ethanol is responsible for increasing land use over what it would otherwise be and thus causing greenhouse gas emissions from the land conversion. Sorting out what portion of future yield growth is due to ethanol and what portion would have occurred anyway would, however, be exceedingly difficult.

In our view, the results from recent studies indicate that:

- **The impact of corn-based ethanol and soy biodiesel on greenhouse gas emissions depends on how their expansion affects land use both in the United States and around the world.**

As is true of corn-based ethanol and soy biodiesel:

- **Life-cycle analyses do not account for the potential land use impacts of biomass crops and the overall greenhouse gas emissions of cellulosic ethanol.**

The net greenhouse gas impacts of cellulosic ethanol depend on where biomass crops are grown. If, for example, a biomass crop is grown on existing cropland, it will displace existing crops. Those crops will likely be grown on other land in the United States or other countries. One study estimated that cellulosic ethanol would increase greenhouse gas emissions by 50 percent relative to gasoline if biomass crops were grown on existing cropland.[31] Another study concluded, however, that the land use impact would be minimal or nonexistent if the biomass is grown on abandoned or marginal cropland.[32]

As we have seen, research indicates that life-cycle analyses alone are inadequate for the purpose of estimating the greenhouse gas emissions from biofuels. There is a need to analyze more fully the direct and indirect land use impacts of biofuels and the greenhouse gas emissions from those land use impacts. Unfortunately, there are relatively few academic studies of land use impacts. In addition, the studies cited above do not adequately resolve the issue of how biofuels affect land use.

Federal law requires the EPA to consider land use impacts when determining whether biofuels meet certain greenhouse gas reduction standards.

Currently, both the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) are studying the land use impacts of biofuels. The EPA is required for purposes of the federal Renewable Fuels Standard to develop methods to determine whether certain biofuels meet the legislative standards of 20, 50, or 60 percent reductions in greenhouse gas emissions. The methods must, according to federal law, take into account indirect land use impacts. EPA is circulating a draft of proposed methods among interested parties but has not released it publicly.

[31] *Ibid.*, 1239.

[32] Fargione et al., 1236.

The California Air Resources Board is estimating the greenhouse gas impacts of various biofuels, including the effects of land use changes, to determine whether various biofuels meet California's low carbon fuel standard. In addition to the federal government and California, a group of 11 northeastern states recently agreed to develop fuel standards that consider the indirect land use impacts of ethanol production. We also expect there to be additional university research on the issue of land use impacts.

Estimating land use impacts requires the use of sophisticated models to make projections about future land use changes.

Estimating the land use impacts of biofuels like corn-based ethanol will not be an easy task or one that will be simple to explain. The analysis will need to be based on international economic, land use, and other models that estimate the impact future biofuel expansion will have on agricultural prices and production and also on land use. Looking at actual land use changes is not sufficient because they have occurred for a variety of reasons. In addition, examining past land use changes does not address the real purpose of the analysis. That purpose is to estimate land use impacts from future mandated expansions in biofuel production. In addition, the analysis will need to make assumptions about future agricultural and industry conditions, such as corn yields in bushels per acre and ethanol conversion yields in gallons per bushel. As noted earlier, those assumptions are themselves the subject of debate, so consensus on land use impacts may be difficult to achieve.

In our view, land use impacts have not been fully and adequately addressed. However, existing research suggests that the greenhouse gas emission estimates from life-cycle analyses cannot be taken at face value. The overall greenhouse gas impacts of biofuels depend on the significance of land use impacts.

Indirect Greenhouse Gas Emissions

Most life-cycle studies do not consider the impact of indirect greenhouse gases or aerosol emissions.

Nearly all life-cycle analyses include the greenhouse gases that directly affect climate. These direct greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). However:

- **Most life-cycle analyses do not include other gases that indirectly affect climate.**

These gases—which include oxides of nitrogen (NO_X), carbon monoxide (CO), and non-methane organic compounds (NMOC)—indirectly affect climate through their impact on ozone concentrations. A 2004 report from the University of California, Davis estimated that including just the impacts of NO_X would change the estimates of overall greenhouse gas emissions for various fuels by about 3 to 5 percent compared with the typical analysis that does not include indirect greenhouse gases.[33]

Perhaps even more significantly:

[33] Mark Delucchi, *Conceptual and Methodological Issues in Lifecycle Analyses of Transportation Fuels* (Davis, CA: Prepared for the United States Environmental Protection Agency, October 2004), 16.

- **Most life-cycle analyses do not account for aerosol emissions.**

Aerosols are emitted during some transportation fuel life cycles and are a particular concern for diesel engines. Some aerosols like sulfates are reflective and have a cooling effect on climate. However, other aerosols like black carbon are absorbing and have a warming effect. Black carbon, which is emitted from diesel engines, is particularly important because it has a far greater impact on global warming than the direct greenhouse gases. For example, while carbon monoxide has a weight of 1 per unit of mass, black carbon has a weight of 680, when considered over a 100-year period.[34] The weight for black carbon is also higher than those for methane (23) and nitrous oxide (296).[35] These relative weights indicate the importance of various factors in the formation of greenhouse gases. One study that considered the impact of aerosols like black carbon, as well as indirect greenhouse gas emissions, found that soy biodiesel significantly increased greenhouse gas emissions compared with diesel fuel.[36]

Nitrous Oxide Emissions

The standard assumption used in life-cycle analyses about nitrous oxide emissions from fertilizer applications to biofuel crops has been recently challenged by a Nobel Prize-winning chemist.

Another relatively major unresolved issue is the magnitude of nitrous oxide emissions that occur due to fertilizer applications to biofuel crops like corn and soybeans. As noted above, nitrous oxide is one of the three direct greenhouse gases and, per unit of mass, is far more important than the other two. However, a 2008 study authored by a Nobel Prize-winning chemist and others estimated that:

- **Nitrous oxide emissions during the growth of agricultural crops like corn and soybeans are three to five times larger than assumed in current life-cycle analyses.[37]**

The study also concluded that this single factor was potentially large enough to change the results of life-cycle analyses.[38] In other words, biofuels such as corn ethanol may increase greenhouse gas emissions relative to petroleum-based fuels.[39]

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[34] *Ibid.*, 116-117.

[35] These are the weights assigned by the Intergovernmental Panel on Climate Change. See Energy Information Administration, *Comparison of Global Warming Potentials from IPCC's Second and Third Assessment Reports* (Washington, DC: United States Department of Energy, December 2004), http://www.eia.doe.gov/oiaf/1605/archive/gg04rpt/global.html, accessed February 19, 2009.

[36] Mark Delucchi, *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials* (Davis, CA: Institute of Transportation Studies, University of California, Davis, December 2003), 415.

[37] P.J. Crutzen, A.R. Mosier, K.A. Smith, and W. Winiwarter, "N2O Release from Agro-Biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels," *Atmospheric Chemistry and Physics* 8 (2008): 389-395.

[38] *Ibid.*, 393.

[39] The study examined corn ethanol, rapeseed biodiesel, and sugarcane ethanol.

Coproduct Markets

Life-cycle analyses typically attribute some of the greenhouse gas emissions and fossil fuels used in the production of biofuels to the coproducts made along with biofuels. Without these coproduct credits, corn-based ethanol might provide minimal net energy compared to the energy used in its production and would have larger greenhouse gas emissions than typically estimated. While using coproduct credits is a reasonable method:

- **Life-cycle analyses typically do not consider whether the value of coproducts would diminish at higher levels of biofuel production.**[40]

With greater levels of production, the market value of certain coproducts of biofuels may decline. This is particularly important for glycerol, which is a coproduct of soy biodiesel production and may approach saturation levels with increasing national levels of soy biodiesel production. The price of soymeal, which is produced from soybeans along with the soy oil used for biodiesel, could also decline. The price of soymeal would be affected not only by increasing production of biodiesel, but also the increasing production of ethanol. Distillers grains—which are a coproduct of ethanol production—can be used as a replacement for soymeal in feed for certain animals. In addition, there are scientific guidelines that place limits on the amount of distillers grains that should be fed to certain types of animals. At high levels of corn ethanol production, the value of distillers grains may be reduced.

Petroleum Fuel Benchmark

Because of our state's reliance on petroleum imported from Canada, green-house gas reductions from ethanol consumed in Minnesota may be a little higher than the national average.

Gasoline and diesel fuel are increasingly being produced from unconventional sources such as tar sands reserves. The largest exporter of oil to the United States is Canada, which produced 43 percent of its crude oil from tar sands resources in 2006 and is expected to increase that percentage to 90 percent by 2025.[41] Canadian oil accounted for only about 12 percent of the total oil supply to the United States in 2007, but it accounted for about three-fourths of Minnesota's oil supply in 2006.

Life-cycle analyses typically compare the greenhouse gas emissions from biofuels to those from conventional gasoline or diesel fuel. The failure to consider greenhouse gas emissions from unconventional sources such as tar sands may have more limited impact on national level analyses. However:

- **For Minnesota, the failure of life-cycle analyses to consider unconventional sources of gasoline means that the greenhouse gas emissions from petroleum-based fuels have been understated.**

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[40] Larson (2006), 118.

[41] Alex Charpentier, Joule Bergerson, and Heather MacLean, "Understanding the Canadian Oil Sands Industry's Greenhouse Gas Emissions, *Environmental Research Letters* 4: 014005, 2 (January 20, 2009), http://www.iop.org/EJ/article/1748-9326/4/1/014005/erl9_1_014005.pdf?request-id=68672afc-f7d9-4061-bca5-45e7afd9997b, accessed February 12, 2009.

Based on the findings of a recent study, we estimate that the life-cycle emissions from gasoline used in Minnesota would be between 3 and 9 percent higher than those estimated for conventional gasoline and typically used in life-cycle analyses.[42] This difference could grow in the future as a higher percentage of Canadian oil is expected to be produced from oil sands.

Indirect Emissions from Petroleum Products

Finally:

- **Life-cycle analyses do not include any indirect greenhouse gas emissions that occur from petroleum production or the military efforts to protect foreign sources of oil.**

We are not aware of any life-cycle analyses that include the land use impacts of expanding oil production throughout the world. This can be a concern particularly if rainforests or other undeveloped lands are used for oil production.

In addition, some proponents of biofuels say that a portion of the United States military budget is used to protect foreign sources of oil. In addition to the additional expenses incurred on behalf of petroleum-based fuels, greenhouse gas emissions occur from military operations that are designed to protect oil resources. While estimates have been made on the costs of such military operations, we are not aware of any estimates of resulting greenhouse gas emissions. In Chapter 4, we will examine the cost issue in more detail because serious questions have been raised about many of the cost estimates used by proponents of biofuels. These questions are also relevant to any discussion of indirect greenhouse gas emissions due to military operations.

Conclusion

Overall, we find that:

- **The exact impact of corn-based ethanol and soy-based biodiesel on greenhouse gas emissions is unclear at this time.**

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[42] Charpentier et al. reviewed 13 studies of greenhouse gas emissions from oil sands operations. Based on the review, the authors calculated the life-cycle greenhouse gas emissions from three technologies for producing reformulated gasoline from oil sands and compared them with estimates for gasoline from conventional oil sources. Measured in grams of CO_2 equivalents per kilometer traveled, the greenhouse gas emissions ranged from 260 to 320 for surface mining and upgrading, 270 to 340 for in situ production, and 320 to 350 for in situ with upgrading. These estimates can be compared with 250 to 280 grams of CO_2 equivalents per kilometer for conventional gasoline. Comparing the midpoints of these ranges, we calculated that the life-cycle greenhouse gas emissions for gasoline from oil sands were between 9.4 and 26.4 percent higher than for conventional gasoline. The figures in the text reflect the assumptions that 76 percent of Minnesota oil comes from Canada and 43 percent of Canadian oil is produced from oil sands. If a national study found that ethanol reduced greenhouse gas emissions by 19 percent compared with conventional gasoline, the reduction may be more like 21 to 25 percent for Minnesota due to Minnesota's greater reliance on Canadian oil sands petroleum.

The impact of biofuels on greenhouse gas emissions is unclear at this time.

While corn ethanol and soy biodiesel have been shown to reduce greenhouse gas emissions using life-cycle analyses, recent studies of potential land use impacts have raised significant doubts about these conclusions. The scientific and regulatory communities are currently focusing more attention on land use impacts. However, a consensus on the exact impact of corn ethanol and soy biodiesel on greenhouse gas emissions—including the effect of land use on emissions—has yet to emerge.

As pointed out above, there are also other significant issues about how greenhouse gas emissions are measured for both biofuels and petroleum-based fuels. Some of these issues have the potential to significantly affect any conclusions about the impact of biofuels on greenhouse gas emissions relative to petroleum-based fuels. As a result, we do not think the issue of how corn ethanol and soy biodiesel affect greenhouse gas emissions has been resolved by the scientific community.

AIR POLLUTANTS

Compared with studies of greenhouse gas emissions, relatively few life-cycle studies have examined the impacts of biofuels on various air pollutants. In this section, we discuss two major life-cycle studies that comprehensively examined the impacts of corn ethanol and cellulosic ethanol from "well to wheels." In addition, we discuss one life-cycle study that examined biodiesel. More studies have examined the tailpipe emissions of motor vehicles than have considered the full life-cycle emissions. These "tank to wheels" studies provide useful information, but they fail to consider the "well to tank" emissions that occur on farms and at biofuel plants and their counterparts at oil wells and refineries.[43]

A major study completed in 2005 examined the life-cycle emissions for a large number of future fuel and vehicle propulsion options.[44] Among the options studied were E85 corn ethanol, E85 cellulosic ethanol, and reformulated gasoline for a 2010-model year, full-sized General Motors pickup truck. The same fuel

[43] For a synthesis of tailpipe emissions results, see Lisa Graham, Sheri Belisle, and Cara-Lynn Baas, "Emissions from Light Duty Gasoline Vehicles Operating on Low Blend Ethanol Gasoline and E85," *Atmospheric Environment* 42 (2008): 4498-4516. Combining the results of two new studies with previous studies, this article found that, relative to gasoline, E85 results in statistically significant decreases in tailpipe emissions of nitrogen oxides (-45 percent), non-methane hydrocarbons (-48 percent), 1,3-butadiene (-77 percent), and benzene (-77 percent); statistically significant increases in emissions of formaldehyde (73 percent) and acetaldehyde (2540 percent); and no statistically significant changes in carbon monoxide, carbon dioxide, and non-methane organic gases. The results for E10 are somewhat different. Relative to gasoline, E10 results in a statistically significant decrease in carbon monoxide emissions (-16 percent); statistically significant increases in non-methane hydrocarbons (9 percent), non-methane organic gases (14 percent), acetaldehyde (108 percent), 1,3-butadiene (16 percent), and benzene (15 percent); and no statistically significant changes in tailpipe emissions of nitrogen oxides, carbon dioxide, methane, nitrous oxides, and formaldehyde.

[44] Norman Brinkman, Michael Wang, Trudy Weber, and Thomas Darlington, *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions* (May 2005).

E85 from corn-based ethanol increases total emissions of five major air pollutants but reduces them in urban areas.

options were also studied for a hybrid electric version of the same vehicle.[45] As Table 3.2 indicates, the study found that:

- **E85 corn ethanol increases total emissions of five major pollutants relative to gasoline, but reduces emissions of these pollutants in urban areas.**

Table 3.2: Percentage Change in Various Air Emissions for E85 Corn and Cellulosic Ethanol Relative to Reformulated Gasoline

Pollutant	E85 Corn Ethanol	E85 Cellulosic Ethanol
Total Emissions		
Carbon Monoxide	3%	7%
Particulate Matter (PM_{10})	242	38
Sulfur Oxides	125	-94
Nitrogen Oxides	94	110
Volatile Organic Compounds	21	24
Emissions in Urban Areas		
Carbon Monoxide	-2%	-2%
Particulate Matter (PM_{10})	-13	-17
Sulfur Oxides	-40	-87
Nitrogen Oxides	-22	-25
Volatile Organic Compounds	-5	-4

NOTE: Changes in emissions were based on life-cycle emissions for E85 ethanol use in a full-size General Motors pickup truck relative to reformulated gasoline. Results were rounded to the nearest percent.

SOURCE: Office of the Legislative Auditor, analysis of data from Norman Brinkman, Michael Wang, Trudy Weber, and Thomas Darlington, *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions* (May 2005), D-3.

Compared with reformulated gasoline, E85 corn ethanol increases total emissions of carbon monoxide by 3 percent, nitrogen oxides by 94 percent, particulate matter with a diameter of 10 microns or less (PM_{10}) by 242 percent, sulfur oxides by 125 percent, and volatile organic compounds by 21 percent. In contrast, emissions are reduced in urban areas: carbon monoxide (-2 percent), nitrogen oxides (-22 percent), PM_{10} (-13 percent), sulfur oxides (-40 percent), and volatile organic compounds (-5 percent). These results occur because many of the emissions from E85 corn ethanol occur at ethanol plants or on farms in rural areas.[46] Despite differences in tailpipe emissions that favor corn ethanol for most

[45] For the most part, the results for a hybrid electric vehicle using the three different fuels were similar to those for the standard vehicle. However, emissions from the hybrid electric vehicle were generally lower than those for the standard vehicle for any particular fuel type.

[46] In addition, for gasoline, emissions at refineries tend to occur in urban areas.

of these pollutants, total emissions for E85 corn ethanol are higher for all five pollutants.[47]

In addition, the results from this life-cycle study indicate that:

- **E85 cellulosic ethanol has similar effects on the five major pollutants studied except that total emissions of sulfur oxides are significantly lower for cellulosic ethanol compared with gasoline.**

Table 3.2 shows similar results for E85 cellulosic ethanol as for E85 corn ethanol for carbon monoxide, nitrogen oxides, and volatile organic compounds. However, the results for sulfur oxides are very different. For cellulosic ethanol, total sulfur oxide emissions are reduced 94 percent relative to gasoline, while E85 corn ethanol emissions are 125 percent higher than those for gasoline. Particulate emissions are also different. Total PM_{10} emissions are 242 percent higher for corn ethanol than gasoline but only 38 percent higher for cellulosic ethanol compared with gasoline.

In 2006, a second life-cycle analysis examined the performance of E85 blends of corn ethanol and cellulosic ethanol made either from corn stover or woody residue.[48] The results for corn ethanol were similar to those in the 2005 study. Corn ethanol increases total emissions, but lowers urban emissions, of these five pollutants. The results for cellulosic ethanol are somewhat different from the earlier study. The differences are in part due to the specific types of cellulosic ethanol modeled and in part due to the study's projection of improvement in cellulosic technology by the years 2012 and 2030. We will focus on the projections for 2012, which only include cellulosic ethanol made from corn stover. The study's findings for cellulosic ethanol from corn stover in 2012 are somewhat similar to those in the 2005 study. However, the study found that cellulosic ethanol would increase total sulfur oxide emissions compared with gasoline in 2012, while the earlier study estimated a large reduction in these emissions for cellulosic ethanol.[49] Any estimates for cellulosic ethanol should be considered preliminary until it is clear how cellulosic ethanol will be produced.

Unfortunately, the life-cycle impacts of E10 and E20 on major air pollutants have not been studied and could be different than the results for E85.

Unfortunately, neither of these studies analyzed the life-cycle impacts of lower blends of corn ethanol such as E10 or E20. Since tailpipe emission results are different for E10 and E85 for some pollutants, the overall life-cycle emissions could also be different for E10 and E85.[50] In addition, the results in both studies were based on the average current corn ethanol plant. It is possible that technology being used in newer plants will affect the impact of corn ethanol on

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[47] According to Hill et al. (2006), 11207, tailpipe emissions are lower for E85 corn ethanol for carbon monoxide, volatile organic compounds, and PM_{10}.

[48] M. Wu, M. Wang, and H. Huo, *Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States* (Argonne, IL: Argonne National Laboratory, November 7, 2006).

[49] A small reduction in sulfur oxide emissions for cellulosic ethanol from corn stover relative to gasoline was estimated for 2030.

[50] See the tailpipe emission results for E10 and E85 in Graham et al. (2008).

various air pollutants. However, we are not aware of any life-cycle studies that have examined newer plant technology.

The air pollution health impacts of ethanol are beginning to be studied and are the subject of controversy.

The air pollution health impacts of ethanol are widely disputed. The results referenced above suggest that ethanol may have beneficial effects in urban areas, where levels of these air pollutants are of greatest concern. The increases in rural areas may be of less concern due to lower existing levels of these pollutants and a smaller population that may be affected. A few recent studies have criticized ethanol's impact on health. For example, a Stanford University study found that nationwide use of E85 would increase ozone by 4 percent in the United States relative to gasoline and increase ozone-related mortality, hospitalization, and asthma.[51] The study also found that the effects would vary by region, with increases projected for Southern California and the Northeast and decreases projected for the Southeast. These conclusions have been criticized for a variety of reasons including the unrealistic assumption that E85 would be used nationwide.[52] However, the EPA acknowledges that even more modest increases in ethanol use would result in a small increase in ozone formation.[53]

A 2009 study quantified the monetary costs of certain environmental impacts of gasoline, corn ethanol, and cellulosic ethanol.[54] The study considered the impacts of particulate emissions of 2.5 microns or less ($PM_{2.5}$) and greenhouse gas emissions. The study used various methods to estimate $PM_{2.5}$ levels in each of 6,358 grid cells across the continental United States and used EPA programs to estimate the human health impacts of increased $PM_{2.5}$ exposure.[55] Despite corn ethanol's higher production of $PM_{2.5}$ in non-urban areas and lower production in urban areas, the study found that corn ethanol increased the costs of $PM_{2.5}$ exposure relative to gasoline. The study found that the costs of emissions were higher for corn ethanol than gasoline, even if advanced natural gas ethanol plants produced the ethanol.[56] Finally, the study concluded that cellulosic ethanol produced from a number of sources reduced the costs of $PM_{2.5}$ exposure relative to gasoline.

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[51] Mark Z. Jacobson, "Effects of Ethanol (E85) Versus Gasoline Vehicles on Cancer and Mortality in the United States," *Environmental Science & Technology* 41 (2007): 4150-4157.

[52] For example, see Renewable Fuels Association, *Response to Mark Jacobson E85 Study*, http://www.ethanolrfa.org/objects/documents/1071/reapresponse_jacobsone85.pdf, accessed January 15, 2009.

[53] Assessment and Standards Division, *Office of Transportation and Air Quality, Regulatory Impact Analysis: Renewable Fuel Standard Program* (Washington, DC: Environmental Protection Agency, April 2007), 211.

[54] Jason Hill, Stephen Polasky, Erik Nelson, David Tilman, Hong Huo, Lindsay Ludwig, James Neumann, Haochi Zheng, and Diego Bonta, "Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline," *Proceedings of the National Academy of Sciences* 106, no. 6 (February 10, 2009): 2077-2082.

[55] The study considered both direct emissions of $PM_{2.5}$ and indirect sources of $PM_{2.5}$ resulting from atmospheric reactions involving sulfur oxides, nitrogen oxides, ammonia, and volatile organic compounds.

[56] The study compared the costs for a relatively modest increase in ethanol production (1 billion gallons) and the energy-equivalent amount of gasoline.

Life-cycle impacts of biodiesel relative to diesel fuel were estimated in a 1998 study of urban buses.[57] As Table 3.3 shows:

- **Relative to diesel fuel, biodiesel reduces life-cycle emissions of carbon monoxide, total particulate matter, and sulfur oxides, while increasing nitrogen oxides.**

Biodiesel reduces the emissions of several air pollutants while increasing nitrogen oxides.

Table 3.3: Percentage Change in Various Air Emissions for Biodiesel Relative to Diesel Fuel

Pollutant	B2	B5	B20	B100
Carbon Monoxide	-1%	-2%	-7%	-34%
Particulate Matter	-1	-2	-6	-32
Sulfur Oxides	*	*	-2	-8
Nitrogen Oxides	*	1	3	13

NOTE: Changes in emissions were based on life-cycle emissions for biodiesel use in an urban bus relative to diesel fuel. Results were rounded to the nearest percent. An asterisk (*) indicates that the percentage change was less than 0.5 percent.

SOURCE: J. Sheehan, V. Camobreco, J. Duffield, M. Grabowski, and H. Shapouri, *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus* (Golden, CO: National Renewable Energy Laboratory, 1998), 256.

According to the study, pure biodiesel (B100) reduced carbon monoxide by 35 percent, total particulate matter by 32 percent, and sulfur oxides by 8 percent. Biodiesel increased nitrogen oxides by 13 percent. The impacts of various blends of biodiesel and diesel were estimated to be proportionate to their biodiesel content. For example, the impacts of B20 relative to diesel fuel included decreases of 7 percent for carbon monoxide, 6 percent for total particulate matter, and 2 percent for sulfur oxides. B20 increased nitrogen oxides by 3 percent.

WATER QUALITY

Concerns have been raised about the impact of increasing biofuel production on the quality of both surface waters and groundwater. The concerns mainly focus on corn-based ethanol and, to a lesser degree, on soybean-based biodiesel. Cellulosic ethanol is believed by many to have more environment-friendly characteristics, although it could also have impacts on water quality.

The basis for the concerns about corn ethanol revolve primarily around the potential damage to water quality from fertilizer and pesticide runoff and soil erosion during the production of corn. Ethanol plants discharge significant amounts of wastewater, which can also be a concern. In addition, blending

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[57] J. Sheehan, V. Camobreco, J. Duffield, M. Grabowski, and H. Shapouri, *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus* (Golden, CO: National Renewable Energy Laboratory, 1998).

ethanol with gasoline increases the risk of corrosion of underground fuel tanks and potential leakages to surrounding soil and groundwater supplies.

In this section, we will primarily discuss concerns about fertilizer and pesticide runoff and soil erosion since these are the major sources of concern regarding water quality. While wastewater discharges can be a concern, less has been written about their impact. Wastewater discharges from ethanol plants are also subject to regulation by the Minnesota Pollution Control Agency. Runoff and soil erosion is subject to much less regulation.

Fertilizers and pesticides used on corn can cause water quality problems.

Corn requires more fertilizers and results in more soil erosion than any other crop in the United States. According to the United States Department of Agriculture, over 95 percent of corn acres in the United States were fertilized with nitrogen and treated with herbicides from 1991 to 2003. Phosphate fertilizer was applied to about 80 percent of corn acres, while insecticides were used on 30 percent.[58] Corn farming accounts for nearly 40 percent of nitrogen fertilizer consumption in the United States and as much as 80 percent in Midwestern states.

When runoff or soil erosion occurs, these chemicals can be carried to surface waters and groundwater. Nitrogen is highly soluble in water and exacerbates algae outbreaks that, upon decomposition, consume large amounts of oxygen and choke off the supply of oxygen for fish and other creatures. Excess phosphates also contribute to this process, but are somewhat more manageable.

Nitrogen's effect on surface waters results in the formation of "dead zones," or areas where fish and other aquatic life cannot survive. The dead zone in the Gulf of Mexico is one of these zones. It is the third largest mapped to date and is greatly affected by agriculture in the Midwest. Nitrogen from agricultural sources, such as fertilizer and manure, is estimated to contribute about 65 percent of the nitrogen entering the Gulf of Mexico from the Mississippi Basin. Minnesota contributes about 5 percent of the nitrogen and phosphorus reaching the Gulf of Mexico.

Runoff and soil erosion can also impact groundwater supplies and adversely affect drinking water and potentially human health. The United States Geological Survey has found that 9 percent of domestic wells sampled do not meet drinking water standards. Agriculture was identified as the major source of the problem.

Some agricultural practices have changed over time and have helped moderate the impact on surface waters and groundwater. The increased adoption of "no-till" methods has helped decrease soil erosion. In addition, less fertilizer is being used per acre for corn production. Since 1985, the amount of nitrogen applied per planted acre of corn has declined 10 percent nationwide. Because yields have

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[58] In Minnesota, the percentages were over 95 percent for nitrogen and herbicides, over 85 percent for phosphate, and about 10 percent for insecticides.

increased, the amount of nitrogen used per bushel of corn decreased 31 percent between 1985 and 2007.[59]

However, some analysts have estimated that expansion of corn ethanol would increase problems with water quality. For example, researchers estimated that expanding annual ethanol production to between 15 billion gallons and 36 billion gallons in 2022 would increase the average amount of nitrogen reaching the Gulf of Mexico by 10 to 34 percent.[60] A reduction in nitrogen entering the Gulf—not an increase—is needed to meet the target set in hopes of reducing the size of the dead zone in the Gulf.

This study used, however, very conservative estimates of future increases in corn yield per acre. The growth rates used were between zero and 1 percent per year, which are below the average annual growth rate of 1.67 percent over the last 40 years. As a result, the researchers estimated that a significant amount of additional land would be needed for corn production even with an annual production level of 15 billion gallons, which is the level now anticipated by the federal Renewable Fuel Standard.[61] The additional land in corn production would result in greater use of nitrogen fertilizer and thus increased nitrogen entering the Gulf of Mexico.

The impact of corn-based ethanol on water quality depends on whether ethanol growth results in an expansion in the number of acres of corn planted.

In our view, the net impact of corn-based ethanol on water quality depends crucially on land use impacts. If growth in corn yields and corn-to-ethanol conversion yields are large enough to accommodate the growth in corn ethanol use, then the land needed for corn in the Midwest or the United States may not need to expand beyond current acreage devoted to ethanol. In that case, it would be difficult to argue that corn ethanol is causing an expansion of the dead zone in the Gulf of Mexico or elsewhere. However, if corn ethanol production expands faster than yields allow—as it has in recent years—then additional land will need to be devoted to ethanol production. In that case, ethanol expansion would be responsible for some growth in water quality problems. There is also the potential for indirect land use impacts in other countries, as we discussed earlier in the section on greenhouse gas emissions.

Soybeans, which are used to produce biodiesel, also require the use of fertilizers and pesticides. However, they use only about 1 percent of the nitrogen used by corn per unit of energy gained through biofuel production. In addition, soybeans use 8 percent of the phosphorus and 13 percent of the pesticides per net unit of energy gained.[62] In addition, pesticides used in corn production "tend to be more

[59] Similarly, declines occurred for phosphorus and potash fertilizers applied to corn fields. These declines follow a period of significant increases.

[60] Simon Donner and Christopher Kucharik, "Corn-Based Ethanol Production Compromises Goal of Reducing Nitrogen Export by the Mississippi River," *Proceedings of the National Academy of Sciences* 105, no. 11 (March 18, 2008): 4513-4518.

[61] The scenario of 36 billion gallons of annual corn ethanol production results in even greater expansion of corn acreage and increased nitrogen use and runoff. However, this level of corn ethanol production is not called for by the federal Renewable Fuel Standard (RFS). The RFS would only give credit up to 15 billion gallons of corn ethanol per year.

[62] Hill et al. (2006), 11207-11208.

environmentally harmful and persistent than those used to grow soybeans."[63] Even though the net energy gained per acre of corn is at least double that for an acre of soybeans, corn ethanol still requires greater use of fertilizers and pesticides than soy biodiesel.

It could be argued that the expansion of biofuel production has already impacted land use in the United States. As observed in Chapter 1, all of the growth in United States corn production since 2001 has been used to increase corn-based ethanol production. Soybean use for biodiesel has also grown significantly. Since 2001, the amount of land planted with corn has increased 14 percent, while acreage devoted to soybeans has increased 2 percent. The combined acreage devoted to corn and soybeans in the United States grew 8 percent between 2001 and 2008.

Generally, scientists say that cellulosic ethanol will not have the water quality impacts characteristic of corn production. For example, a 2006 study concluded that ethanol produced from high-diversity prairie grasses would use only a small fraction of the fertilizers and pesticides used by corn ethanol or soy biodiesel.[64] Furthermore, the grasses could be grown on abandoned agricultural lands and would reduce greenhouse gas emissions more than traditional biofuels while producing nearly the same amount of net energy per acre as corn ethanol.[65]

While biomass crops used for cellulosic ethanol could be grown with small amounts of fertilizers and pesticides, it is unclear how they would be grown.

Two issues about cellulosic ethanol have not yet been studied in any detail. First, while cellulosic crops could be grown with a minimum of fertilizers and pesticides, it is unclear what crops will be produced and how farmers will grow them. For example, it may be possible to grow switchgrass without significant fertilizer or pesticide use. But farmers may find it profitable to use one or both of these products to improve switchgrass yields. Second, it is not clear how the wastewater stream from cellulosic ethanol plants will differ from corn ethanol plants. As a result, the exact impacts of cellulosic ethanol on water quality are not entirely clear at this time, although scientists generally think that they will be significantly better than for corn ethanol.

WATER SUPPLY

The use of water in the production of ethanol is also a concern because the production of ethanol is a water-intensive process. In Minnesota, ethanol plants used an estimated 3.8 gallons of water per gallon of ethanol produced in 2006. The water usage by ethanol plants has been declining and was 5.5 gallons per gallon of ethanol in 1998. These figures are based on reports from the ethanol plants receiving producer payments. The average water usage for all ethanol plants in Minnesota may be lower, since the figures do not include the newest plants built in the state. Newer plants tend to recycle their water within the plants

[63] *Ibid.*, 11207.

[64] Tilman et al. (2006), 1600.

[65] *Ibid.*, 1599-1600.

more than older plants and thus have lower water consumption per gallon of ethanol.

The water used to irrigate corn is a much larger concern than the water used by ethanol plants, but only 3 percent of Minnesota's corn crop is irrigated.

However, if irrigation of corn is considered, the overall water usage for corn ethanol is significantly greater than the usage at ethanol plants. We estimate that about 20 gallons of water were used per gallon of ethanol in Minnesota in 2003, compared with over 200 gallons of water nationwide.[66] The figure for Minnesota is much lower than the national estimate because corn irrigation is less common in Minnesota. In 2003, only 3 percent of Minnesota corn acreage was irrigated, compared with 14 percent nationwide.

The use of water to grow corn and produce ethanol should not be viewed as unusual. Irrigation is often used throughout the United States for agricultural crops. Furthermore, the use of water by ethanol plants is not unusual compared with industrial plants or golf courses. The use of water to produce corn ethanol is, however, greater than that used to produce gasoline, according to a recent study.[67] The study shows that between 0.07 and 0.14 gallons of water per mile are consumed in vehicles powered by gasoline. This amount compares with between 0.15 and 0.35 gallons of water per mile in vehicles powered by E85 made from non-irrigated corn and an average of 28 gallons of water per mile in vehicles powered by E85 made from irrigated corn.[68] While vehicles powered by diesel fuel use between 0.05 and 0.11 gallons of water per mile, vehicles using B100 made from non-irrigated soybeans consume less water—between 0.01 and 0.02 gallons per mile. However, vehicles using B100 made from irrigated soybeans use an average of 8 gallons of water per mile.[69]

Whether the water used for corn ethanol is a problem depends on the water resources in the areas in which ethanol plants locate and corn is grown. In parts of the United States, water table levels are dropping, and additional pressure from ethanol and irrigated corn is placing additional pressure on scarce resources. For example, large portions of the Ogallala (or High Plains) aquifer, which stretches

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[66] Our estimate is based on the most recent data available on irrigation of cropland in the United States.

[67] Carey King and Michael Webber, "Water Intensity of Transportation," *Environmental Science & Technology* 42, no. 21 (September 24, 2008): 7866-7872. The results of this study are based on conventional gasoline and diesel fuel. For Minnesota, it would be appropriate to also consider the water usage for Canadian oil sands production.

[68] The results for E85 cellulosic ethanol made from corn stover were roughly similar to those for corn ethanol. For cellulosic ethanol processed from corn stover on non-irrigated fields, water usage per mile of travel was between 0.25 and 0.41 gallons per mile. If the corn stover came from irrigated fields, the average water consumption was 23 gallons per mile.

[69] All the figures cited in this paragraph are based on a life-cycle analysis of water consumption including the mining or farming of the feedstock for the fuel, the processing and refining of the feedstock into the final fuel, and the efficiency with which the fuel can propel the vehicle. The authors did not include water usage for transporting the feedstock to the refinery, transporting the fuel to retail locations, and manufacturing and installing physical facilities. In addition, water available for biofuel crops through rain was not included. The figures cited in the paragraph are also based on the consumption of surface water or groundwater net of water withdrawn from and returned to these sources.

from west Texas up into South Dakota and Wyoming, have experienced water table declines of over 100 feet.[70]

In Minnesota, the Department of Natural Resources (DNR) is responsible for issuing water appropriation permits to those users who appropriate more than 10,000 gallons per day or 1 million gallons per year. Permits are issued to various types of users, including ethanol plants and agricultural crop irrigators. The DNR has some safeguards in place to ensure that the impact of water use by ethanol plants on available water resources is monitored. The DNR modified the permit for one ethanol plant after monitoring showed that the plant's water usage was adversely affecting local groundwater levels.[71] As a result, the plant was required to stop using groundwater and draw its water from a surface water source that could provide the necessary water.

There is some indication that corn irrigation has increased relative to the irrigation of other crops in recent years.

There is some indication that ethanol expansion is increasing the amount of major crop irrigation in Minnesota. From 2003 to 2007, major crop irrigation increased 25 percent. This increase appears to be due to two factors. First, the number of acres of corn planted grew significantly in 2007, as farmers switched to corn instead of soybeans or other crops. Since corn tends to be irrigated with more water per acre than other major crops, total irrigation increased in 2007. Second, the amount of irrigation water applied per acre of corn increased 32 percent from 2003 to 2007. Although weather could have played a role in this increase, there was no similar trend for other major crops. The amount of irrigation water applied per acre of other major crops increased only 2 percent over this period. As a result, irrigation may be increasing as ethanol expansion provides incentives for farmers to increase corn production and perhaps to increase yields by irrigating corn.

Whether this trend is a basis for concern is unknown. It is unclear whether the increase is causing any significant problems for the state's water resources. In addition, it is unclear whether the trend we observed through 2007 is permanent.[72] However, this trend needs to be monitored by the DNR and other state agencies.

CONSERVATION RESERVE PROGRAM

Another concern about both corn-based ethanol and soy-based biodiesel is that their expansion may take acres out of the federal Conservation Reserve Program (CRP). CRP provides environmental and wildlife benefits by paying landowners to convert agricultural lands to grass, trees, or wildlife cover, or use other

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[70] National Research Council, *Water Implications of Biofuels Production in the United States* (Washington, DC: National Academies Press, 2008), 19.

[71] According to DNR officials, the agency fully understood the limitations of the aquifer at the beginning of the project and directed the ethanol plant to pursue alternative sources of water. After the plant shifted to using surface water, the aquifer quickly began to recover.

[72] In 2008, corn acreage in both Minnesota and the United States declined, although it remained higher than in recent years other than 2007. Minnesota irrigation data for 2008 were not available during our study.

conservation practices. The benefits of CRP include improvement of surface water quality, protection of groundwater quality, creation of wildlife habitat, preservation of soil productivity, and reduction of wind erosion damages.

Established in 1985, the CRP is the federal government's largest land conservation program and included 34.7 million acres, as of September 2008. Enrollment in the program was down about 2.06 million acres (or 6 percent) from September 2007, although enrollment increased during most of the current decade. In Minnesota, enrollment also declined from September 2007 to September 2008 by about 46,000 acres (or 3 percent), ending the federal fiscal year at 1.78 million acres. This decline came after a significant decline in the late 1990s and strong growth during the current decade.

Conservation experts and advocates are concerned that CRP enrollment will continue to fall, in part due to biofuel expansion and other factors that are contributing to higher agricultural commodity prices. Through January 2009, national CRP enrollment is already down another 1.07 million acres (or 3 percent). In Minnesota, CRP enrollment is down another 90,000 acres (or 5 percent). Furthermore, conservationists are concerned about potentially large loss of CRP acres in future years, particularly for decisions to be made in the fall of 2011 through 2013.[73] Although some would claim that little CRP acreage is likely to be farmed, evidence from an Iowa State University study suggests otherwise. The study found that significant amounts of CRP acreage in Iowa would be brought into corn production at high corn prices.[74]

Nevertheless, we found that:

It is unclear whether the expansion of biofuel production has caused recent reductions in Conservation Reserve Program (CRP) acreage.

- **There is conflicting evidence as to whether conventional biofuel expansion is responsible for recent losses in CRP acreage.**

In the last two years, the increase in corn and soybean acres has been much greater than the decline in CRP acreage. Consequently, expansion of corn ethanol and soy biodiesel could be playing a role in CRP declines along with other factors. From September 2006 to September 2008, the combined corn and soybean acres planted in the United States increased by about 7.85 million acres, while CRP acreage declined 1.29 million acres. Over the same time period, corn and soybean acres planted in Minnesota grew by about 100,000 acres, and CRP acreage declined by about 14,000 acres. Obviously, the increased corn and soybean acres are coming from other sources besides CRP lands. The increase in corn and soybean acreage could have come from unused cropland, land used for other crops, or pasture land.

[73] A total of 186,000 acres were up for renewal in the falls of either 2007 or 2008, and a total of 136,000 acres are up for renewal in the falls of either 2009 or 2010. However, the acres up for renewal increase to 128,000 in the fall of 2011; 294,000 in 2012; and 131,000 in 2013.

[74] Silvia Secchi and Bruce Babcock, "Impact of High Crop Prices on Environmental Quality: A Case of Iowa and the Conservation Reserve Program," Working Paper 07-WP 447 (Ames, IA: Iowa State University, May 2007).

However, biofuel and agricultural expansion does not seem to be related to CRP acreage when examined over the 2001-08 period during which biofuel production has seen the greatest expansion. During that period, combined corn and soybean acres planted in the United States increased 8 percent. But, CRP acreage was up 3 percent over the same period. In Minnesota, combined corn and soybean acres planted grew 5 percent, while CRP acreage increased 12 percent.

It would be inappropriate at this point to lay the blame for recent declines in CRP enrollment solely on biofuels. Even though higher agricultural commodity prices may be one of the factors behind declines in CRP participation, biofuel expansion has been only partially responsible for higher commodity prices. As we will discuss in Chapter 4, there are a number of reasons for the increase in commodity prices experienced worldwide in recent years.

The impact of biofuel expansion on CRP land set-asides should be monitored.

The potential impact of conventional biofuels on CRP should be monitored by state and federal officials. In particular, the potential loss of CRP acreage in 2011 through 2013 would be significant and potentially damaging to the environment and wildlife. In addition, state officials should consider the potential impact on CRP of growing grass or other biomass crops for cellulosic ethanol. Some state officials are concerned that the abandoned croplands often cited as potential sites for biomass crops are mostly CRP lands. The water quality and wildlife impacts of growing biomass crops on CRP lands should be carefully analyzed by state agencies.

SUMMARY

Proponents of conventional biofuels such as corn ethanol and soy biodiesel have claimed they have significant environmental benefits such as reduced greenhouse gas emissions and lower emissions of various air pollutants. In recent years, critics have alleged that these conventional biofuels increase greenhouse gas emissions, may cause growth in air pollution-related health problems, increase water quality problems, stress local water supplies, and threaten the preservation of environmentally sensitive areas and wildlife habitat.

However, our review of existing research suggests that:

- **The environmental impacts of conventional biofuels are unclear in some respects and more complicated than is often acknowledged by both supporters and detractors of biofuels.**

For each environment topic examined in this chapter, we have expressed concerns about the ability of available research and evidence to definitely determine the environmental impacts of corn ethanol and soy biodiesel. For example, we found that the impact of corn ethanol and soy biodiesel on greenhouse gas emissions is unclear. Most life-cycle analyses indicate these biofuels reduce greenhouse gas emissions over petroleum-based fuels. In addition, the reduction may be a little higher in Minnesota than the nation due to our greater reliance on Canadian oil sands petroleum and the use of alternative fuels by three ethanol plants as an energy source. However, the potential land use impacts of biofuels, while uncertain, are of sufficient potential magnitude that they could offset the estimated reductions. We have also pointed out a number of other weaknesses in existing life-cycle analyses that raise questions about the validity of their results.

Furthermore, the health impacts of corn ethanol are unclear because ethanol increases overall emissions of key air pollutants while decreasing them in urban areas. Adverse impacts on water quality from waste streams at biofuel plants can be mitigated through monitoring and existing regulatory authority. The impacts of corn ethanol and soy biodiesel on water quality and CRP lands depend on whether additional land is needed to grow corn or soybeans. The need for additional land depends on how fast biofuel production is expanded relative to the growth in crop and crop-to-biofuel yields.

Even if we give conventional biofuels the benefit of the doubt:

At best, the environmental impacts of conventional biofuels are mixed and relatively modest at the blending levels that are achievable nationwide.

- **The environmental impacts of conventional biofuels are at best mixed, with some potentially positive and some negative impacts.**

For example, assuming land use impacts are minimal, corn ethanol and soy biodiesel reduce greenhouse gas emissions. But, they use more water than petroleum-based fuels and may negatively impact water quality and wildlife habitats. The impact of corn ethanol on urban air pollution may be beneficial, although overall air pollution from corn ethanol use is higher than for gasoline. Furthermore:

- **The environmental impacts of corn ethanol and soy biodiesel are relatively modest at the production levels that are achievable nationwide.**

The potential greenhouse gas emissions and air pollutant reductions are meaningful but relatively modest for those products that can be sustained nationally without significant land use impacts. Nationwide use of E10 and B2 produced only from corn and soybeans is probably feasible over the next 6 to 11 years without a significant increase in the amount of land dedicated to these crops. But the potential emission reductions for these blending levels are relatively small at best. Nationwide use of E20 and B5 would provide a little greater reduction in emissions but would require significant increases in the land devoted to biofuel production using corn and soybeans. Although using E85 and B20 might offer significant reductions, achieving these levels of use nationwide is not feasible with corn and soybeans alone.

In addition:

- **While soy biodiesel appears to have more beneficial environmental impacts than corn ethanol, the lower yields of biofuel from an acre of soybeans may reduce or erase any potential advantage.**

Biodiesel appears to have some advantages over corn ethanol. For example, pure biodiesel appears to reduce greenhouse gas emissions by a larger percentage than pure corn ethanol. However, the higher yields of ethanol that can be produced from an acre of corn mean that, absent land use impacts, the greenhouse gas reductions from an acre of corn may be larger than from an acre of soybeans.[75]

We have emphasized the limitations of corn ethanol and soy biodiesel in achieving higher blends of biofuels. However, it may be possible to achieve higher blending levels if alternative feedstocks are used to supplement corn and soybeans. Cellulosic ethanol and algae-based biodiesel are two possibilities. As we have seen:

Cellulosic ethanol is thought to have considerably more positive environmental impacts than corn-based ethanol, but questions remain about where biomass crops would be grown.

- **Cellulosic ethanol is believed to have considerably more positive environmental impacts than corn-based ethanol, but is still in the development stage and not economically competitive with corn ethanol.**

Cellulosic ethanol may produce much greater reductions in greenhouse gas emissions, may require considerably less fertilizer and pesticide, and may be able to be grown on marginal or abandoned cropland. But there is also uncertainty about where cellulosic crops would be grown, how they would be fertilized, what chemicals and fossil fuels would be needed to convert the crops to ethanol, and whether they could be relatively competitive with corn ethanol and gasoline on an economic basis.

Algae-based biodiesel is believed by some to have great promise as an environmentally better alternative to biodiesel produced from soybeans or other crop seeds. Some claim that algae-based biodiesel would require less land and fossil fuels to produce and could be produced on land unsuitable for agriculture. Clearly algae-based biodiesel has promise, but it is in the early stages of research and development. As a result, few scientific studies have examined its environmental impacts. More needs to be known about potential production processes before its environmental impacts can be better understood.

Overall, we do not see any environmental reason for Minnesota to change its current mandates for ethanol and biodiesel use. However, we think that the environmental impacts of corn ethanol and soy biodiesel should be monitored by state agencies.

Biofuel land impacts on greenhouse gas emissions need to be monitored because EPA rules may affect the ability of biofuels produced by new biofuel plants to qualify for federal blending credits. In addition, it is appropriate that the state review the analyses done by various academic, government, and private entities and consider whether changes in state biofuel policies are needed. In particular, we recommend that:

[75] At first glance, it may not make sense to compare corn ethanol and soy biodiesel since they are used to produce different fuels that are used in different types of engines and vehicles. However, they do compete with one another for land.

RECOMMENDATION

The Environmental Quality Board (EQB), with assistance from its member agencies, should track how the federal government and other states are handling the issue of greenhouse gas emissions from indirect land use emissions. The EQB should also review work done by academic researchers. The EQB should report back to the Legislature on its findings and should recommend any needed changes in biofuel policies.

We think that EQB provides the proper forum for discussion of this issue, since its members come from a number of agencies with an interest in this issue and pertinent expertise.[76] However, the Governor has recommended transferring the functions of EQB to the Minnesota Pollution Control Agency (MPCA). In that event, we would recommend that MPCA be responsible for handling this issue with input from other agencies such as the Department of Agriculture and the Department of Natural Resources.

More information is needed on the potential sources of biomass for cellulosic ethanol, the land requirements, and the potential environmental impacts.

We also think that it is very important for Minnesota to plan for future cellulosic ethanol use by considering the sources of future cellulosic feedstock. Corn ethanol has been a useful biofuel for Minnesota, but it has some environmental and land limitations compared with cellulosic ethanol. If the nation desires to increase the biofuel content of its motor fuel, it will need sources of feedstock for cellulosic ethanol. To the extent that those sources require additional land for growing the feedstock, the state should consider what types of land are available and would be appropriate for that use.[77] More specifically, we recommend that:

RECOMMENDATION

The Environmental Quality Board and its member agencies should study the potential sources of biomass in Minnesota that could be used to produce cellulosic ethanol. The EQB should also consider what additional land requirements would be needed for that biomass and how the biomass could be grown in Minnesota with minimal environmental impact.

The Department of Natural Resources and the Forest Resources Council have already begun a process to identify supplies of forest biomass and to build consensus around the highest and best use of woody biomass, which may or may not be cellulosic biofuel. Our recommendation is consistent with that effort but is more comprehensive in that it includes all potential sources of biomass. While

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[76] The EQB has members from the departments of agriculture, administration, natural resources, employment and economic development, health, transportation, and commerce. The MPCA and the Board of Water and Soil Resources are also represented on the EQB. In addition, four private citizens are members of the EQB.

[77] Not all sources of cellulosic ethanol would require additional land for feedstock production. Feedstocks like solid waste, wood waste, and corn stover are already produced and would not need to be grown on additional land. However, feedstocks requiring land include prairie grasses, switchgrass, miscanthus, and poplar trees.

we have directed this recommendation to the EQB and its member agencies, it could be directed to the Next Generation Energy Board, if the EQB is eliminated.

We also think that certain environmental impacts of corn ethanol and biodiesel should be monitored on an ongoing basis by the state. For example, we recommend that:

RECOMMENDATION

As part of its ongoing monitoring process, the Department of Natural Resources should closely monitor trends in irrigation for biofuel crops like corn and soybeans.

We noticed a significant increase in the amount of corn irrigation in 2007. It is unclear whether this was a temporary phenomenon or the start of a trend. Given the growth in corn ethanol production, future trends should be monitored.

In addition, we think that land use trends should be monitored. If future growth in corn ethanol and soy biodiesel expands land use for biofuels, it may adversely affect greenhouse gas emissions, water quality, and wildlife habitat. Ongoing information on land use would help inform future decisions about biofuel policy.

RECOMMENDATION

The Environmental Quality Board should monitor how biofuel expansion is affecting land use, including the trends in the land used for agricultural crops like corn and soybeans and the land set aside by farmers for preservation and environmental purposes.

If warranted by land use trends, other agencies or the Legislature could develop strategies to restrict biofuel expansion or mitigate any adverse impacts.

4 Economic Impact

According to proponents, biofuels have economic benefits, as well as energy and environmental advantages. They say that domestic production of biofuels keeps money spent on fuels in the United States instead of being sent abroad. Producers of biofuels and growers of corn and soybeans earn additional income and, in turn, spend money within their local communities—thus increasing economic activity within the United States. Proponents also claim that competition from ethanol has reduced gasoline prices. In addition, proponents argue that biofuel production reduces the need for military spending to protect access to foreign oil supplies.

Critics question whether conventional biofuels like corn and soybeans have had much of an effect on the national economy. They point to higher food and meat prices as a consequence of expanded biofuel production. In addition, they argue that the cost of subsidies for corn ethanol and soy biodiesel is high and offsets any economic benefits from domestic production. Finally, critics suggest that ethanol and biodiesel have generally added to the cost of fuel despite generous subsidies.

In this chapter, we examine the potential economic impact of biofuels, particularly corn ethanol. We first consider the methods a study needs to use in order to provide a true estimate of the net economic impact of biofuels. We also discuss the types of benefits and costs that must be examined in order to provide a comprehensive examination of the economic impact. We then discuss the contributions and shortcomings of existing studies. These studies include some that purportedly estimate the overall economic impact of the ethanol industry, as well as studies that address one or more of the benefits or costs that are part of the economic impact of biofuels.

MEASURING BENEFITS AND COSTS

Many factors affect the economic impact of biofuels.

In order to properly measure the overall economic impact of biofuel policies, it is important to account for all of the benefits and costs and to measure the benefits and costs properly. The main economic benefits and costs that have been identified by various studies include:

- **the benefits of reduced oil imports and increased domestic biofuel production;**

- **the benefits of reduced economic disruption from oil price or supply shocks less the costs of increased economic disruption due to feedstock shortages and price increases;**

- **the benefits of increased agricultural production net of the costs of reduced livestock production;**

- **the value of environmental benefits net of environmental costs;**
- **the benefits of reduced military spending;**
- **the net impact on fuel prices;**
- **the costs of increased food prices; and**
- **the government costs of biofuel subsidies less any reduced subsidies for agricultural commodities and oil.**

The economic impact of biofuels is best measured by focusing on the impact of a particular biofuel policy or a specific change in biofuel consumption.

To measure these benefits and costs properly, one must examine them on a marginal basis for a given policy. One study cited by proponents of biofuels estimated that the "hidden" costs of oil were $305 billion in 2003.[1] That figure was later updated to $825 billion in 2006.[2] The earlier figure was interpreted by another advocacy group as meaning that the price of gasoline, if it included all these hidden costs, would increase to $5.28 per gallon in 2003.[3] Among the many problems with the original study is the failure to consider the marginal impact of a particular policy. The estimate includes the impact of all United States imports of petroleum, but does not explain how and at what cost the United States could eliminate all oil imports. Given current technology, eliminating all imports would come at a tremendous cost no matter how it was done. The land and food price impacts would be very significant if the nation tried to replace all imports, which are now about two-thirds of our nation's oil consumption. Efforts to conserve energy would not be able to save that much oil without a tremendous sacrifice of production and consumption of goods and services.

Appropriate measures of economic impact consider the marginal impact of a particular policy such as a mandate to increase biofuel consumption from a base level to a higher level of use. For example, an analyst could evaluate the economic impact of the 2007 federal Renewable Fuel Standard, which raised minimum biofuel usage from the levels set in 2005 legislation. Alternatively, one could consider the impact of all current biofuel usage in the United States relative to the option of no biofuel usage. In either case, the marginal impact would be to replace only a portion of oil imports. As we saw in Chapter 2, biofuels currently replace a relatively small percentage of all gasoline and diesel fuel consumption by motor vehicles.

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[1] Milton Copulos, *America's Achilles Heel: The Hidden Costs of Imported Oil—A Strategy for Energy Independence* (Washington, DC: National Defense Council Foundation, October 2003), 53, http://ndcf.dyndns.org/ndcf/energy/NDCF_Hidden_Costs_of_Imported_Oil.pdf, accessed September 17, 2008.

[2] Milton Copulos, *The Hidden Cost of Oil: An Update* (Washington, DC: National Defense Council Foundation, January 8, 2007), http://ndcf.dyndns.org/ndcf/energy /NDCF_Hidden_Cost_2006_summary_paper.pdf, accessed September 17, 2008.

[3] Institute for the Analysis of Global Security, *NDCF Report: The Hidden Cost of Imported Oil* (Potomac, MD: October 30, 2003), http://www.iags.org/n1030034.htm, accessed September 17, 2008.

Unlike the hidden-cost-of-oil estimate mentioned above, appropriate measures of economic impact examine the costs of a particular policy, as well as the benefits. Without specifying how a reduction in imports will occur, an estimate gives no consideration to the costs of a particular policy or action. Implementing a Renewable Fuel Standard or a subsidy program for biofuels has both costs and benefits.

Finally, the petroleum savings of any biofuel program need to be accurately estimated. As discussed in Chapter 2, ethanol production requires the use of some petroleum and other fossil fuels. In addition, ethanol has only about two-thirds the energy content of gasoline. Consequently, given current technology, a gallon of ethanol replaces about 0.69 gallons of gasoline.

STUDIES OF OVERALL IMPACT

During this evaluation, we reviewed numerous studies that examined the economic impact of biofuels. These studies considered one or more of the types of benefits or costs outlined above. In our view:

We were not able to find any studies of the economic impact of biofuels that were both comprehensive and objective.

- **Currently available studies do not examine the economic impact of biofuels in a comprehensive and objective manner.**

Studies from proponents of biofuels typically include the direct impact of biofuels, which consists of the value of ethanol production.[4] Studies often include the indirect impact of spending by ethanol and corn producers on various goods and services. They may also include the full value of corn production in a state or in the nation.[5] In addition, some studies add induced impacts on all sectors due to the direct and indirect impact of ethanol and corn production.[6]

These studies are described as economic impact studies of either the ethanol industry, or the corn and ethanol industry. However, they are simply measuring the value of the industry's production, spending, and induced spending. They are not considering the net impact of a biofuel policy and are not measuring the marginal impact of a policy. Finally, these studies consider neither the economic costs of biofuel production nor all of the benefits.

Despite our concerns about existing studies, we suspect that the economic impact of biofuel production has a net positive impact on the Minnesota economy. We have not done a thorough analysis of the economic impact, but we think that

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[4] For example, see John Urbanchuk, *Contribution of the Ethanol Industry to the Economy of the United States* (Wayne, PA: LECG LLC for the Renewable Fuels Association, February 17, 2009), http://www.ethanolrfa.org/objects/documents/2187/2008_ethanol_economic_contribution.pdf, accessed February 23, 2009. See also Su Ye, *Economic Impact of the Corn and Ethanol Industry in Minnesota* (St. Paul, MN: Minnesota Department of Agriculture, 2008).

[5] Ye, *Economic Impact*.

[6] *Ibid*. In this study, the direct impacts are the value of corn and ethanol outputs. The indirect impacts are the effects on other economic sectors caused by purchases made by producers in the corn and ethanol industries. The induced impacts are the effects on all economic sectors due to the spending of income generated by the direct and indirect impacts.

ethanol and biodiesel have had a positive impact for several reasons. First, Minnesota does not produce any oil, so production of alternative fuels is replacing imports from Canada or other states. Second, some increase in crop production and prices could also be attributed to biofuel production. Finally, the costs of state biofuel subsidies are probably small in comparison with the amount of increased income and economic activity. Similarly, the reduction in the costs of federal subsidies to Minnesota taxpayers would be relatively small if Minnesota did not have a biofuel industry. The economic impact of Minnesota biofuel policy on other factors such as fuel prices and national defense spending is unclear.

STUDIES OF SELECTED BENEFITS OR COSTS

There are studies that have a more limited focus on one or more of the economic benefits or costs of biofuels. In what follows, we describe the various types of benefits and costs in more detail. We also describe how these benefits and costs can be measured properly. To the extent that studies provide useful information, we present a brief summary of the key results from those studies.

Reduced Imports and Increased Domestic Biofuel Production

A key benefit of biofuels is increased domestic output and reduced imports.

By reducing oil imports and increasing spending on domestic biofuel, subsidies and mandates for biofuels increase jobs and income within the United States. Dollars that would otherwise go abroad to purchase imports stay within the United States and increase domestic income. The additional income earned in the United States is much more likely to be spent here than the income received by foreign oil producers.

As we described earlier, some studies have estimated the total value of domestic biofuel production or the overall value of all oil imports. But these studies are estimating the overall economic reach of the biofuel industry and not the marginal impact of a particular policy. In addition, it may not be appropriate to assume that every gallon of reduced petroleum use comes from a reduction in imports rather than domestic production. If domestic production of oil is adversely affected by biofuel production, the impacts on the two domestic fuel industries could offset each other.

A proper measure of the marginal impact of a biofuel policy would also consider the impact of biofuel production on imports of goods or services used to produce biofuels. While it is unlikely that corn, the main input in ethanol production, would be imported, ethanol production requires the use of fossil fuels. Natural gas imports are increasing, and additional use of natural gas may require, in part, additional imports.

Agricultural Production

Increased domestic production of corn and soybeans is a likely consequence of policies that mandate or provide incentives for increased production and use of ethanol and biodiesel. However, any measure of the increased production probably should not include the entire value of corn used in the production of ethanol. Much of that corn would have been produced anyway. Using corn for ethanol may reduce the amounts of corn available for other uses. Those other uses include exports, food industry uses, and animal feed.

Impact of biofuels on crop and livestock production needs to be carefully measured.

The increased production of corn due to ethanol production would include a portion of the increased land used for corn production and possibly a portion of the increase in corn yields per acre.[7] Although it would be hard to measure, a portion of the increase in corn yields could be included to the extent that increased ethanol production induced innovations that increased yields. It may also be appropriate to include the small premium that farmers may receive from ethanol plants for their corn. The corn used for ethanol is purchased within a limited area and not sold for exports or shipped long distances. As a result, it commands a slightly higher price. But because shipping costs are less, some shippers like barge operators lose business.

Despite the additional feed provided by the coproducts of biofuel production, the net effect of increased biofuel production may be to increase the price of animal feed. Higher feed prices have a negative impact on livestock producers. The initial reaction of producers to higher input costs is to sell more animals and reduce their herds or flocks. While that response may initially lower meat prices, it eventually increases prices because of the lower supply of animal meat due to smaller herds or flocks.

Lower profits and production for livestock producers that are due to increased biofuel production should be considered costs and may offset some of the economic benefits of increased ethanol and corn production. Proponents have cited a study from Texas A&M University, which found that ethanol expansion only explains a small portion of the increase in corn prices in recent years.[8] However, that study also found that the net impact of increased ethanol production was negative for Texas because of its impact on the state's livestock industry.

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[7] An increase in the amount of land used for corn production could be due to other factors that are increasing the price of corn. For example, increased demand for exports or other corn uses could increase the price of corn. Alternatively, other factors such as increased input costs or droughts could reduce the supply of corn and consequently increase the price of corn.

[8] David P. Anderson, Joe Outlaw, Henry Bryant, James Richardson, David Ernstes, J. Marc Raulston, J. Mark Welch, George Knapek, Brian Herbst, and Marc Allison, "The Effects of Ethanol on Texas Food and Feed," (College Station, TX: Agricultural and Food Policy Center, Texas A&M University, April 10, 2008).

Environmental Impacts

The environmental impacts of biofuels can also be assigned an economic value. Economists consider the environmental impacts of fuel consumption to be externalities that are not captured in the price of the fuels. As externalities, they impose costs on society because they increase global warming and air pollution, or have other negative impacts. To the extent that biofuels improve environmental conditions compared with petroleum-based fuels, biofuels have a benefit that can be quantified in dollars. However, if biofuels worsen water quality or other environmental aspects in comparison with petroleum fuels, they have costs that should also be taken into account.[9]

Measuring the economic value of environmental impacts of biofuels is difficult due to the lack of consensus on those impacts.

A few studies have attempted to measure the economic value of environmental impacts. For example, one study measured the net impact of an increase in biofuel use on the value of greenhouse gas emissions and on the value of health impacts of particulate matter emissions.[10] The study concluded that corn-based ethanol has higher environmental costs than gasoline, while the costs of cellulosic ethanol are lower than those for gasoline. This study is exemplary in its careful measurement of the impact of a specific increase in biofuel use. However, its results are controversial because there is no clear consensus in the scientific and regulatory communities on the impact of corn-based ethanol on greenhouse gas emissions. Its findings on particulate matter are questioned by biofuel proponents because corn-based ethanol decreases urban emissions, while increasing total emissions compared with gasoline. It has generally been believed this pattern of emissions has net benefits since more people live in urban areas. The study used EPA models to estimate where particulate emissions would travel and measured health costs accordingly.

Another study calculated the cost of biofuel subsidies per unit of greenhouse gas emissions reduced. This study compared the result with estimated prices for carbon reduction in various markets and concluded that the cost of reducing greenhouse gases with ethanol are high relative to market rates for carbon reduction.[11] One problem with this study is that it compares all of the subsidy costs of biofuels to just one of its potential benefits.[12]

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[9] Biofuels reduce petroleum use but increase the use of other fossil fuels such as natural gas and coal. The greenhouse gas or air pollution impacts of using these fossil fuels are taken into account in life-cycle analyses. However, any other environmental impacts from increased fossil fuel use from biofuels or gasoline would need to be taken into account in a full examination of the environmental benefits and costs of a biofuel policy.

[10] Hill et al., *Climate Change and Health Costs* (2009).

[11] Doug Koplow of Earth Track, Inc., *Government Support for Ethanol and Biodiesel in the United States: 2007 Update* (Geneva, Switzerland: Global Subsidies Initiative of the International Institute for Sustainable Development, October 2007), 35-36.

[12] It separately calculates the total subsidies per unit of petroleum displaced and the total subsidies per unit of fossil fuel replaced. These are somewhat useful measures, but it would be preferable to compare the subsidies (and other costs) of biofuel use to all the benefits of biofuels.

In general, no study has comprehensively examined all of the environmental benefits and costs of biofuels. Even if a study had examined the economic value of environmental impacts in a comprehensive manner, the results would be controversial. As we pointed out in Chapter 3, it is not entirely clear how biofuels impact key aspects of the environment.

Fuel Prices

Biofuel policies may affect the price paid by consumers for automotive fuels, although either an increase or decrease in price is possible. Policies could also affect the prices paid for other fossil fuels that are used in the production of biofuels.

The impact of corn-based ethanol on the price of fuel used by motor vehicles can come from two sources. First, increased use of biofuels will reduce the demand for gasoline and its price. Second, the overall price of blended fuel can be higher or lower than the price of gasoline, depending on the price of ethanol less the value of the ethanol blending tax credit relative to the price of gasoline.[13]

Impact on Petroleum or Gasoline Prices

Ethanol may affect the price of motor fuel by reducing the demand for and the price of petroleum-based fuels.

Two studies have estimated the impact on petroleum or gasoline prices. A working paper from Iowa State University estimated the impact of ethanol production on gasoline prices over the period of 1995 through 2007.[14] The study found that the average ethanol production over this period—which we estimate to be close to 2.6 billion gallons per year—reduced gasoline prices by 29 to 40 cents per gallon. These reductions in price are about 17 to 24 percent of retail gasoline prices during that period of time. These estimated reductions are extremely large considering the relatively small amount of United States oil consumption replaced by ethanol.[15] We estimate that the average level of ethanol production over this period reduced United States oil consumption by roughly 1.3 percent. Furthermore, United States oil consumption represents only a portion of

[13] If the price of ethanol less the tax credit is greater than the price of gasoline, the overall price of blended fuel will be higher than the price of gasoline. But if the adjusted price of ethanol is lower than the price of gasoline, the price of the blended fuel will be lower than the price of gasoline. The magnitude of the impact of the adjusted ethanol price on the price of blended fuel depends on the percentage of ethanol in the blended fuel. The ethanol price has a much greater impact on the price of the blended fuel if the blend is E85 than if it is E10.

[14] Xiaodong Du and Dermot Hayes, "The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry," (Ames, IA: Center for Agricultural and Rural Development, Iowa State University, Working Paper 08-WP 467, April 2008).

[15] The authors attribute this "surprisingly large" estimated reduction in gasoline prices to ethanol's addition of refining capacity to a United States refinery industry that was operating close to capacity. An alternative explanation is that the study greatly overstated the impact of ethanol on gasoline prices because it failed to consider that the oil refinery industry may have added capacity in the absence of an increase in ethanol production. An increase in the capacity of the oil refinery industry would have reduced gasoline prices from the levels observed by the study's authors. *Ibid.*, 13-14.

world oil demand. It is difficult to understand how such a small reduction in overall demand could affect gasoline prices so much.

But studies reach vastly different conclusions about the impact of ethanol on wholesale gasoline prices.

A study from Oak Ridge National Laboratory estimated the impact of a one million barrel a day reduction in United States oil imports.[16] The study found that the decrease in world crude oil prices from a one million barrel per day reduction in oil imports would be about 82 cents per barrel on average.[17] That price decrease is about a 1.5 percent reduction in the price of crude oil for the year examined in the study.[18] This result implies a price reduction of two cents per gallon for an assumed 15.3 billion gallon per year reduction in crude oil imports. It would take 24.6 billion gallons of ethanol consumption to replace that much oil. As a result, the price reduction estimated in the Iowa State University study appears to be far greater than estimated in other studies.[19]

However, the Oak Ridge study estimates a savings of $8.90 for every barrel of oil reduced due to the impact of import reductions on crude oil prices. For smaller percentage decreases in the consumption of imports than represented by one million barrels per day, the estimated percentage price decrease is proportionately smaller. But even for smaller reductions in imports, the result still amounts to about 21 cents for every gallon reduction in gasoline imports.[20]

The methodology used in the Oak Ridge estimate has been criticized as being "built on shaky ground."[21] In particular, the conclusions of the price studies that form the foundation for the Oak Ridge estimate have been criticized as being "problematic."[22]

As a result, it is not exactly clear what impact biofuels have on the price of gasoline. Although some analysts have estimated large impacts, these estimates have been criticized by others.

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[16] Paul Leiby, *Estimating the Energy Security Benefits of Reduced U.S. Oil Imports* (Oak Ridge, TN: Oak Ridge National Laboratory for the U.S. Department of Energy, revised July 23, 2007).

[17] *Ibid.*, 36.

[18] The author also states that other studies have found similar price effects from a million barrel per day reduction in oil imports. Those results range from a price decrease of 0.8 percent to a decrease of 2.9 percent for an import reduction of one million barrels per day. *Ibid.*

[19] By focusing on the price of gas and not crude oil, however, the Iowa State University study includes both the impact on crude oil prices and the impact on refinery prices for gasoline. As mentioned earlier, Du and Hayes suggest that the large impact on gasoline prices they found may be due to capacity constraints on the oil refinery industry.

[20] The savings from the reduction of imports includes: (1) reduced spending because imports have been decreased; and (2) reduced spending because the price of a barrel of oil is lower. We discussed the first item in the previous section on "Reduced Imports and Increased Domestic Biofuel Production." The second item is the 21 cents per gallon estimate referred to in the Oak Ridge study as the "monopsony premium."

[21] Douglas Bohi and Michael Toman, Resources for the Future, *The Economics of Energy Security* (Boston, MA: Kluwer, 1996), 56.

[22] *Ibid.*, 38-52 and 55.

Relative Prices of Ethanol and Gasoline

Ethanol can also affect the price of blended motor fuel if the wholesale price of ethanol is different from the wholesale price of gasoline.

As mentioned earlier, ethanol can impact the price of motor fuel depending on how the wholesale price of pure ethanol, net of the blender's credit, compares with the wholesale price of pure gasoline. Although the net price of ethanol may either be higher or lower than the price of gasoline, it has generally been lower in recent years. According to the Minnesota Department of Agriculture, the net price of ethanol has averaged about 33 cents per gallon lower than gasoline during the last five years.[23] An E10 blend of gasoline would then lower the overall price of motor fuel by about 3.3 cents per gallon compared with pure gasoline. Based on the department's estimates, E10 would have lowered the price of motor fuel by 1.4 cents per gallon over the last 19 years. Because these estimates subtract the cost of the federal tax credit and any previous state tax credits from the overall price of ethanol, the amount of the subsidies must be separately counted as a program cost.

Economic Disruption

The Oak Ridge National Laboratory study also estimates the marginal impact of macroeconomic disruption and adjustment costs due to a reliance on foreign oil. These costs arise when oil prices spike due to coordinated action by oil-producing countries to reduce supply. Alternatively, oil prices may spike due to military or terroristic actions that drastically cut world oil supplies. The Oak Ridge study estimates that these costs are about $4.68 per barrel for United States oil imports, or about 11 cents per gallon of gasoline.

However, the assumptions behind this estimate have been criticized.[24] For example, some analysts have suggested that the economy of the United States is now less affected by oil price spikes than it was in previous years. Since studies from those previous experiences form the basis for the Oak Ridge economic disruption estimate, the purported change in the economy's susceptibility to oil price spikes may make the economic disruption estimate suspect. However, this issue is not resolved among economists and analysts.[25]

Some studies have also estimated the costs of the nation's Strategic Petroleum Reserve (SPR) and included them as a cost savings possible with increased biofuel use. The Oak Ridge study did not include the SPR because the United States has not varied the size or budget of the SPR in response to changes in oil imports or consumption.[26] As a result, it may be reasonable to assume that the

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[23] The average ethanol price during this period was $2.13 per gallon, while average gasoline price was $1.95 per gallon. Subtracting the federal tax credit from the ethanol price results in a net ethanol price of $1.62 per gallon, which is 33 cents lower than the average price of gasoline.

[24] *Ibid.*, 54-56.

[25] For a recent analysis of the economic effects of energy price shocks, see Lutz Kilian, "The Economic Effects of Energy Price Shocks," *Journal of Economic Literature* 46, no. 4 (December 2008): 871-909.

[26] Leiby, *Estimating the Energy Security Benefits*, 21-22.

cost of the SPR may not change much unless biofuels can replace a large part of the nation's oil consumption.

Finally, it is important to recognize that there may be economic disruptions and adjustment costs in an economy that relies on biofuels. A drought or other unfavorable weather conditions could drastically cut the available supplies of corn and increase the cost of producing ethanol. Alternatively, other factors could also increase the world price of corn and increase the cost of ethanol. We are not aware of any study that addresses this potential cost of biofuels.

Food Prices

There has been considerable controversy over the impact of increased biofuel production on food prices.

The impact of biofuel production on food prices has been a much discussed topic in the last several years. The interest in the impact of biofuels has been prompted by very large increases in the prices of agricultural commodities such as corn, soybeans, wheat, and rice during a period of biofuel expansion.[27] For example, the price of corn increased from less than $2.00 per bushel during much of 2005 to over $6.00 in mid-2008. Since then, the price has fallen to between $3.30 and $4.00 per bushel. The average prices received by our nation's farmers for corn and soybeans grew by 110 percent and 78 percent, respectively, between the 2005-06 and 2007-08 marketing years. For the 2008-09 marketing year, prices are expected to be lower but well above their historical levels.[28]

Increased commodity prices have led, in part, to modest increases in food prices in the United States and other developed nations and large food price increases in undeveloped nations.[29] In the United States, food prices increased 4.9 percent in 2007 and 5.9 percent in 2008, compared with overall increases in the consumer price index of 4.1 and 0.1 percent. During the previous three years, inflation in food prices was less than the overall rate of inflation.

Biofuel critics have blamed corn-based ethanol and, to a lesser extent, soy-based biodiesel for these food price increases. However, academic and other

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[27] Expansion of biofuel production increases the demand for agricultural commodities like corn and soybeans and thus tends to increase commodity prices. Because these commodities are used to produce various food products, their higher prices tend to increase food prices. However, as we discuss in this section, many other factors may influence the level of commodity and food prices.

[28] March 2009 projections from the United States Department of Agriculture suggest that corn and soybean prices during the 2008-09 marketing year will be about 7 or 8 percent lower than during the previous year.

[29] The price increases in undeveloped nations were larger because commodity costs represent a much larger share of the cost of food in those countries. In the United States, commodities undergo significant processing and are a relatively minor share of the overall cost of food. In undeveloped nations, food costs are also a more significant part of the overall cost of living than in developed nations. As a result, increases in commodity prices had a much greater impact on the overall cost of living in undeveloped nations. See the example in Ronald Trostle, *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices* (Washington, DC: Economic Research Service, U.S. Department of Agriculture, WRS-0801, revised July 2008), 25-25. See also Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations, *OECD-FAO Agriculture Outlook: 2008-2017* (Paris, France: OECD, 2008), for data and discussion on these points.

researchers agree that factors other than biofuel expansion in the United States and elsewhere have contributed significantly to food price increases. The factors include: (1) growing worldwide demand for food (and corn-fed meat in particular); (2) weather-related crop shortfalls in other countries; (3) a weak U.S. dollar, which made U.S. exports cheaper than those grown in other countries; (4) high energy costs, which increase the costs of production for farmers and food processing companies; (5) commodity speculation; and (6) foreign government policies to limit exports of commodities.[30] In addition, already low year-end stocks of various commodities added to the pressure on prices from other sources.

Many factors besides biofuel expansion contributed to recent increases in food prices.

Studies do not agree on the magnitude of the impact of biofuel expansion on food prices. Some studies say that biofuels have had a relatively small impact on food prices. They estimate that other factors—such as a growing demand for food and lower supply due to the effect of soaring oil prices on production costs—played a much greater role in the increase in commodity prices. Other studies implicated biofuel expansion as the key factor in commodity price increases.

Although it is difficult to sort out the exact impact of biofuels on food prices, most analysts agree that biofuel expansion causes at least a small increase in food prices. As a result, any comprehensive study of the economic impact of biofuels should account for this factor.

Net Subsidy Costs

Studies of economic impact should properly account for the net marginal government costs of a biofuel policy. Biofuel subsidies—such as the tax credits for blending corn ethanol, biodiesel, and cellulosic ethanol—should be included, as well as any other subsidies or government spending needed to implement a biofuels policy.

The costs of government subsidies for various fuels should be carefully measured in any economic impact study.

However, other government costs may be reduced and should be subtracted from biofuel subsidies. For example, as biofuel production has increased, agricultural commodity subsidies have decreased. In the last several years, there has been a large drop in commodity subsidies due to the higher market prices of agricultural commodities. Although some biofuel proponents have claimed the total drop in these subsidies was a benefit of biofuel production, only a small portion of the reduced commodity subsidies can be attributed to biofuel production increases. As we observed earlier, agricultural commodity prices have increased in recent years for a variety of reasons. Biofuel production increases explain only a part of those price increases and, consequently, only a portion of the decrease in commodity subsidies.

Most studies that have examined biofuel subsidies have not taken this approach. They typically tally up the costs of all biofuel subsidies, rather than consider the incremental costs incurred due to implementation of a particular policy or a

[30] For example, see Randy Schnepf, *High Agricultural Commodity Prices: What Are the Issues?* (Washington, DC: Congressional Research Service, May 6, 2008), 16-24.

specific increase in biofuel use. Other studies examine the total subsidies for oil, and some compare biofuel subsidies to oil subsidies. The studies of subsidies often include favorable tax treatments that are available to many types of businesses and not just oil or biofuel companies. One study of oil subsidies included the public costs of police, fire, and emergency vehicles that respond to motor vehicle accidents. A study of biofuel subsidies included the value of market protection offered to ethanol by the tariff on imports of foreign ethanol. These types of estimates do not measure the marginal cost of a particular biofuel policy. Generally, implementing a biofuel policy will not change highway protection costs or tax expenditures applicable to all companies. The tariff on foreign imports of ethanol could be separately evaluated for its impact on the United States.[31] However, the market value of the tariff is not a government cost and does not necessarily figure into an estimate of the economic impact of increasing biofuel production.

Reduced Defense Spending

Numerous studies have estimated the costs of protecting world oil supplies, particularly those in the Persian Gulf. These studies generally suffer from one fatal flaw. They tend to estimate the total military costs of oil protection, not the costs that could be saved by increasing biofuel production by a specific amount.[32]

It is difficult to measure the impact of increased biofuel consumption on national defense spending.

One study used a more sophisticated approach.[33] Its authors argued that it was important to consider how much Congress would reduce military spending under various scenarios. The most relevant scenario to our discussion of biofuel policy considered how much military spending might decline if motor vehicles in the United States did not consume any oil. The study estimated that military spending could be reduced between $5.8 and $25.4 billion per year. This estimate was equivalent to a cost reduction of between 3 and 15 cents per gallon of gasoline or diesel fuel used in motor vehicles.[34]

For our purposes, the problem with that estimate is that biofuels will not replace all gasoline and diesel used in motor vehicles in the conceivable future. Even if we accept the methodology of this study, the potential impact of current biofuel policies on defense spending is significantly less than the estimates outlined above.

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[31] The tariff prevents sugarcane ethanol from Brazil from being imported in greater quantities. Compared with corn ethanol, sugarcane ethanol costs less to produce, saves more fossil fuel energy, and results in much larger reductions in greenhouse gas emissions. Importing ethanol, however, would not reduce overall imports of motor fuel.

[32] For example, see Copulos, *The Hidden Cost of Oil*. See also International Center for Technology Assessment, "Gasoline Cost Externalities: Security and Protection Services," an update to *The Real Price of Gasoline* (Washington, DC: January 25, 2005), http://www.icta.org/doc/RPG%20security%20update.pdf, accessed September 17, 2008.

[33] Mark Delucchi and James Murphy, *U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles* (Davis, CA: Institute for Transportation Studies, University of California, Davis, revised March 2008).

[34] *Ibid.*, 23.

It should also be noted that some experts believe that estimating the impact of reducing oil consumption on military spending is exceedingly difficult and problematic.[35] Military spending in the Persian Gulf and in other parts of the world with oil reserves is undertaken for a variety of security and foreign policy reasons. The amount of military spending may not be very responsive to changes in the amount of United States oil imports or total United States oil consumption. As a result, some analysts do not make estimates of the impact on military spending.[36]

SUMMARY

No existing study truly measures the overall economic impact of biofuel policies or production. Some studies claim to measure the economic impact but are only measuring the size of the industry and its positive effects on other industries. A comprehensive and objective study of the economic impact of biofuels would examine all impacts, including both positive and negative effects. In addition, measuring economic impact is meaningful only if the analysis focuses on the marginal changes brought about by a particular biofuel policy or set of policies. Many studies that have estimated the costs of oil fail to consider the marginal impact of a change in policy.

However, our discussion of the various types of economic impacts from biofuels shows the difficulties faced by any objective study. In several areas, the direction and magnitude of the economic impact of biofuels is unclear.[37]

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[35] Leiby, *Estimating the Energy Security Benefits*, 21.

[36] Bohi and Toman, *The Economics of Energy Security*, 53-54.

[37] In recognition of the controversy over the impact of biofuels, the United States Congress directed the Secretary of the Treasury, in consultation with other agencies, to contract with the National Academy of Sciences for an analysis of current scientific findings on certain impacts. Among other items, the study is required to address the effects of an increase in biofuel production on: (1) the prices of fuel, feed, grain crops, forest products, and land; (2) the environment; (3) exports and imports of grains and forest products; (4) taxpayers; and (5) crop acreage, forest acreage, and other land use. The study requested by 2008 legislation also will include projections for future biofuel production, a comparative analysis of corn ethanol versus other biofuels, and an assessment of the need for additional scientific inquiry. See Public Law 110-234, sec. 15322, 122 Stat. 923 (2008).

5 State Subsidies

Minnesota has been a leader in the development of biofuels, particularly corn ethanol and soy biodiesel. The Legislature has implemented blending mandates for both ethanol and biodiesel. In recent years, the Legislature has enacted legislation that increases the required blends of ethanol and biodiesel in the future.

Furthermore, Minnesota has long provided subsidies for ethanol production. In addition, the Job Opportunity Building Zones (JOBZ) program has been used to provide tax breaks to newer ethanol plants and biodiesel production facilities located outside the Twin Cities metropolitan area. In 2007, the Legislature provided $3 million in funds to the Next Generation Energy Board for grants for the development of second generation biofuels. Recently, the Governor proposed a new Green JOBZ program that could be used, among other things, for biofuel businesses statewide.

In this chapter, we examine the producer payment program for ethanol producers and the JOBZ program. The impact of the Next Generation Energy Board grants was not examined in detail because the program first issued grants in November 2008. We also consider how subsidies for biofuel producers might be better designed in the future.

PRODUCER PAYMENT PROGRAM

Since 1987, Minnesota's producer payment program has provided about $314 million to ethanol producers.

As mentioned in Chapter 1, Minnesota began providing payments to ethanol producers in fiscal year 1987. Generally, the payments have been 20 cents per gallon of ethanol produced for the first 15 million gallons of annual ethanol production. For any individual producer, these regular payments are thus limited to $3 million each year. Producers were limited to ten years on the program for any new plant or expansion of a plant that increased the producer's annual production to at least 15 million gallons.

Through fiscal year 2008, about $314 million has been received by a total of 20 ethanol producers. Under current law, Minnesota has committed to pay the eight producers still entitled to regular payments a total of $8.5 million during fiscal years 2009 and 2010. In addition, 11 producers qualify for "deficiency"

The producer payment program provided important incentives during the early stages of development for corn-based ethanol.

payments totaling $50.5 million.[1] The deficiency payments would be paid over a four-year period including fiscal years 2009 through 2012 provided that future appropriations are sufficient to pay these amounts. The deficiency payments consist of regular payments that were delayed during fiscal years 2003 through 2007 due to state budget shortfalls. During this period, producers were paid 13 cents per gallon rather than 20 cents.

In our view:

- **The producer payment program provided subsidies when they were needed during the early stages of ethanol development, but they have continued even when not needed to stimulate ethanol production.**

Minnesota's producer payment program provided important incentives to corn ethanol producers during the 1980s and 1990s when corn ethanol was a relatively new and emerging industry. However, this program, by guaranteeing at least ten years of subsidies for any new plant or plant expansion up to a total production of 15 million gallons per year, has outlived its usefulness in stimulating ethanol production. The program is only designed to make payments for the first 15 million gallons of production, while today's ethanol plants tend to produce between 50 and 100 million gallons. The subsidies do not provide any incentive to produce more than 15 million gallons of ethanol per year.

But the program has continued even as producers made large profits.

In addition, for most of the ethanol companies in Minnesota, these payments have been a relatively small share of their revenues in recent years. The profitability of these companies has mainly depended on the spread between ethanol and corn prices, since corn is the major input for the production of ethanol. The management of natural gas and other fuel costs and the sale of coproducts are other important factors in profitability. State producer payments have played a rather small role in recent years. In fact:

- **Over the last five years, ethanol producers in the producer payment program have earned after-tax profits of $619 million.**

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[1] Two companies once eligible for deficiency payments are no longer eligible to receive them. The 2008 Legislature enacted a requirement that ethanol companies may not receive deficiency payments if they are no longer producing ethanol. Gopher State Ethanol stopped producing ethanol during the spring of 2004 and filed for bankruptcy. But under existing law at that time, the Minnesota Department of Agriculture was obligated to pay deficiency payments totaling $263,104 to assignees for the bankrupt company in August 2005, August 2006, and August 2007. Because of the new statutory requirement (*Minnesota Statutes* 2008, 41A.09, subd. 3a (h)), payments of $2,104,936 are no longer owed to the company. In late 2008, Melrose Dairy Proteins stopped producing ethanol at its cheese plant. The plant made ethanol from cheese whey, but company officials decided to use the whey to make other products. As a result, the state no longer owes the company $347,491 in deficiency payments.

These profits far exceed the producer payments of $93 million that were paid to these plants over this period.[2] In addition, as Table 5.1 indicates:

- **The average rates of return on equity for ethanol producers in the producer payment program have been extremely high over the last five years.**

During three of the last five years, producers in the program were earning enough profits in five to seven months to pay off all of their long-term debts.

The returns on equity were 16 percent, 42 percent, 53 percent, 45 percent, and 14 percent during this period.[3] As a group, these producers were earning enough profit in five to seven months to pay off all of their long-term debt during the reporting years 2005 through 2007.[4] Furthermore, at the end of the most recent fiscal year reported to the Minnesota Department of Agriculture, these ethanol producers had a total of $51 million in cash assets and another $57 million in other investments.

Table 5.1: Profits of Minnesota Ethanol Producers Receiving State Producer Payments

	Reporting Year[b]				
Combined Results[a]	2004	2005	2006	2007	2008
Total Net Income after Taxes (in millions)	$34	$126	$195	$204	$60
Sales Revenues (in millions)	$565	$803	$918	$1,160	$1,369
Return on Total Equity	16%	42%	53%	45%	14%
Profit Margin on Sales	6%	16%	21%	18%	4%
Year-End Long-Term Liabilities (in millions)	$127	$70	$82	$95	$104
Year-End Equity (in millions)	$204	$301	$370	$457	$442

[a] For each year except 2004, there were 12 ethanol producers reporting their financial results to the Minnesota Department of Agriculture. In 2004, there were 13 producers reporting results, including one producer that entered bankruptcy in 2004. Some companies have non-ethanol related sales and income, which are included in the figures reported above.

[b] Each company receiving producer payments reports financial results for its most recently completed fiscal year. The reports received in 2008 cover fiscal years ending between November 30, 2007, and September 30, 2008.

SOURCE: Minnesota Department of Agriculture.

[2] Companies receiving producer payments have different fiscal years. The most recent data was reported in 2008 and contained financial information on companies for fiscal years ending between November 30, 2007, and September 30, 2008.

[3] Financial information on individual producers are nonpublic, so this report presents only aggregate data on the producers that reported information to the Minnesota Department of Agriculture.

[4] These ethanol companies did not generally pay off all of their long-term debt, but this example illustrates the enormous size of the profits during the reporting years 2005 through 2007.

The high rates of return were due to extremely favorable conditions in the ethanol industry, particularly during the reporting years 2005 through 2007. Low corn prices relative to ethanol prices made ethanol an attractive business. As a result, many companies and organizations were building new ethanol plants or expanding existing plants.

However:

- **The financial condition of the ethanol industry has deteriorated during the last year.**

The financial condition of the ethanol industry has deteriorated in the last year with some producers continuing to earn profits and others experiencing losses.

The corn ethanol industry is undergoing tougher times due to a narrowing of the margin between ethanol and corn prices. Nationally, some ethanol companies are in bankruptcy. Some newly constructed plants, including several in Minnesota, have not been opened due to their owners' financial troubles. Many of the problems experienced nationally are due to companies that lost money on hedging bets on the price of corn. Some companies experiencing financial difficulties are simply locked into buying corn at high prices relative to the current price of ethanol.

These problems have occurred due to wide swings in the prices of oil and corn over the last several years. Both oil and corn prices soared dramatically until the fall of 2008, when both decreased significantly. Because corn prices fell less than oil prices, the spread between ethanol and corn prices has declined significantly and has reduced profits of ethanol producers. Some analysts say that the average ethanol producer was breaking even in December 2008.[5] Because ethanol producers vary in their contract prices for corn, some producers have continued to make a profit, while others are operating at a loss. More established producers with lower debt may also be faring better than newer producers with a high debt load. The latest financial reports from the companies in the producer payment program show reduced profits in general and losses for more than one-third of producers still in the program.

Most of the remaining payments in the program are deficiency payments to make up for payments reduced during difficult budget years for state government. Ethanol supporters justify these payments as a moral imperative—meaning the state should pay what it first committed to pay ethanol producers. Supporters are also concerned that reducing or eliminating producer payments would jeopardize the financial condition of Minnesota's more established ethanol producers. In addition, supporters are concerned that some ethanol producers would stop producing ethanol, thus potentially preventing the state from achieving the E20 mandate planned for 2013.

However, a strong case can also be made for eliminating the producer payment program. The ethanol producers in the program have benefited from the

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[5] Midwest AGnet, "Average Ethanol Plant Saw No December Profit," http://www.midwestagnet.com/Global/story.asp?s=9801192, accessed February 9, 2009. See also Agricultural Marketing Resource Center, Iowa State University, ethanol profitability web site at http://www.agmrc.org/renewable_energy/ethanol/profitability.cfm.

Although there are reasons to continue the producer payment program, a strong case can be made for ending it.

subsidies provided by the state and have made significant profits in recent years. The state's subsidies were intended at one time to pay for each plant's capital investments. Even if the subsidies fall short of those expectations, the producers' profits have generally far exceeded their long-term debts. Furthermore, continuing state subsidies to these companies may not serve a useful purpose. Unless margins become worse, these companies are likely to continue operating as long as their revenues cover their marginal costs. If some stop producing, it would likely be because they committed to buying corn at much higher prices than the current price of corn. Producer payments in fiscal year 2010 and subsequent years are not expected to be major factors in the sales revenues of ethanol producers. The subsidies only represent about 1 percent of the sales revenues reported by participating ethanol producers in their most recent financial statements.

RECOMMENDATION

The Legislature should consider ending the current producer payment program for corn-based ethanol programs and redirecting the funds to programs designed to further reduce fossil fuel use and greenhouse gas emissions.

The Legislature could use the program's budgeted funds of $30.3 million over the 2010-11 biennium to help reduce the state's budget deficit. Alternatively, these funds could be used to help induce biofuel or biomass production that has greater environmental and energy security benefits. The funds could be used for additional appropriations to the Next Generation Energy Board for bioenergy projects, or for green jobs initiatives proposed by various legislators and the Governor. Existing ethanol producers should also be eligible for such funding if they install technology and equipment to reduce their greenhouse gas emissions and their consumption of fossil fuels.

We recognize that any decision to end the current producer payment program is a "close call" at this time. While the corn ethanol industry made significant profits in recent years, the condition of the industry has changed in the last year. However, we think the future of the producer payment program is an issue that should be debated within the Legislature.

JOBZ SUBSIDIES

The Job Opportunity Building Zones (JOBZ) program provides state and local tax breaks to selected businesses. About 380 businesses have participated in the program, and 324 businesses were still active in the program as of March 13, 2009. Among the participants in JOBZ are six of Minnesota's 18 ethanol plants. The other twelve ethanol plants were built prior to the creation of the JOBZ program and participated in the producer payment program. In addition to the six operating ethanol plants that are in the JOBZ program, three additional projects are JOBZ participants, including two plants that are under construction and one project that is on hold.[6] Besides these ethanol plants, two large biodiesel producers are JOBZ participants.

Last year, we conducted an evaluation of the JOBZ program. We found that JOBZ had been used at times to provide unnecessary subsidies. Companies that did not need the subsidies and would have expanded anyway at the same location or elsewhere in Minnesota were allowed to participate in the program. In addition, the JOBZ program provided subsidies to businesses without an analysis of whether the subsidies were justified by economic or other benefits to the state.

The lack of adequate program screening resulted from the lack of state controls over participation. Local governments were allowed to make the decisions on who could participate in the program. Furthermore, local governments had little incentive to make tough decisions since most of the tax breaks provided to JOBZ businesses are paid for by the state. Under these circumstances, a local community found it in its best interest to offer JOBZ to a company that was planning to open a facility in either that community or another nearby Minnesota community. From the state's perspective, however, this incentive was not in the state's best interest since no subsidy was truly needed to get the business to locate in rural Minnesota.

Some of the ethanol producers receiving JOBZ subsidies expanded at a time when favorable market conditions, rather than state tax breaks, were driving expansion decisions.

Ethanol companies participating in JOBZ were making a decision to expand at a time that was favorable for the profitability of ethanol. A careful analysis of the business by the state might have shown that there was little need to subsidize ethanol plants given market conditions. Some of the ethanol producers that received JOBZ approval would have likely located in Minnesota without the JOBZ subsidies. Minnesota has a plentiful supply of corn, and conditions were highly favorable in the ethanol industry from 2004 through 2007.

If a company decided not to build an ethanol plant in a particular Minnesota community, it was likely that the company might build in another Minnesota community. Alternatively, another company or set of investors would build an ethanol plant there or nearby due to the site's favorable features. Consequently, in our view:

- **JOBZ subsidies have been provided to some ethanol plants without careful consideration at the state level of whether those subsidies were needed.**

As a result of our JOBZ evaluation, the Department of Employment and Economic Development (DEED) established new procedures for the JOBZ program that require state approval of any application for participation. In addition, the department has established new criteria for JOBZ participation and a scoring system for evaluating business projects that apply for participation. While the department has taken some steps to improve the JOBZ program, we think it is worth reemphasizing the following recommendation.

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[6] An additional two plants under construction and one in the planning stage are not participating in the JOBZ program.

RECOMMENDATION

The Department of Employment and Economic Development should only provide JOBZ or other subsidies to businesses, including biofuel producers, if: (1) it can be clearly demonstrated that subsidies are needed, and (2) the proposed expansion provides significant economic benefits to the state relative to the costs of the tax breaks.

In the next section, we offer additional recommendations for future subsidies based on our assessment of the broader environmental and energy goals of the state.

FUTURE SUBSIDIES

As the preceding chapters discuss, the environmental and energy benefits of biofuels can vary significantly depending on the characteristics of the fuel and the production process. In general, cellulosic ethanol is considered superior in many respects to corn ethanol. Cellulosic ethanol appears to provide greater reductions in fossil fuel use and greenhouse gas emissions and may be grown on marginal land with less fertilizer and pesticide. Minnesota hopes to mandate the use of E20 and already produces enough corn ethanol to achieve that goal. Minnesota also has adopted a goal of reducing greenhouse gas emissions. In addition, policy makers would like to improve surface water quality because its citizens and tourists enjoy the lakes and rivers of the state. Finally, policy makers wish to safeguard groundwater quality because it is essential for the health of our citizens. However, with the exception of the one-time grant program administered by the Next Generation Energy Board:

If future subsidies are needed, they should focus on biofuel production that provides significant environmental and energy reduction benefits.

- **Minnesota's existing subsidy programs are not designed to maximize the energy and environmental benefits of biofuels.**

Existing programs have helped Minnesota reach the point where ethanol production is more than sufficient to achieve an E20 mandate. But we think the emphasis in the future should be on working toward the goals of improving the environment and reducing fossil fuel use, as well as meeting blending mandates.[7] In particular, we offer the following recommendation.

RECOMMENDATION

Any future subsidies for biofuels, including JOBZ subsidies, should only be provided if biofuel production provides significant environmental and energy reduction benefits.

[7] We are not necessarily endorsing a new subsidy program for biofuels. However, we are saying that any new program established by the Legislature should meet these criteria.

We think that the state should focus particular attention on cellulosic ethanol. However, corn ethanol plants or expansions that adopt new technology that substantially reduces energy use or reduces greenhouse gas emissions or other environmental impacts should also be considered.

In light of the state's experience with the producer payment and JOBZ programs, we think that some additional criteria for biofuel subsidies are appropriate.

Any future biofuel subsidies should be discontinued once producers reach a certain level of profitability.

RECOMMENDATION

Biofuel subsidies should only be provided when they are needed and, unlike the producer payment program, should stop when producers reach a certain level of profitability.

In the JOBZ program, there was inadequate screening of applications to see if subsidies were really needed to bring about expansion of the ethanol industry. In the producer payment program, subsidies continued even after the need for the subsidies had passed. Subsidy programs can be designed that end or are suspended temporarily when profits are made.[8]

Finally, we think that the state needs to be better prepared for the next generation of biofuels. The establishment of the Next Generation Energy Board was a first step. The Board has begun the process of examining alternative energy technologies and fuels for their feasibility and applicability to Minnesota. Through its grants, it has invested funds in projects to improve knowledge about various bioenergy alternatives. As technology progresses in future years, it will be important for Minnesota policy makers, through the Next Generation Energy Board, to continue monitoring the developments with cellulosic ethanol and algae-based biodiesel, as well as other issues. In addition, policy makers will need to continue to gain a better understanding of the market niches that would be best suited for Minnesota.

RECOMMENDATION

The Next Generation Energy Board—with the assistance of the Department of Agriculture and the Department of Employment and Economic Development—should continue to study where Minnesota may have potential opportunities to reduce energy dependence and greenhouse gas emissions through further development of its biofuel industry.

[8] For example, see Colbey Sullivan, *Designing Incentives for Renewable Energy Producers: Fixed v. Variable Subsidies* (St. Paul, MN: Minnesota House Research Department, January 2007). See also Wallace Tyner and Justin Quear, "Comparison of a Fixed and Variable Corn Ethanol Subsidy," *Choices* 21, no. 3 (2006): 199-202.

List of Recommendations

- The Environmental Quality Board (EQB), with assistance from its member agencies, should track how the federal government and other states are handling the issue of greenhouse gas emissions from indirect land use emissions. The EQB should also review work done by academic researchers. The EQB should report back to the Legislature on its findings and should recommend any needed changes in biofuel policies (p. 65).

- The Environmental Quality Board and its member agencies should study the potential sources of biomass in Minnesota that could be used to produce cellulosic ethanol. The EQB should also consider what additional land requirements would be needed for that biomass and how the biomass could be grown in Minnesota with minimal environmental impact (p. 65).

- As part of its ongoing monitoring process, the Department of Natural Resources should closely monitor trends in irrigation for biofuel crops like corn and soybeans (p. 66).

- The Environmental Quality Board should monitor how biofuel expansion is affecting land use, including the trends in the land used for agricultural crops like corn and soybeans and the land set aside by farmers for preservation and environmental purposes (p. 66).

- The Legislature should consider ending the current producer payment program for corn-based ethanol programs and redirecting the funds to programs designed to further reduce fossil fuel use and greenhouse gas emissions (p. 85).

- The Department of Employment and Economic Development should only provide JOBZ or other subsidies to businesses, including biofuel producers, if: (1) it can be clearly demonstrated that subsidies are needed, and (2) the proposed expansion provides significant economic benefits to the state relative to the costs of the tax breaks (p. 87).

- Any future subsidies for biofuels, including JOBZ subsidies, should only be provided if biofuel production provides significant environmental and energy reduction benefits (p. 87).

- Biofuel subsidies should only be provided when they are needed and, unlike the producer payment program, should stop when producers reach a certain level of profitability (p. 88).

- The Next Generation Energy Board—with the assistance of the Department of Agriculture and the Department of Employment and Economic Development—should continue to study where Minnesota may have potential opportunities to reduce energy dependence and greenhouse gas emissions through further development of its biofuel industry (p. 88).

MINNESOTA DEPARTMENT OF AGRICULTURE

April 9, 2009

Mr. Jim Nobles, Legislative Auditor
Office of the Legislative Auditor
1st Floor Centennial Office Building
653 Cedar Street
St. Paul, MN 55155

Dear Mr. Nobles:

Thank you for the opportunity to comment on the OLA's report on Biofuel Policies and Programs. We commend your staff for their comprehensive review and thoughtful analyses of the complex energy, environmental and economic issues associated with biofuels production and use. We concur with the report's conclusion that Minnesota has been a leader in the development and use of ethanol and biodiesel in fuels. We also agree that ethanol and biodiesel reduce fossil fuel energy consumption, and that, despite some discrepancies in the technical literature, ethanol and biodiesel generally reduce greenhouse gas emissions in comparison with petroleum-based fuels. In addition, we concur that the use of advanced biofuels such as cellulosic ethanol will provide increasing benefits to the state's economy, energy dependence and environmental profile. However, we disagree with the way in which some of the report's conclusions were construed, and would like to highlight the following additional points:

1) <u>The Minnesota ethanol program has had a profoundly positive impact on the state's economy.</u>

In 2007, Minnesota's 850 million gallon ethanol industry was responsible for $2.27 billion in economic impact to the state and the creation of more than 4,300 jobs.[1] Similarly, Minnesota's 60 million gallon biodiesel industry and supporting soybean production provided an economic impact of $928 million and an employment impact of more than 5,600 jobs in 2005.[2] These figures underscore the success of Minnesota's programs and policies for supporting its biofuels industries. Minnesota consumers have also enjoyed savings from the displacement of foreign petroleum-based fuels with homegrown biofuels. Over the past eight years, the net price of a gallon of ethanol has averaged 23 cents lower than a gallon of gasoline in Minnesota.[3] Moreover, biofuels production has added crop value and income for farmers.

The OLA report acknowledges the generally positive economic impact of the biofuels industry nationwide. However, it does not cite figures for total economic impact, job creation and consumer savings in Minnesota, asserting that existing studies are inadequate because they do not assess marginal effects. This information provides important context, and should be included in any comprehensive review of renewable fuels issues. We believe the use of a long-standing reliable tool like the University of Minnesota's IMPLAN program—as used in the Minnesota Department of Agriculture's analyses of the economic impact of the corn, ethanol and biodiesel industries in Minnesota—is superior to understating the considerable economic and employment benefits these industries contribute to

[1] Ye, Su, "Economic Impact of the Corn and Ethanol Industry in Minnesota," Minnesota Department of Agriculture, 2008.
[2] Ye, Su, "Economic Impact of Soy Diesel in Minnesota," Minnesota Department of Agriculture, 2006.
[3] Groschen, Ralph, "Legislative Report on Ethanol: Review of E20," Minnesota Department of Agriculture, 2008.

Minnesota.[4] Furthermore, while the biofuels industry benefits to farmers are noted, the OLA report's limited discussion minimizes its overall importance. A comparison of the annual economic impact to the state's economy ($2.27 billion from ethanol and $928 million from biodiesel in one year, as noted above) dwarfs the $93 million 5-year subsidy cited in the report's summary. Given the benefits of this to urban and rural communities, we believe that this should have been included as one of the major findings of the report.

2) Based on its goals and subsequent success, Minnesota's ethanol producer payment program should not be prematurely terminated.

A. The producer payment program was initiated to incentivize the development of an ethanol industry in Minnesota.

The OLA report recommends ending the producer payment program, arguing that Minnesota's ethanol plants no longer require state support. The producer payment program was initiated in 1986 to develop an ethanol industry that was virtually non-existent in Minnesota. This development initiated local farmer ownership of processing plants in Minnesota and shifted production profits from a few large corporations to scores of smaller local production facilities spread over the United States, especially in the Midwest.

As the producer payment program continued, the Minnesota Legislature encouraged plants to invest in new and improved technology to increase efficiency and maintain added value and economic impact to the state's economy long after the incentive payments stopped. In doing so, many plants incurred additional debt thereby increasing their vulnerability to the negative impacts of the current market downturn. Allowing the program to sunset as set in statute rather than ending it prematurely will enable Minnesota to maintain its leadership in local ownership and progressive biofuels policy.

It is important to note that OLA's research methods as outlined in the report's introduction suggest that staff did not visit any ethanol plants during the course of their research. We think it would have been prudent to do so in evaluating the impact of the ethanol industry in Minnesota and determining whether the producer payment continues to function as a necessary source of support for these plants.

B. Future subsidies must continue to build a bridge between first- and second-generation biofuel products.

The OLA report also argues that Minnesota's biofuel subsidy programs are not designed to maximize energy and environmental benefits, and to that end, recommends that future subsidies focus on cellulosic ethanol. First, the ethanol producer payment program was established as an economic development and air quality attainment tool in an effort to address issues relevant to the time. The program has been successful in meeting its intended goals as set out by the Legislature.

Second, most industry analysts agree that cellulosic ethanol technology is not yet commercially viable—in the meantime, Minnesota would do well to continue supporting its existing and increasingly innovative ethanol industry as a bridge to the future. As noted in OLA's report, three Minnesota ethanol plants are currently using biomass and other sources of renewable energy to replace heat and power. Developing these technologies has already reduced fossil fuel inputs to the ethanol production process,

[4] The IMPLAN (Impact Analysis for Planning) program and database is an economic impact assessment modeling system widely used in the U.S. by economic forecasters and analysts for policy-making purposes. IMPLAN applies input-output relationships or interlinkages of output-producing industries or sectors in a functioning economy of a region and estimates the economic impact of an industry or sector output.

and has the potential to lead to a viable approach to cellulosic ethanol. This illustrates the point that the young ethanol industry has many efficiency improvements on the horizon. By contrast, the dwindling supplies of conventional crude oil and the advent of oil sands and oil shale for crude oil production indicate that fossil fuels are likely to move in the opposite direction. Should the producer payment program end and Minnesota's plants suffer significant losses as a result, the state may forfeit the opportunity to produce cellulosic ethanol in the future.

3) Estimates of greenhouse gas emissions and energy savings from biofuels in Minnesota must be compared to appropriate petroleum fuel benchmarks.

The OLA report acknowledges the need for greater review of the greenhouse gas emissions impacts from petroleum fuels. However, none of the studies cited in OLA's report factored in the increased carbon impact that likely represents Minnesota's crude oil sources. As acknowledged by the OLA report, a large percentage of crude oil used in Minnesota refineries is from Canada. A 2005 study by a Canadian environmental policy institute estimated that 75 percent of the crude exported from Canada at that time was derived from "oil sand" deposits.[5] Therefore, OLA's comparisons of ethanol and biodiesel energy balance and emissions factors with those of gasoline and diesel fuel are likely skewed in favor of the petroleum products.

OLA's report also points out that very little petroleum is used in the production of ethanol. In fact, about 1 million Btus of petroleum are used to make 20 million Btus (264 gallons) of ethanol, compared to 909,000 Btus (9.1 gallons) of gasoline.[6] In terms of petroleum usage, ethanol production yields 22 times more energy to drive vehicles and equipment than gasoline. Crude oil is becoming more scarce and expensive to produce over time, making it a prime factor in the nation's increasing national debt and a point of concern as the United States becomes more dependent on foreign sources of petroleum. Such dependence creates vulnerability to political and military pressure from around the world; therefore, it would seem prudent to maximize the return to this dwindling natural resource. At the same time, ethanol and biodiesel should not be looked to as, or criticized for not being, a single, perfect solution for our energy needs. Rather it should be viewed as a significant part of a larger overall strategy that includes conservation and other approaches to address the enormous challenge of meeting the growing energy needs of America and the world.

Thank you for the opportunity to respond.

Sincerely,

Gene Hugoson
Commissioner of Agriculture

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[5] Woynillowicz, Dan et. al., "Oil Sands Fever: The Environmental Implications of Canada's Oil Sands Rush," The Pembina Institute, November 2005.

[6] Btu refers to British thermal unit, a common unit used to describe the energy content of fuels.

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Minnesota
DEPARTMENT OF NATURAL RESOURCES

April 10, 2009

James Nobles, Legislative Auditor
Office of the Legislative Auditor
658 Cedar Street
St. Paul, Minnesota 55155

Dear Mr. Nobles:

Thank you for the opportunity to respond to the findings of the Office of Legislative Auditor's final draft of the *Biofuel Policies and Programs* report. The report recognizes the complexities surrounding biofuel production and addresses some of the questions regarding environmental impacts and benefits.

The report recommends that the Environmental Quality Board (EQB) and its member agencies study potential sources of biomass. The Minnesota DNR and Forest Resources Council, under direction from the Forestry Sub-Cabinet have begun a process to identify the supply of forest biomass and to build consensus around the highest and best use of woody biomass, which may or may not be cellulosic biofuel. There is value in a parallel process around agricultural biomass.

The report recommends that DNR and other agencies monitor trends in irrigation water use and crop production. The DNR does request crop information on annual water use reports and will make water use data summaries available to address this recommendation.

Thank you for the opportunity to comment on the report.

Sincerely,

Mark Holsten, Commissioner
MN Department of Natural Resources

c: Gene Hugoson, Department of Agriculture Commissioner

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