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Report to Congressional Requesters

August 2009

BIOFUELS

Potential Effects and Challenges of Required Increases in Production and Use

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Highlights

Highlights of GAO-09-446, a report to congressional requesters

August 2009

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Potential Effects and Challenges of Required Increases in Production and Use

Why GAO Did This Study

In December 2007, the Congress expanded the renewable fuel standard (RFS), which requires rising use of ethanol and other biofuels, from 9 billion gallons in 2008 to 36 billion gallons in 2022. To meet the RFS, the Departments of Agriculture (USDA) and Energy (DOE) are developing advanced biofuels that use cellulosic feedstocks, such as corn stover and switchgrass. The Environmental Protection Agency (EPA) administers the RFS.

This report examines, among other things, (1) the effects of increased biofuels production on U.S. agriculture, environment, and greenhouse gas emissions; (2) federal support for domestic biofuels production; and (3) key challenges in meeting the RFS. GAO extensively reviewed scientific studies, interviewed experts and agency officials, and visited five DOE and USDA laboratories.

What GAO Recommends

GAO suggests that the Congress consider requiring EPA to develop a strategy to assess lifecycle environmental effects of increased biofuels production and whether revisions are needed to the VEETC. GAO also recommends that EPA, DOE, and USDA develop a coordinated approach for addressing uncertainties in lifecycle greenhouse gas analysis and give priority to R&D that addresses future blend wall issues. DOE, USDA, and EPA generally agreed with the recommendations.

View GAO-09-446 or key components.
For more information, contact Patricia Dalton at (202) 512-3841 or daltonp@gao.gov.

What GAO Found

To meet the RFS, domestic biofuels production must increase significantly, with uncertain effects for agriculture and the environment. For agriculture, many experts said that biofuels production has contributed to crop price increases as well as increases in prices of livestock and poultry feed and, to a lesser extent, food. They believe that this trend may continue as the RFS expands. For the environment, many experts believe that increased biofuels production could impair water quality—by increasing fertilizer runoff and soil erosion—and also reduce water availability, degrade air and soil quality, and adversely affect wildlife habitat; however, the extent of these effects is uncertain and could be mitigated by such factors as improved crop yields, feedstock selection, use of conservation techniques, and improvements in biorefinery processing. Except for lifecycle greenhouse gas emissions, EPA is currently not required by statute to assess environmental effects to determine what biofuels are eligible for inclusion in the RFS. Many researchers told GAO there is general agreement on the approach for measuring the direct effects of biofuels production on lifecycle greenhouse gas emissions but disagreement about how to estimate the indirect effects on global land use change, which EPA is required to assess in determining RFS compliance. In particular, researchers disagree about what nonagricultural lands will be converted to sustain world food production to replace land used to grow biofuels crops.

The Volumetric Ethanol Excise Tax Credit (VEETC), a 45-cent per gallon federal tax credit, was established to support the domestic ethanol industry. Unless crude oil prices rise significantly, the VEETC is not expected to stimulate ethanol consumption beyond the level the RFS specifies this year. The VEETC also may no longer be needed to stimulate conventional corn ethanol production because the domestic industry has matured, its processing is well understood, and its capacity is already near the effective RFS limit of 15 billion gallons per year for conventional ethanol. A separate $1.01 tax credit is available for producing advanced cellulosic biofuels.

The nation faces several key challenges in expanding biofuels production to achieve the RFS's 36-billion-gallon requirement in 2022. For example, farmers face risks in transitioning to cellulosic biofuels production and are uncertain whether growing switchgrass will eventually be profitable. USDA's new Biomass Crop Assistance Program may help mitigate these risks by providing payments to farmers through multi-year contracts. In addition, U.S. ethanol use is approaching the so-called blend wall—the amount of ethanol that most U.S. vehicles can use, given EPA's 10 percent limit on the ethanol content in gasoline. Research has been initiated on the long-term effects of using 15 percent or 20 percent ethanol blends, but expanding the use of 85 percent ethanol blends will require substantial new investment because ethanol is too corrosive for the petroleum distribution infrastructure and most vehicles. Alternatively, further R&D on biorefinery processing technologies might lead to price-competitive biofuels that are compatible with the existing petroleum distribution and storage infrastructure and the current fleet of U.S. vehicles.

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Abbreviations

AST	above-ground storage tanks
BCAP	Biomass Crop Assistance Program
CRP	Conservation Reserve Program
DDG	dried distiller's grains
DOE	Department of Energy
EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
MTBE	methyl tertiary butyl ether
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
R&D	research and development
RFS	Renewable Fuel Standard
RIN	renewable identification number
UST	underground storage tanks
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VEETC	Volumetric Ethanol Excise Tax Credit
2008 Farm Bill	Food, Conservation, and Energy Act of 2008

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United States Government Accountability Office
Washington, DC 20548

August 25, 2009

The Honorable Barbara Boxer
Chairman
Committee on Environment
and Public Works
United States Senate

The Honorable Susan M. Collins
United States Senate

As requested, this report discusses the challenges and potential effects associated with the increased production and use of biofuels in the United States. We are suggesting that the Congress consider actions to address the potential environmental effects of increased biofuels production and whether revisions are needed to federal financial support for the production of conventional ethanol. We are also recommending that the Secretaries of Agriculture and Energy and the Administrator of the Environmental Protection Agency take actions to minimize the potential effects of the nation's biofuels production efforts.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies of this report to other appropriate congressional committees; the Secretaries of Agriculture, Energy, the Interior, and the Treasury; and the Administrator of the Environmental Protection Agency. The report also will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions about this report, please contact me at (202) 512-3841 or daltonp@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs can be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix XI.

Patricia A. Dalton

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Managing Director
Natural Resources and Environment

Executive Summary

Purpose

For the past several decades, the United States has enjoyed relatively inexpensive supplies of crude oil, which has accounted for almost all of the energy consumed for transportation. However, this reliance on petroleum for transportation makes the U.S. economy vulnerable to even minor disruptions in the global crude oil supply, harms U.S. balance of payments in trade, and contributes to greenhouse gas emissions—primarily carbon dioxide, methane, and nitrous oxide—which has resulted in global climate change with potentially damaging long-term effects. The federal government has promoted biofuels as an alternative to petroleum-based fuels since the 1970s, and production of the most common U.S. biofuel—ethanol from corn starch—reached 9 billion gallons in 2008. The Energy Policy Act of 2005 created a Renewable Fuel Standard (RFS) that generally required gasoline and diesel in the United States[1] to contain 4 billion gallons of renewable fuels, such as ethanol and biodiesel, in 2006 and 7.5 billion gallons in 2012.[2] The Energy Independence and Security Act (EISA) of 2007 expanded the RFS by requiring that U.S. transportation fuel contain 9 billion gallons of renewable fuels in 2008 and increasing annually to 36 billion gallons in 2022.[3] The 36-billion-gallon total must include at least 21 billion gallons of advanced biofuels—defined as renewable fuels other than ethanol derived from corn starch that meet certain criteria—and can include up to 15 billion gallons of conventional biofuels—defined as ethanol derived from corn starch. EISA requires that most advanced biofuels (at least 16 billion of the 21-billion-gallon total) be produced from cellulosic materials, or feedstocks, including perennial grasses, crop residue, and the branches and leaves of trees. However, advanced biofuels are at the earliest stages of being commercially produced in the United States, and a number of logistical and technical challenges must still be overcome before they are economically viable. In addition, some research

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

[2]Pub. L. No. 109-58, §1501 (2005). The act authorizes the EPA Administrator, in consultation with the Secretaries of Agriculture and Energy, to waive the RFS levels established in the act, by petition or on the Administrator's own motion, if meeting the required level would severely harm the economy or environment of a state, a region, or the United States or there is an inadequate domestic supply. Throughout this report, the RFS levels established in the act are referred to as requirements, even though these levels could be waived by the EPA Administrator.

[3]Pub. L. No. 110-140, § 201 (2007).

in recent years has questioned the extent to which corn starch ethanol, as compared with gasoline, reduces lifecycle greenhouse gas emissions that occur during the process of growing, harvesting, and transporting the feedstock; producing the biofuel; and using the biofuel in a vehicle. Some research has also identified other adverse environmental effects from producing corn for ethanol.

The Chairman of the Senate Committee on Environment and Public Works and Senator Susan M. Collins asked GAO to assess several issues related to increased U.S. production of ethanol and other biofuels. Specifically, this report examines (1) the known agricultural and related effects of increased biofuels feedstock production in the United States; (2) the known environmental effects of increased feedstock cultivation and conversion and biofuels use in the United States; (3) the results, assumptions, and limitations of key scientific analyses of the lifecycle greenhouse gas effects of biofuels produced from different feedstocks; (4) federal support for developing a domestic biofuels industry; (5) federal funding for advanced biofuels research and development (R&D); and (6) key challenges in meeting the RFS's specified levels.

To assess the effects of increased biofuels production, GAO used a snowball sampling technique that identified 62 studies on the agricultural effects, 62 articles on the environmental effects, and 46 articles on the lifecycle greenhouse gas effects published in scientific journals and government publications. Next, GAO identified recognized experts in each field, in collaboration with the National Academy of Sciences, and interviewed them using a semistructured interview format. In addition, GAO interviewed program managers, scientists, economists, researchers, and other staff from the Departments of Agriculture (USDA), Energy (DOE), the Interior, and the Treasury; the Environmental Protection Agency (EPA); the National Science Foundation; and the Department of Commerce's National Oceanic and Atmospheric Administration. To assess federal support for developing a domestic biofuels industry, GAO obtained Treasury data on federal tax expenditures, reviewed relevant economic literature, and interviewed cognizant federal officials and academic and government economists. GAO applied conventional economic reasoning in analyzing the incidence of tax credits. To assess federal funding support for advanced biofuels R&D, GAO obtained DOE, USDA, and EPA data on their obligations for R&D and loan guarantees for fiscal years 2005 through 2008 and interviewed cognizant agency officials. To assess key challenges in meeting the RFS's requirements, GAO reviewed relevant documents, including federal and industry reports; interviewed federal agency officials and scientists, and representatives of nongovernmental organizations and industry associations. In doing this work, GAO conducted site visits at DOE's National Renewable Energy Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory and USDA's National Center for Agricultural Utilization Research and Eastern Regional Research Center. See chapter 1 for a more detailed discussion of GAO's methodology.

Background

Biofuels, such as ethanol and biodiesel, are an alternative to petroleum-based transportation fuels and are produced from renewable sources such as corn, sugar cane, and soybeans. In 2008, the United States consumed about 138 billion gallons of gasoline and about 10 billion gallons of biofuels, primarily ethanol. Ethanol, the most common U.S. biofuel, is mainly used as a gasoline additive in blends of about 10 percent ethanol and 90 percent gasoline, known as E10, which is available in most states. A relatively small volume is also blended at a higher level called E85—a blend of 85 percent ethanol and 15 percent gasoline—which can only be used in specially designed vehicles, known as flexible-fuel vehicles, that can use either gasoline or E85 for fuel. About 98 percent of domestic ethanol is made from corn grown in the Midwest. The corn starch can be converted relatively easily into sugar and then fermented and distilled into ethanol.

The RFS requires that U.S. transportation fuels in 2022 contain 36 billion gallons of biofuels. To be eligible for consideration under the RFS, renewable fuels produced by biorefineries that begin construction after EISA's enactment on December 19, 2007, must generally achieve at least a 20 percent reduction in lifecycle greenhouse gas emissions as compared with petroleum fuels. However, advanced biofuels and biomass-based diesel must generally achieve at least a 50 percent reduction in lifecycle greenhouse gas emissions relative to baseline petroleum fuels, while cellulosic biofuels must generally achieve at least a 60 percent reduction, regardless of when the biorefinery producing the fuel was constructed.[4] Currently, EPA determines a biofuel's eligibility under the RFS based, in part, on its lifecycle greenhouse gas emissions. However, after 2022, EISA requires that EPA, in coordination with DOE and USDA, establish the RFS

[4]While EISA specifies the reductions in lifecycle greenhouse gas emissions that each type of renewable fuel must achieve, it also authorizes EPA to adjust the required reductions if the specified reduction is not commercially feasible for fuels made using a variety of feedstocks, technologies, and processes. EPA's proposed rule, if finalized, would adjust the reduction for advanced biofuels to 44 or 40 percent. 74 Fed. Reg. 24904 (May 26, 2009).

based, in part, on the impact of the production and use of renewable fuels on the environment, including on air quality, wildlife habitat, water quality, and water supply. EPA is undertaking some of these analyses and included a partial assessment of water and air impacts in the preamble to the proposed RFS rulemaking, published on May 26, 2009, even though this information is currently not used to determine which biofuels are eligible for consideration under the RFS.

Also, at least 16 billion of the 36 billion gallons of biofuels required in 2022 are to be made from such cellulosic feedstocks as perennial grasses, crop residue, and wood waste. Cellulosic feedstocks are diverse. Some feedstocks are abundant and relatively inexpensive, and their use could greatly expand biofuel production. These feedstocks might also raise farm income, reduce greenhouse gas emissions, and improve water quality as compared with conventional corn starch ethanol. However, at present, the technology to economically grow, harvest, and transport cellulosic feedstocks is untested on a large scale. In addition, most of the energy in plant and tree biomass is locked away in complex cellulose and hemicellulose molecules, and technologies to produce biofuels from this type of feedstock economically are still being developed. Some cellulosic biorefineries are piloting the use of biochemical processes in which microbes and enzymes break down complex plant molecules to produce ethanol, while others are piloting the use of thermochemical processes, which use heat and chemical catalysts to turn plant material into a liquid that more closely resembles petroleum.

Principal Findings

Biofuels Production Has Had Mixed Effects on U.S. Agriculture, but the Effects of Expanded Production Are Less Certain

Biofuels production has had mixed effects on U.S. agriculture with regard to land use, crop selection, livestock production, rural economies, and food prices. For example, the increasing demand for corn for ethanol production has contributed to higher corn prices, provided economic incentives for some producers to devote additional acres to corn production, and resulted in reduced production of other crops, such as soybeans and cotton. While higher corn prices have created additional income for corn producers, they have also increased feed costs for livestock producers. At the same time, the number of biorefineries producing ethanol or other biofuels has grown considerably, offering new employment opportunities in rural communities as well as a boost to local commerce and tax revenues, although experts' views on the magnitude and permanence of these benefits varies. In addition, according to USDA and other sources, the increasing use of corn for ethanol production, among other factors such as high energy costs and tight global grain supplies, likely contributed to higher retail food prices by increasing the price of corn used for food processing and animal feed. The potential future effects of expanded biofuels production, including production of new energy crops for advanced biofuels, are uncertain but could be significant, particularly to the extent these new crops affect the production of other crops and livestock. Some USDA farm, forest, conservation, and extension programs could potentially support the transition to cellulosic feedstock production, although changes may be needed for these programs to “level the playing field” in light of the support they already provide for the production of food and feed crops.

Increased Biofuels Production Could Have a Variety of Environmental Effects, but the Magnitude Is Largely Unknown

The increased cultivation of corn for ethanol, its conversion into biofuels, and the storage and use of these fuels could affect water supply, water quality, air quality, soil quality, and biodiversity, but future movement toward cellulosic feedstocks could reduce some of these effects. Corn is a relatively resource-intensive crop, requiring significant amounts of fertilizer and pesticide applications and additional water to supplement rainfall, depending on where the crop is grown. As a result, some experts believe that increased corn starch ethanol production may result in the cultivation of corn on arid lands that require irrigation, contributing to additional ground and surface water depletion in water-constrained regions. In addition, some experts believe additional corn production will lead to an increase in fertilizer and sediment runoff, impairing streams and other water bodies. Furthermore, experts believe that as cultivation of some crops such as corn for biofuels production increases, environmentally sensitive lands currently enrolled in conservation programs may be moved back into production, thereby increasing cultivation of land that is susceptible to erosion and decreasing available habitat for threatened species. However, some of these effects on water quality and habitat may be mitigated by the use of certain agricultural conservation practices. In the future, farmers may also adopt cellulosic feedstocks, such as switchgrass and crop residues, which could reduce water and land-use effects relative to corn. In addition, the process of converting feedstock into biofuels may also adversely affect water supply, water quality, and air quality as more biorefineries move into production. For example, biorefineries require water for processing biofuels and will need to draw from existing water resources, which are limited in some potential production areas. However, the effects will depend on the location and size of the facility and the feedstock used. Finally, the storage and use of certain ethanol blends may pose other environmental problems, such as leaks in underground storage tanks that are not certified to store such blends and increased emissions of certain air pollutants when ethanol is used in most cars; however, less is known about the extent of these effects. Although EPA included a partial assessment of water and air effects in the preamble of its May 2009 RFS proposed rulemaking, EISA does not require EPA to determine what fuels are eligible for consideration under the RFS based on their lifecycle environmental effects, apart from greenhouse gas emissions.

Researchers Disagree on How to Account for Indirect Land-Use Changes in Estimating the Lifecycle Greenhouse Gas Effects of Biofuels Production

Twelve key scientific studies that GAO reviewed provided a wide range of estimates on the lifecycle greenhouse gas emissions of biofuels relative to fossil fuels—from a 59 percent reduction to a 93 percent increase in emissions for conventional corn starch ethanol, a 113 percent reduction to a 50 percent increase for cellulosic ethanol, and a 41 percent to 95 percent reduction for biodiesel. Most of the studies found that corn starch ethanol achieves some greenhouse gas reduction benefits and that cellulosic ethanol is likely to be more beneficial. Different assumptions about the agricultural and energy inputs used in biofuel production and how to allocate the energy used in this production to co-products, such as distiller's grains, primarily explain why the greenhouse gas emission estimates among these studies varied. However, most of these studies did not attempt to account for the effect of increased biofuels production on indirect land-use changes—converting nonagricultural lands elsewhere in the world to replace agricultural land used to grow biofuels crops to maintain world production of food, feed and fiber crops—even though it is widely recognized that land-use changes could be the most significant source of lifecycle greenhouse gas emissions associated with biofuels production. Three studies that have addressed indirect land-use changes in their methodologies each reported that biofuels had a net increase in greenhouse gas emissions relative to fossil fuels and concluded that indirect land-use changes, in fact, eliminate the greenhouse gas reduction benefits associated with corn starch ethanol, biodiesel, and even cellulosic biofuels when produced from certain feedstocks.

Many of the lifecycle analysis researchers GAO interviewed stated there is general consensus on the approach for measuring the direct effects of increased biofuels production, but disagreement about assumptions and assessment methods for estimating the indirect effects of global land-use change. EPA is required to assess significant greenhouse gas emissions from land-use change because only biofuels that achieve certain lifecycle emission reductions relative to petroleum fuels are eligible for consideration under the RFS. In particular, researchers disagree about what nonagricultural lands will be converted to maintain world production of food, feed, and fiber crops. Although research for measuring indirect land-use changes as part of the greenhouse gas analysis is only in the early stages of development, EISA directed EPA to promulgate a rule to determine the lifecycle greenhouse gas emissions of biofuels included in the RFS, including significant emissions from land-use changes. Several researchers told GAO that the lack of agreement on standardized lifecycle assumptions and assessment methods, combined with key information gaps in such areas as feedstock yields and domestic and international land-use data, greatly complicate EPA's ability to promulgate this rule.

Federal Tax Credits, the RFS, and the Ethanol Tariff Have Primarily Supported Conventional Corn Starch Ethanol

The federal government has supported the development of a domestic biofuels industry primarily though tax credits, the RFS, and a tariff on ethanol imports. The Energy Tax Act of 1978, among other things, provided tax incentives designed to stimulate the production of ethanol for blending with gasoline, which were restructured as the Volumetric Ethanol Excise Tax Credit (VEETC) in 2005.[5] Subsequently, in December 2007, EISA expanded the RFS by substantially increasing its annual biofuel volume requirements, including up to 9 billion gallons of conventional corn starch ethanol in 2008 and up to 15 billion gallons of conventional corn starch ethanol in 2015. As a result, the VEETC's annual cost to the Treasury in forgone revenues could grow from $4 billion in 2008 to $6.75 billion in 2015 for conventional corn starch ethanol, even though the 2008 Farm Bill reduced the VEETC from 51 cents to 45 cents per gallon for ethanol starting in 2009. The United States also controls ethanol imports, which qualify for the VEETC, by imposing a tariff of 54 cents per gallon plus 2.5 percent of the ethanol's value. However, two of these tools—the VEETC and the RFS—can be duplicative with respect to their effects on ethanol consumption. Because U.S. ethanol consumption is unlikely to exceed the 10.5 billion gallons allowed under the RFS in 2009, unless crude oil prices rise significantly, GAO and others have found that under current market conditions the VEETC does not stimulate additional ethanol consumption. In addition, the processing technology for the conventional corn starch ethanol industry is mature and its production capacity is nearing the effective RFS limit of 15 billion gallons per year for conventional ethanol beginning in 2015. In light of this situation, some recent studies have suggested that the VEETC be terminated or phased out

[5]The tax credit is paid to the crude oil refiners or gasoline wholesalers that blend the ethanol with gasoline.

or be revised by, for example, modifying it to provide a stimulus when crude oil prices are low but reducing its size when crude oil prices rise. The economists GAO interviewed noted that removing the VEETC would affect motor fuel blenders, consumers, and biofuels producers differently, depending upon market conditions. For example, one economist stated that when the RFS causes biofuels consumption to be higher than it otherwise would be, most of the VEETC's benefits go to consumers with lower crude oil prices and go to producers with higher crude oil prices. Another economist said that motor fuel blenders would likely lose if the VEETC were removed, but the exact impacts would depend on supply and demand elasticities.

In addition to the VEETC, which predominantly benefits conventional corn starch ethanol, the Congress has provided tax credits of $1 per gallon for producing or blending advanced biodiesel and $1.01 per gallon for producing cellulosic biofuels. Both biodiesel and cellulosic biofuels have high production costs that have limited their ability to compete in fuel markets. To date, these tax credits have predominantly supported biodiesel production because only small amounts of cellulosic biofuels are currently being produced. The RFS requirement for biodiesel rises from at least 500 million gallons in 2009 to at least 1 billion gallons in and beyond 2012 and for cellulosic biofuels rises from at least 100 million gallons in 2010 to at least 16 billion gallons in 2022.

Federal R&D Mainly Supports the Development of Advanced Cellulosic Biofuels

DOE and USDA, the principal federal sponsors of biofuels R&D, obligated about $500 million to develop advanced cellulosic biofuels in fiscal year 2008. In February 2009, the American Recovery and Reinvestment Act of 2009 appropriated $800 million to DOE for biomass-related projects, and in March 2009 the Omnibus Appropriation Act, 2009, appropriated $217 million for DOE's biomass and biorefinery systems R&D program. A substantial portion of DOE's funding supports its Integrated Biorefineries Program, which seeks to demonstrate technologies for using a wide variety of cellulosic feedstocks and operating profitably once construction costs are covered, and R&D on next-generation cellulosic feedstocks, such as algae. USDA's biofuels R&D seeks, among other things, to develop practices and systems that maximize the sustainable yield of high-quality bioenergy feedstocks by, for example, maximizing the harvest of corn stover (the cobs, stalks, leaves, and husks of corn plants) while maintaining soil organic matter.

Significant Challenges Must Be Overcome to Meet the RFS's Increasing Volumes of Biofuels

The domestic biofuels industry faces multiple challenges to meet the RFS's increasing volume requirement of biofuels, particularly cellulosic and other advanced biofuels. For example, cost-effective methods and technologies need to be developed to address the logistical difficulties in collecting, transporting, and storing the leaves, stalks, tree trunks, and other feedstocks that cellulosic biorefineries will process. Also, some DOE, EPA, and USDA officials expressed concern about inconsistencies in how EISA and the 2008 Farm Bill define renewable biomass because municipal waste and wood residues on federally managed forest land are excluded under EISA but not under the 2008 Farm Bill. If not resolved, these inconsistencies could complicate the promulgation of regulations and implementation of programs for achieving the RFS. Another challenge lies in the cellulosic conversion technology itself, which needs more commercial development and is expensive relative to the cost of producing ethanol from corn starch. Researchers are still developing pretreatment processes and biochemical and thermochemical refining technologies. While the RFS requires only modest amounts of biodiesel beginning in 2009, this industry faces its own set of challenges, including the cost of feedstocks and a limited U.S. market.

An immediate challenge facing the expansion of the domestic biofuels industry under the RFS is infrastructure limitations for distributing, storing, and using increasing volumes of ethanol because, for example, pipelines do not exist to cost effectively transport biofuels from biorefineries in the Midwest to East and West Coast markets. The U.S. biofuels distribution infrastructure can deliver current volumes of ethanol to consumers. However, the nation may reach the blend wall—the point where all of the nation's gasoline supply is blended as E10 and extra volumes of ethanol cannot be readily consumed—as early as 2011 because EPA, under the Clean Air Act, currently limits the ethanol content in gasoline to 10 percent for most U.S. vehicles, the current economic slowdown has reduced U.S. gasoline consumption, and the RFS requires increasing amounts of biofuels. DOE has initiated R&D to determine the long-term effects of using blends above 10 percent ethanol on a car's emission control system and engine. If EPA and vehicle manufacturers find that the current U.S. vehicle fleet cannot use higher ethanol blends, additional ethanol consumption will be limited to flexible-fuel vehicles that can use E85. However, expanding E85 consumption would require substantial investment in an ethanol distribution and storage infrastructure that is distinct from the existing petroleum distribution and storage system and increased consumer purchases of flexible-fuel vehicles. Advances in thermochemical processing technology could yield nonethanol products that the existing petroleum refining and distribution infrastructure can use—and therefore reduce blend wall issues.

Conclusions

The RFS requires that the nation's transportation fuel contain 36 billion gallons of biofuels in 2022, primarily advanced biofuels. To date, the domestic biofuels industry has achieved about 30 percent of this level, largely through the production of conventional corn starch ethanol. Going forward, federal agencies face significant challenges to ensure the domestic biofuels industry can meet the RFS's more demanding advanced biofuel requirements, while minimizing any unintended adverse effects. For example, one key challenge is identifying and mitigating any adverse environmental effects. Given the potential for increased biofuels production to further exacerbate existing environmental problems, GAO believes that assessing the viability of a biofuel feedstock will be incomplete without a consideration of the related lifecycle environmental effects. Although EPA's May 2009 proposed rulemaking included a partial analysis of water and air effects of biofuel production, EISA does not require EPA to determine what renewable fuels are eligible for consideration under the RFS based on their lifecycle environmental effects, apart from greenhouse gas emissions. A second key challenge is addressing the likelihood that ethanol production will exceed the capability of the petroleum infrastructure and today's fleet of vehicles to distribute and use the ethanol, referred to as the blend wall. The nation will need to make a substantial investment in a new ethanol distribution infrastructure to reach the RFS requirements, unless cost-effective biofuel products are developed that the existing petroleum refining, distribution, and storage infrastructure can use. A third key challenge is inconsistencies in how EISA and the 2008 Farm Bill define renewable biomass that, if not resolved, could complicate federal agencies' efforts to promulgate regulations and implement programs for achieving the RFS.

EISA, the 2008 Farm Bill, and the American Recovery and Reinvestment Act of 2009 have extended and expanded existing programs, authorized new ones, and appropriated substantial funding for R&D to stimulate the domestic biofuels industry. In particular, EISA significantly expanded the RFS to require that U.S. transportation fuels contain 36 billion gallons of biofuels in 2022, while the 2008 Farm Bill somewhat reduced the VEETC and established a new tax credit for advanced cellulosic biofuels. With these many efforts, federal agencies are challenged to not only be efficient in minimizing duplicative incentives, but also to ensure that existing and new federal programs are harmonized to promote advanced biofuel production and more effectively achieve the RFS. How federal agencies choose to address these challenges will shape the effect that biofuels production will have on the nation's continuing efforts to balance the need for new sources of energy, the increasing demand for food, and the need to protect the environment.

GAO provides two matters for congressional consideration and three recommendations for executive action to help address these challenges.

Matters for Congressional Consideration

In addition to the currently required lifecycle greenhouse gas emissions analysis, the Congress may wish to consider amending EISA to require that the Administrator of the Environmental Protection Agency develop a strategy to assess the effects of increased biofuels production on the environment at all stages of the lifecycle—cultivation, harvest, transport, conversion, storage, and use—and to use this assessment in determining which biofuels are eligible for consideration under the RFS. This would ensure that all relevant environmental effects are considered concurrently with lifecycle greenhouse gas emissions.

Because the RFS allows rapidly increasing annual amounts of conventional biofuels through 2015 and the conventional corn starch ethanol industry is mature, the Congress may wish to consider whether revisions to the VEETC are needed. Options could include maintaining the VEETC, reducing the amount of the tax credit or phasing it out, or modifying the tax credit to counteract fluctuations in crude oil prices.

Recommendations for Executive Action

To improve EPA's ability to determine biofuels' greenhouse gas emissions and define fuels eligible for consideration under the RFS, GAO recommends that the Administrator of the Environmental Protection Agency and the Secretaries of Agriculture and Energy develop a coordinated approach for identifying and researching unknown variables and major uncertainties in the lifecycle greenhouse gas analysis of increased biofuels production. This approach should include a coordinated effort to develop parameters for using models and a standard set of assumptions and methods in assessing greenhouse gas emissions for the full biofuel lifecycle, such as secondary effects that would include indirect land-use changes associated with increased biofuels production.

To minimize future blend wall issues and associated ethanol distribution infrastructure costs, GAO recommends that the Secretaries of Agriculture and Energy give priority to R&D on process technologies that produce biofuels that can be used by the existing petroleum-based distribution and storage infrastructure and the current fleet of U.S. vehicles.

To address inconsistencies in existing statutory language, GAO recommends that the Administrator of the Environmental Protection Agency, in consultation with the Secretaries of Agriculture and Energy, review and propose to the appropriate congressional committees any legislative changes the Administrator determines may be needed to clarify what biomass material—based on type of feedstock or type of land—can be counted toward RFS.

Agency Comments and GAO's Evaluation

GAO provided USDA, DOE, and EPA with a draft of this report for their review and comment. In its written comments, USDA stated that the report is comprehensive, well written, and accurate. Regarding the recommendation for determining biofuels' lifecycle greenhouse gas emissions, USDA agreed with the general premise implicit in the recommendation, but cited the need to ensure that coordinated scientific discussions do not lead to standard methods that become codified in regulations that would inhibit the adoption and use of new information and improved or more appropriate methods as they become available. GAO agrees with USDA's concern that the RFS regulation should not codify standard methods that might inhibit the development of better information or methods for assessing lifecycle greenhouse gas emissions. However, because only three scientific studies have examined the effects of indirect land-use changes, GAO believes that a coordinated approach for identifying and researching unknown variables and major uncertainties will benefit EPA's lifecycle analysis. Regarding the recommendation for giving priority to R&D for producing biofuels that can be used by the existing petroleum-based infrastructure, USDA agreed that this is an important goal, but cited other similarly important biofuels R&D goals that its scientists are pursuing. Regarding the recommendation for clarifying what biomass material can be counted toward the RFS, USDA agreed that the executive agencies should consult on a definition and then propose any legislative changes to the appropriate congressional committees, stating that the department supports the 2008 Farm Bill's definition. USDA also provided four substantive comments on the report. First, while the department does not dispute most findings and conclusions, USDA noted that the report generally tends to emphasize negative aspects of increased biofuels production. GAO notes that USDA, in its comments, acknowledged the environmental challenges posed by increased biofuel production, and GAO agrees that strategies to mitigate these effects are currently being researched. While GAO believes its reporting of the research on these effects has been balanced, GAO reviewed this discussion and provided additional clarification where appropriate. Second, USDA stated that the report is written as if EPA's study on the RFS is still in progress and suggests that the report discuss EPA's findings and conclusions. GAO notes that EPA recently published peer reviewers' assessments of four key components of the lifecycle greenhouse gas emissions analysis in its May 2009 proposed rule. GAO believes that this peer review is an important first step for scientists to understand and validate the assumptions and models that EPA's lifecycle analysis used and that GAO's characterization of EPA's rulemaking is accurate. Third, USDA suggested that the report discuss legislative restrictions on eligibility for some competitive research programs, which it believes are important obstacles to achieving the best possible biofuels research. GAO notes that examining the funding restrictions in the Energy Policy Act of 2005 and other legislation that exclude federal government owned and operated research facilities from receiving DOE grant funds was beyond the scope of work for this review. Finally, USDA said the assessment in appendix VI of the impact of linkages between the corn ethanol industry and the livestock industry needed clarification and correction. GAO agrees and has revised the appendix, as appropriate. See appendix VIII for USDA's comments.

In its written comments, DOE also addressed each of the three recommendations. Regarding the recommendation for determining biofuels' lifecycle greenhouse gas emissions, DOE noted that EPA already consults with DOE on these matters and added that DOE would welcome the opportunity to become more engaged in this process if requested to do so by the EPA Administrator. Regarding the recommendation for giving priority to R&D for producing biofuels that can be used by the existing petroleum-based infrastructure, DOE commented that it has already expanded in this direction, noting recent and planned initiatives. For example, DOE cited a new solicitation to fund consortia to accelerate the development of advanced biofuels under the American Recovery and Reinvestment Act also supports infrastructure-compatible fuels and algae-based fuels, and DOE anticipates that hydrocarbon fuels will become a higher priority in the future and contribute to RFS requirements for advanced biofuels. Regarding the recommendation for clarifying what biomass material can be counted toward the RFS, DOE stated that the department would welcome the opportunity to participate in deliberations about how to clarify the biomass definition if requested to do so by the EPA Administrator, adding that DOE supports an expansion of biomass eligibility to include materials that do not come from federal lands classified as environmentally sensitive and that can be grown and harvested in a sustainable manner. DOE also provided four substantive comments on the report. First, DOE stated that the blend wall is not necessarily insurmountable to achieving the RFS's goals, citing Energy Information Administration projections that E85 could account for 30 percent of the total ethanol volume in 2020. While GAO does not disagree with this projection, GAO notes that expanded use of E85 would require substantial investment in the ethanol transportation and storage infrastructure—for example, EPA estimates that installing E85 refueling equipment will average $122,000 per facility. Second, DOE suggested that GAO revise its footnote in chapter 1 on Cello Energy's production plans, noting that the company had recently lost a fraud lawsuit. GAO has revised the reference to the Cello biorefinery. Third, in response to GAO's statement citing DOE and ethanol industry expert concern about the limited capacity of the freight rail system, DOE said that ethanol cargo represents a mere fraction of total rail cargo and that the railway industry has plans for major capital expansions over the coming decades. GAO revised its discussion of the freight rail challenges to increased biofuels use in chapter 7 to note, for example, that few blending terminals have the off-loading capacity to handle large train shipments of ethanol. Finally, DOE noted that Kinder-Morgan has performed extensive testing on transporting ethanol in existing petroleum product pipelines in Florida. See appendix IX for DOE's comments.

In its written comments, EPA stated that the report comprehensively identifies the main issues that should be considered when assessing expanded biofuels production. Regarding GAO's suggestion that the Congress consider amending EISA to require that EPA assess the effects of increased biofuels production on the environment at all stages of the lifecycle and use this assessment in determining eligible biofuels under the RFS, EPA said that (1) this issue might best be addressed by the newly created Executive Biofuel Interagency Working Group, (2) EPA has clear authorities and responsibilities under other statutes that may regulate aspects of a biofuel's lifecycle, and (3) EISA requires that EPA evaluate the environmental effects of biofuels and submit a report to the Congress. GAO acknowledges that EPA has the authority under other statutes to mitigate the environmental effects of biofuels and believes that the evaluation currently required by section 204 of EISA will provide a good foundation for the analysis GAO suggests. However, GAO believes the matter for congressional consideration would require EPA to not only assess the lifecycle effects of biofuels, but to actually use these assessments to determine which biofuels are eligible for consideration under the RFS. Regarding the recommendation for determining biofuels' lifecycle greenhouse gas emissions, EPA stated that the agency has worked closely with USDA and DOE in developing the lifecycle assessment methodology for its proposed rule and with the European Union, other international governmental organizations, and scientists on modeling, including the impact of indirect land-use change. GAO notes that while EPA has obtained information from USDA and DOE, its lifecycle analysis methodology was not transparent because EPA did not shared its methodology with outside scientists before its Notice of Proposed Rulemaking for the RFS regulation was published. GAO believes the recently completed peer review of EPA's methodology, including key assumptions and its analytical model, will improve the transparency of EPA's lifecycle analysis. Furthermore, the indirect effects of land-use change on lifecycle greenhouse gas emissions are not well understood, and additional research is needed to address data limitations, unknown variables, and major uncertainties. Regarding the recommendation for clarifying what biomass material can be counted toward the RFS, EPA stated that the agency is working with USDA to identify inconsistencies and interpret how biomass is treated under EISA and the 2008 Farm Bill. EPA also provided two substantive comments on the report. First, EPA stated that the analyses for its May 2009 proposed rule on lifecycle greenhouse gas emissions represent the most up-to-date and comprehensive assessment of many of these issues but commented it was not clear how GAO considered these analyses for this report. As previously stated, GAO believes that EPA's recently completed peer review of the key components of its lifecycle greenhouse gas emissions analysis is an important first step for scientists to understand and validate the data, assumptions, and models that EPA's lifecycle analysis uses. Second, EPA believes that many of the inconsistencies in biofuels assessments in the reported literature can in large part be explained either by differences in what is being modeled or, in some cases, by the use of more precise or up-to-date data and assumptions. GAO agrees with EPA that important progress has been made in quantifying the direct effects of biofuels production on lifecycle greenhouse gas emissions. However, few studies have been performed that assess the indirect effects of land-use change, and further research is needed to improve scientific understanding about the data, assumptions, and assessment models used to estimate these indirect effects. See appendix X for EPA's comments.

In addition, USDA, DOE, and EPA provided comments to improve the report's technical accuracy, which GAO incorporated as appropriate.

Chapter 1: Introduction

The United States consumes more liquid fuels than any other nation—roughly 19.4 million barrels per day, or about 23 percent of world consumption in 2008—even though U.S. consumption fell in 2008 due to high crude oil prices and a weakened economy. The U.S. transportation sector is almost entirely dependent on crude oil and accounts for almost two-thirds of total U.S. consumption. To meet the demand for oil in the face of limited and declining domestic production, the nation imported about two-thirds of its oil in 2008 and will likely continue to do so absent dramatic reductions in consumption or significantly increased use of alternative fuels. Oil is a global commodity with relatively little spare production capacity even as world oil demand has grown substantially in recent years. As demonstrated by the high gasoline prices of 2008, even a minor disruption in global oil supply can cause economic difficulties for tens of millions of Americans. Oil use also adversely affects the environment through the emission of greenhouse gases—primarily carbon dioxide, methane, and nitrous oxide—which has resulted in a warmer global climate system with potentially damaging long-term effects.[1]

Biofuels are an alternative to petroleum-based transportation fuels and are produced from renewable sources, primarily corn, sugar cane, and soybeans.[2] The United States is the world's largest producer of biofuels. The Energy Policy Act of 2005 created a Renewable Fuel Standard (RFS) that generally required U.S. transportation fuel[3] to contain 4 billion gallons of renewable fuels, such as ethanol and biodiesel, in 2006 and 7.5 billion gallons of renewable fuels in 2012, absent a waiver from the Administrator

[1]Greenhouse gases trap a portion of the sun's heat in the atmosphere and prevent the heat from returning to space. The insulating effect, known as the greenhouse effect, moderates atmospheric temperatures, keeping the earth warm enough to support life. According to the Intergovernmental Panel on Climate Change—an organization within the United Nations that assesses scientific, technical, and economic information on the effects of climate change—global atmospheric concentrations of these greenhouse gases have increased markedly as a result of human activities over the past 200 years, contributing to a warming of the earth's climate.

[2]Biofuels can be in solid, gaseous, or liquid form. In this report we refer to liquid biofuels as biofuels.

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

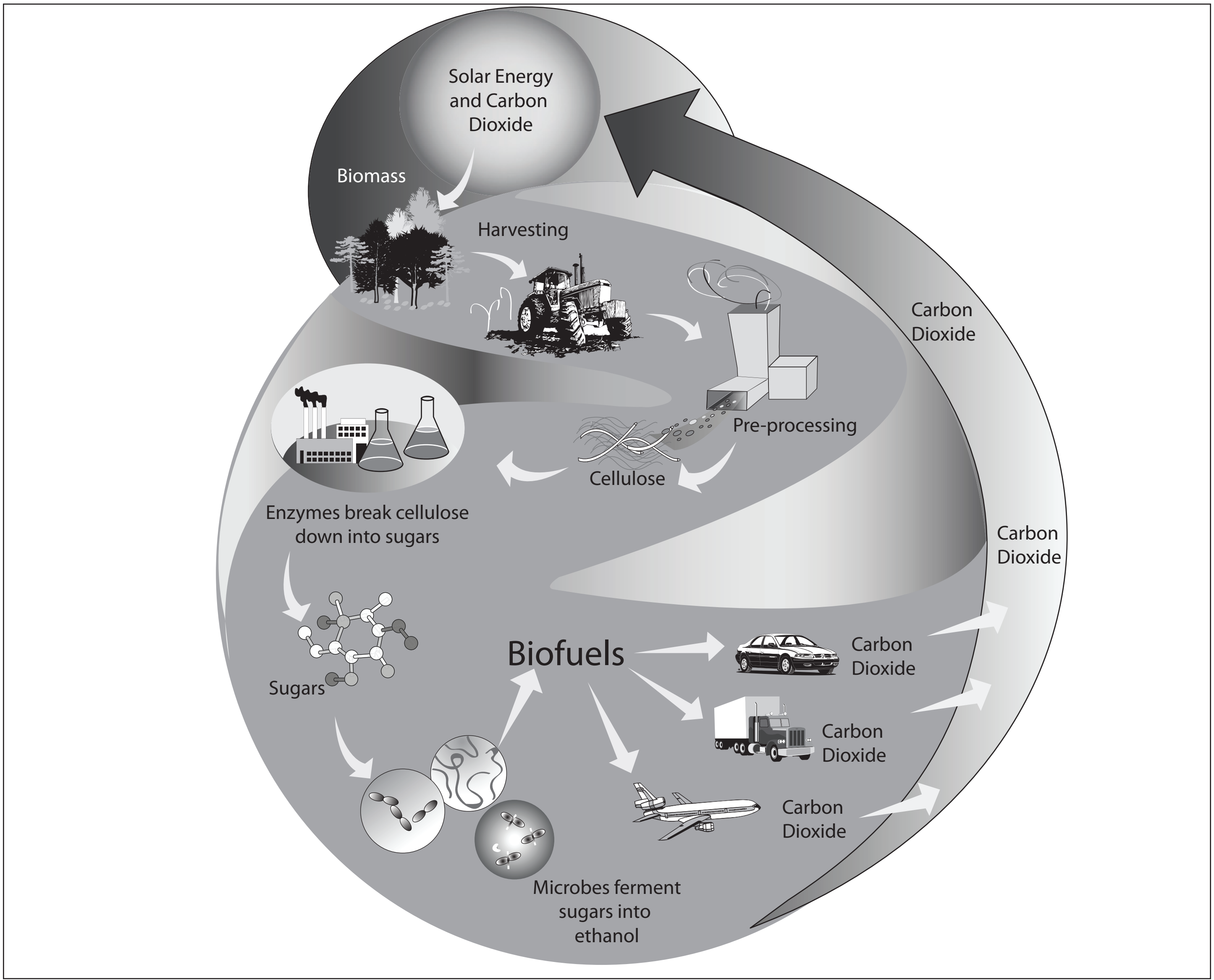
of the Environmental Protection Agency (EPA).[4] The Energy Independence and Security Act (EISA) of 2007 expanded the RFS, requiring that U.S. transportation fuels contain 9 billion gallons of renewable fuels in 2008 and increasing annually to 36 billion gallons in 2022.

In addition to improving the nation's energy security by decreasing oil imports and developing rural economies by raising domestic demand for U.S. farm products, increased biofuels consumption may reduce greenhouse gas emissions as compared with fossil fuels. As shown in figure 1, emissions of carbon dioxide and other greenhouse gases occur in each of the stages of growing, harvesting, processing, and using biofuels. For the past 20 years, researchers have used mathematical models—particularly Argonne National Laboratory's GREET model—to estimate fuel-cycle energy use and lifecycle greenhouse gas emissions directly associated with biofuels production and to compare them with the energy use and emissions of fossil fuels. However, researchers have only recently begun to conduct research on the indirect effects of increased biofuels production by examining the secondary effects of using agricultural lands to grow energy crops. Specifically, researchers are seeking to estimate the added greenhouse gas effects if other lands, locally or elsewhere globally, are cleared and converted into agricultural land to replace the displaced agricultural production—referred to as land-use change.[5] In addition, expanding feedstock supplies and biofuels production may increase the use of scarce water supplies; raise food prices; and reduce soil, water, and air quality.

[4]The act authorizes the EPA Administrator, in consultation with the Secretaries of Agriculture and Energy, to waive the RFS levels established in the act, by petition or on the Administrator's own motion, if meeting the required level would severely harm the economy or environment of a state, a region, or the United States or there is an inadequate domestic supply. Throughout this report, the RFS levels established in the act are referred to as requirements, even though these levels could be waived by the EPA Administrator.

[5]Section 211(o)(1) of the Clean Air Act defines lifecycle greenhouse gas emissions as the aggregate quantity of greenhouse gas emissions—including direct emissions and significant indirect emissions such as significant emissions from land-use changes—as determined by EPA's Administrator, related to the full fuel lifecycle. Lifecycle emissions include 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, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

Figure 1: Greenhouse Gas Emissions Associated with the Biofuels Production Process



Sources: DOE; Art Explosion (images).

Corn Starch Ethanol Is the Primary U.S. Biofuel

Ethanol is the most commonly produced biofuel in the United States, and about 98 percent of it is made from corn that is grown primarily in the Midwest.[6] Corn contains starch, which can be converted relatively easily into sugar and then fermented and distilled into fuel ethanol (ethyl alcohol), the same compound found in alcoholic beverages. Each 56-pound bushel of corn that is processed in a biorefinery yields roughly 2.7 gallons of ethanol fuel. Currently, only the starch from the corn kernel is used to make the fuel, and the remaining substance of the kernel is available to create additional economically valuable products. These are known as co-products and include dried distiller's grains, an animal feed primarily used for beef and dairy cows. About 3 billion bushels of corn, or about 23 percent of the nation's 13-billion bushel corn crop, were used to produce ethanol during the 2007-2008 corn marketing year, according to the U.S. Department of Agriculture's (USDA) February 2009 estimates.[7] USDA estimated that this will increase to 3.7 billion bushels, or about 30 percent of the corn crop, for the 2008-2009 marketing year.[8]

Corn is converted to ethanol through fermentation using one of two standard processes, wet milling or dry milling. The main difference is the initial treatment of the corn kernel. In the wet-mill process, the corn kernel is steeped in a mixture of water and sulfurous acid that helps separate the kernel into starch, germ, and fiber components. The starch that remains after this separation can then be fermented and distilled into fuel ethanol. In the dry-mill process, the kernel is first ground into flour meal and processed without separating the components of the corn kernel. The meal is then slurried with water to form a mash and enzymes are added to convert the starch in the mash to a fermentable sugar. The sugar is then fermented and distilled to produce ethanol. Traditional dry-mill ethanol plants are cheaper to construct and operate than wet-mill plants but yield fewer marketable co-products. Dry-mill plants produce distiller's grains (used as cattle feed) and carbon dioxide (used to carbonate soft drinks) as co-products, while wet-mill plants produce many more co-

[6] Ethanol is also imported from some member nations of the Caribbean Basin Initiative and Brazil, which use sugarcane as their feedstock, and produced from domestically grown sorghum.

[7] The 2007-2008 corn marketing year began September 1, 2007, and ended August 31, 2008.

[8] These estimates were based on 93.5 million planted acres in 2007, of which 86.5 million were harvested, at an average yield of 150.7 bushels per acre. For 2008, USDA estimated that corn growers will plant 86 million acres, of which 78.6 million would be harvested, at an average yield of 153.9 bushels per acre.

products, including corn oil, carbon dioxide, corn gluten meal, and corn gluten feed.

The biggest use of fuel ethanol in the United States is as an additive in gasoline. Ethanol is primarily blended with gasoline in mixtures of about 10 percent, called E10, or less, which can be used in any gasoline powered vehicle. A relatively small volume is also blended at a higher level called E85—a blend of about 85 percent ethanol—which can be used only in specially designed vehicles known as flexible-fuel vehicles because they can use either gasoline or E85. Ethanol contains only about two-thirds of the energy of a gallon of gasoline, so consumers must purchase more fuel to travel the same distance. A gasoline blend containing 10 percent ethanol results in a 2 percent to 3 percent decrease in fuel economy, while in a higher blend such as E85 drivers experience about a 25 percent reduction in fuel economy. Because vehicle manufacturers have generally designed vehicles to operate primarily on gasoline, most warranties for non-flexible-fuel vehicles allow the company to void the warranty if the owner uses fuels containing more than 10 percent ethanol.

Soybean Oil Is the Major U.S. Biodiesel Feedstock

U.S. biodiesel fuel is made from soybeans and other plant oils (such as cottonseed and canola), animal fats (such as beef tallow, pork lard, and poultry fat), and recycled cooking oils.[9] Soybean oil has been the most commonly used biodiesel feedstock in the United States.[10] According to the National Biodiesel Board, soybean oil made up about 65 percent of the feedstock used to produce domestic biodiesel in 2008. The United States is the world's largest soybean producer and exporter—farmers produced about 2.7 billion bushels of soybeans in 2007-2008 and will produce about 3 billion bushels of soybeans in 2008-2009, according to USDA.[11] According to the Energy Information Administration, most U.S. biodiesel production in recent years has been exported to European Union countries.[12] However, the European Commission imposed provisional antidumping

[9]It is generally estimated that 7.5 pounds of soybean oil will yield 1 gallon of biodiesel.

[10]Predominant feedstocks for biodiesel production are rapeseed in Europe and palm, coconut, and castor oils in tropical and subtropical countries.

[11]The 2007-2008 soybean marketing year began September 1, 2007, and ended August 31, 2008.

[12]Energy Information Administration, *Short-Term Energy Outlook Supplement: Biodiesel Supply and Consumption in the Short-Term Energy Outlook*, April 2009.

and antisubsidy duties on U.S. biodiesel imports in March 2009. Biodiesel is most commonly used as a blend with petroleum diesel, and B20 (20 percent biodiesel) is the most commonly used biodiesel blend in the United States. The energy content of a gallon of biodiesel is about 8 percent lower than that of petroleum diesel, causing vehicles running on B20, for example, to experience about a 2 percent decrease in fuel economy. At concentrations of up to 5 percent, biodiesel can be used in any application as if it were pure petroleum diesel. At concentrations of 6 percent to 20 percent, biodiesel blends can be used in several applications that use diesel fuel with minor or no modifications to the equipment, although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends.

Ethanol and Other Biofuels Can Be Produced from a Variety of Biomass

While ethanol is currently produced primarily from sugar- and starch-rich food crops, the biomass in the stalks, stems, branches, and leaves of various plants and trees can also be used to make biofuels. These feedstocks are called cellulosic because much of their biomass is in the form of cellulose, a complex molecule found in plants. Plant biomass is made up primarily of cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are made up of potentially fermentable sugars. Lignin provides the structural integrity of plants by enclosing the tightly linked cellulose and hemicellulose molecules, which makes these molecules harder to reach. Because cellulosic feedstocks are diverse, abundant, and potentially inexpensive, their use could greatly expand biofuel production. Cellulosic feedstocks include:

- *Dedicated annual or perennial energy crops:* includes switchgrass, forage sorghum, miscanthus, hybrid poplar, and willow.
- *Agricultural residues:* includes corn stover (the cobs, stalks, leaves, and husks of corn plants), corn fiber, wheat straw, rice straw, and sugarcane bagasse.
- *Forest residues and by-products:* includes forest thinnings from stand improvement or removal of excess understory trees, forest residues (dead trees and branches), and hardwood sawdust and chips from lumber mills.
- *Municipal and other wastes:* includes household garbage and paper products.

Cellulosic conversion technology currently focuses on two processes:

- *A biochemical process* uses acids and enzymes to break down cellulose and hemicellulose into fermentable sugars. This also makes lignin available to be burned to produce steam and electricity. In a biochemical process, the percentage of the cellulosic feedstock that is made of potentially fermentable sugars will determine its potential ethanol yield.[13]

- *A thermochemical process* uses gasification and pyrolysis technologies to convert biomass and its residues to fuels, chemicals, and power. Gasification—heating biomass with about one-third of the oxygen necessary for complete combustion—produces a mixture of carbon monoxide and hydrogen, known as syngas. Pyrolysis—heating biomass in the absence of oxygen—produces liquid pyrolysis oil. Syngas and pyrolysis oil can then potentially be refined into a number of biofuels products, including ethanol, gasoline, jet fuel, and diesel fuel. Because the thermochemical process can convert the whole plant, including lignin, into fuel, it can potentially produce more biofuel from a feedstock than biochemical conversion. Researchers at the Department of Energy's (DOE) National Renewable Energy Laboratory have reported liquid product yields of 75 percent (by feedstock weight) when using fast pyrolysis, one method of thermochemical conversion.

Some small biorefineries have begun to process cellulosic feedstocks using either biochemical or thermochemical conversion technologies.[14] However, no commercial-scale facilities are currently operating in the United States. DOE is providing up to $272 million, subject to annual appropriations, to support the cost of constructing four small biorefineries that will process cellulosic feedstocks using either a biochemical or thermochemical conversion technology.

[13]See Biomass Research and Development Board, *Increasing Feedstock Production for Biofuels Economic Drivers, Environmental Implications, and the Role for Research* (Washington, D.C., December 2008) for information about biomass yields and fuel yields for different biofuel feedstocks.

[14]For example, Cello Energy recently opened a biorefinery in Bay Minette, Alabama, that uses pyrolysis technology to process tires, hay, straw, wood chips, and switchgrass.

The Federal Government Has Used Tax Expenditures, the RFS, and an Ethanol Import Tariff to Stimulate Domestic Biofuels Production

The Energy Tax Act of 1978, among other things, provided tax incentives designed to stimulate the production of ethanol for blending with gasoline.[15] Specifically, the act authorized a motor fuel excise tax exemption for ethanol blends, which effective January 2005 was replaced by the Volumetric Ethanol Excise Tax Credit (VEETC) to provide ethanol blenders with an excise tax credit of 51-cents per gallon of ethanol through 2008.[16] The Food, Conservation, and Energy Act of 2008 (the 2008 Farm Bill) effectively reduced the VEETC to 45 cents per gallon beginning in 2009 and established a $1.01 per gallon tax credit through 2012 for cellulosic biofuels producers.[17] Additional tax credits that support biofuels include a $1 per gallon tax credit for biodiesel production, tax credits for small producers of ethanol or agri-biodiesel, an income tax credit for alternative fueling infrastructure, and a depreciation deduction for cellulosic ethanol facilities.[18] These tax credits are examples of tax expenditures, so named because they result in revenue losses for the federal government because the government forgoes a certain amount of tax revenue to encourage specific behaviors by a particular group of taxpayers, making them in effect spending programs channeled through the tax system. The largest of these tax expenditures is the VEETC, which cost $4 billion in forgone tax revenue in fiscal year 2008, according to the Department of the Treasury. The 2008 Farm Bill also extended through 2010 a 54-cent-per-gallon tariff on imported ethanol, which offsets the advantage foreign ethanol producers may gain from the VEETC.

The federal government also supports biofuels through the RFS. EISA amended the RFS in 2007 to require that the amount of renewable fuels in transportation fuel in the United States increase from 11.1 billion gallons in 2009 to 36 billion gallons in 2022. However, EISA allows the Administrator of EPA, after consulting with USDA and DOE and holding a public notice and comment period, to reduce the amount of renewable fuels required to be blended in gasoline in whole or in part if the Administrator determines that (1) its implementation would severely harm

[15] Pub. L. No. 95-618, §221 (1978).

[16] Pub. L. No. 108-357, §301 (2004).

[17] The 2008 Farm Bill limits the combined value of all tax credits for cellulosic ethanol to $1.01 per gallon.

[18] Pub. L. No. 101-508, §11502 (1991) Small Ethanol Producer Credit; Pub. L. No. 109-58, §1345, §1342 (2005) Small Agri-Biodiesel Tax Credit and Alternative Fuel Infrastructure Tax Credit; Pub. L. No. 109-432, §209 (2006) Special Depreciation Allowance for Cellulosic Biomass Ethanol Plant Property

the economy or environment of a state, a region, or the United States or (2) there is an inadequate domestic supply.

For 2009, the 11.1 billion gallons of biofuels must include at least 600 million gallons of advanced biofuels—defined as renewable fuel other than ethanol derived from corn starch that meet certain criteria—and up to 10.5 billion gallons of conventional biofuels—defined as ethanol derived from corn starch and includes other biofuels that are not considered to be advanced biofuels.[19] The RFS further specifies that of the 600 million gallon of advanced biofuels for 2009, at least 500 million gallons must come from biomass-based diesel.[20]

Beginning in 2010, the general requirement for advanced biofuel contains separate volume requirements for both biomass-based diesel and cellulosic biofuels. Beginning in 2015 and continuing through 2022, these advanced biofuel requirements essentially limit the annual amount of conventional biofuels that can count toward the RFS to 15 billion gallons. The 36-billion-gallon biofuel requirement for 2022 includes a minimum of 21 billion gallons of advanced biofuels, of which (1) at least 16 billion gallons must be cellulosic biofuels, (2) at least 1 billion gallons must be biomass-based diesel, and (3) the remaining 4 billion gallons can be other advanced biofuels, such as butanol or ethanol derived from sugar or starch other than corn starch.

To be eligible for consideration under the RFS, renewable fuels produced by biorefineries for which construction began after EISA's enactment on December 19, 2007, must generally achieve at least a 20 percent reduction in lifecycle greenhouse gas emissions as compared with baseline petroleum fuels.[21] However, advanced biofuels and biomass-based diesel under the RFS must generally achieve at least a 50 percent reduction in lifecycle greenhouse gas emissions relative to baseline petroleum fuels,

[19]Because of its lower production cost, corn starch ethanol is the predominant U.S. biofuel used to meet the RFS.

[20]EPA determined that the regulatory scheme for the RFS created pursuant to the Energy Policy Act of 2005 did not provide a mechanism for implementing this requirement in 2009. Accordingly, EPA decided to create a combined 2009/2010 requirement by increasing the RFS's 2010 biomass-based diesel requirement by 500 million gallons and allowing obligated parties to demonstrate compliance only at the end of the 2010 compliance period. 73 Fed. Reg. 70643 (Nov. 21, 2008).

[21]Biorefineries for which construction began before EISA's enactment are not subject to this requirement.

while cellulosic biofuels must generally achieve at least a 60 percent reduction, regardless of when the biorefinery producing the fuel was constructed.[22]

EISA requires that EPA promulgate a regulation that determines the lifecycle greenhouse gas emissions of biofuels and delineates which are eligible for consideration under the RFS based on the specified reductions and other statutory requirements. On May 26, 2009, EPA published a Notice of Proposed Rulemaking in the *Federal Register* that proposes the regulatory structure to implement the RFS and methods for calculating the lifecycle greenhouse gas effects of biofuels. Subsequently, in late July 2009, four peer review analyses of key components of EPA's lifecycle analysis were completed: (1) methods and approaches to account for lifecycle greenhouse gas emissions from biofuels production over time, (2) model linkages, (3) international agricultural greenhouse gas emissions and factors, and (4) satellite imagery. The proposed rule, if promulgated, would adjust the required lifecycle greenhouse gas emissions reductions for advanced biofuels from at least a 50 percent reduction to 44 percent or 40 percent in comparison with petroleum fuels.

Although the proposed rule includes an analysis of environmental and health impacts, EISA does not require EPA to determine a fuel's lifecycle impact on the environment, apart from greenhouse gas emissions, in order for a fuel to be eligible for consideration under the RFS. After 2022, EISA requires EPA, in coordination with DOE and USDA, to establish the RFS based, in part, on the impact of the production and use of renewable fuels on the environment, including on air quality, wildlife habitat, water quality, and water supply. On May 5, 2009, the President announced the formation of a Biofuels Interagency Working Group, co-chaired by the Secretary of Agriculture, the Secretary of Energy, and the Administrator of EPA. The working group is tasked, in part, with identifying new policy options to promote the environmental sustainability of biofuels feedstock production, taking into consideration land use, habitat conservation, crop management practices, water efficiency and water quality, as well as lifecycle assessments of greenhouse gas emissions.

[22]While EISA specifies the reductions in lifecycle greenhouse gas emissions that each type of renewable fuel must achieve, it also authorizes EPA to adjust the required reductions if the specified reduction is not commercially feasible for fuels made using a variety of feedstocks, technologies, and processes.

To ensure that the RFS is met, EPA sets a blending standard each year that represents the amount of biofuel that each refiner, importer, and certain blenders of gasoline must use.[23] In November 2008, EPA set the blending standard at 10.21 percent for 2009, which is designed to satisfy EISA's general requirement that transportation fuels contain 11.1 billion gallons of biofuels for the year. This means that most refiners, importers, and blenders of gasoline will have to displace 10.21 percent of their gasoline with biofuels.

Other statutory requirements EPA implements help maintain a market for ethanol. For example, the Clean Air Act Amendments of 1990 require areas with the worst air quality to use reformulated gasoline, which includes oxygenate additives that increase the oxygen content of the fuel and reduce emissions of carbon monoxide in some engines. Methyl tertiary butyl ether (MTBE) was the most common oxygenate additive until recent years, when it was found to contaminate groundwater. As of 2007, MTBE had been banned in 25 states. In its place, ethanol has been increasingly used as the primary oxygenate in gasoline—increasing its demand.

DOE and USDA Support Biofuels R&D and Demonstration

DOE supports biofuels research and development (R&D) efforts through its Biomass Program, within the Office of Energy Efficiency and Renewable Energy, and through its Office of Science. DOE's Biomass Program focuses on (1) developing more sustainable and competitive feedstocks than corn, primarily by exploring technologies to use cellulosic biomass; (2) reducing the cost of producing cellulosic ethanol; (3) converting biomass to biofuels through both biochemical and thermochemical processes; (4) helping to develop a national biofuels infrastructure by, for example, funding the construction of projects demonstrating integrated biorefinery technologies that use multiple feedstocks; and (5) promoting market-oriented activities for accelerating the deployment of biomass technologies.[24] DOE's Office of Science jointly funds projects focused on biomass genomics with USDA and funds and operates three Bioenergy Research Centers, designed to accelerate basic research to develop cellulosic ethanol and other biofuels. DOE is also

[23]The yearly blending standard is calculated as a percentage, by dividing the amount of renewable fuel that the RFS requires to be used in a given year by the amount of gasoline expected to be used during that year, including certain adjustments specified by EISA.

[24]See GAO, *Advanced Energy Technologies: Budget Trends and Challenges for DOE's R&D Program*, GAO-08-556T (Washington, D.C.: March 5, 2008).

responsible for monitoring compliance with the requirement that 75 percent of federal fleet vehicle acquisitions be capable of using alternative fuels and the goal of increasing use of these fuels.[25]

USDA's Agricultural Research Service and Forest Service primarily conduct in-house R&D on feedstock development, sustainable harvest and production, and commercially viable conversion of agricultural feedstocks into fuel ethanol, butanol, biodiesel, pyrolysis-derived fuels, and value added co-products. In addition to these biofuels R&D activities, the Natural Resources Conservation Service administers the following two programs:

- *Environmental Quality Incentives Program:* a voluntary conservation program for farmers and ranchers, to promote agricultural production, forest management, and environmental quality as compatible national goals. The program offers participants financial and technical assistance through contracts ranging from 1- to 10-year terms to install or implement structural and land management practices.
- *Conservation Stewardship Program:* provides payments to encourage producers to address resource concerns in a comprehensive manner by undertaking additional conservation activities and improving, maintaining, and managing existing conservation activities.

The Farm Service Agency administers the Conservation Reserve Program, a cost-share and rental payment program that assists producers in improving soil, water, and wildlife resources. The program encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife plantings, trees, filter strips, or riparian buffers. In addition, the Economic Research Service and Office of the Chief Economist analyze and report on trends and effects associated with biofuels production; the National Agricultural Statistics Service gathers data and reports on several aspects of U.S. agriculture; the Natural Resources Conservation Service gathers data on land use and natural resource conditions and trends on nonfederal lands; and the Forest Service's Forest Inventory and Analysis program is responsible for data collection and publication of information

[25]See GAO, *Federal Energy Management: Agencies Are Acquiring Alternative Fuel Vehicles but Face Challenges in Meeting Other Fleet Objectives*, GAO-09-75R (Washington, D.C.: Oct. 22, 2008).

on status and trends of trees (growth, mortality, and removals), forest products and utilization, and forest land ownership in the United States and the territories.

The Biomass Research and Development Board Coordinates Federal R&D

The Biomass Research and Development Act of 2000 directed the Secretaries of Agriculture and Energy to coordinate policies and procedures that promote R&D leading to the production of biofuels and biobased products.[26] The act created the Biomass Research and Development Board, co-chaired by DOE and USDA with representation from the Office of Science and Technology Policy; the Office of the Federal Environmental Executive; the Departments of Commerce, Defense, the Interior, Transportation, and the Treasury; EPA; and the National Science Foundation. The act also created the Biomass Research and Development Technical Advisory Committee, composed of about 30 representatives from industry, academia, and state government. In addition, the act directed the Secretaries of Agriculture and Energy to establish, in consultation with the Board, a Biomass Research and Development Initiative to award grants, contracts, and financial assistance to carry out research on and development of biofuels and biobased products. The Biomass Research and Development Board issued a multiagency National Biofuels Action Plan in October 2008 and a report in December 2008 to inform research recommendations to address the constraints surrounding availability of biomass feedstocks.[27] The Board has also completed or drafted reports on such subjects as biomass conversion, sustainability, feedstock production, and logistics.

In addition to federal efforts to support biofuel development, several states have established laws and policies to increase the availability and use of biofuels. In 2007, the American Coalition for Ethanol reported that 7 states have mandates that require the use of ethanol-blended fuels, 23 states provide ethanol production incentives, and 13 states offer incentives to encourage retailers to provide biofuels at their stations.

[26]Pub. L. 106-224, Title III, 114 Stat. 428 (as amended by section Pub. L. No. 109-58, Pub. L. No. 110-14, and Pub. L. No. 110-246).

[27]Biomass Research and Development Board, *Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research* (Washington, D.C., December 2008).

Objectives, Scope, and Methodology

The Chairman of the Senate Committee on Environment and Public Works and Senator Susan M. Collins asked us to assess several issues related to the increased production of ethanol and other biofuels in the United States. Specifically, we examined (1) the known agricultural and related effects of increased biofuels feedstock production in the United States; (2) the known environmental effects of increased feedstock cultivation and conversion and biofuels use in the United States; (3) the results, assumptions, and limitations of key scientific analyses of the lifecycle greenhouse gas effects of biofuels produced from different feedstocks; (4) federal support for developing a domestic biofuels industry; (5) federal funding for advanced biofuels R&D; and (6) key challenges in meeting the RFS's specified levels.

To examine known agricultural and related effects of increased biofuels production in the United States, we reviewed recent economic and scientific articles and recent reports of federal agencies. We also reviewed studies, reports, and presentation materials from the Biomass Research and Development Board and obtained relevant USDA data. Specifically, we searched databases including SciSearch, Biosis Previews, ProQuest, EconLit, and AgEcon Search and used a snowball technique to identify relevant peer-reviewed articles. We reviewed scientific articles in peer-reviewed journals that fit the following criteria: (1) the research was of sufficient breadth and depth to provide observations or conclusions directly related to our objectives; (2) the research was targeted specifically toward projecting or demonstrating effects of current biofuels production and advanced biofuels production on U.S. agriculture, namely on food, feed, and livestock markets as well as on overall biofuels feedstock yield and productivity, land-use intensification or expansion, and rural development; and (3) the studies were typically published between 2002 and 2008 by U.S.-based researchers. Based on these criteria, we selected 62 studies (see app. I). Of these, we selected 12 studies for more detailed analysis (see app. II). These studies contain empirical economic analysis and were chosen because they present key assumptions, methods, scenarios, and relevant findings of economic models of biofuels' potential effects on agriculture. For the most part, these studies were national in scope and generated quantitative or empirical results. Some of the studies also modeled the effects of increased biofuels production on relevant agricultural and energy programs or policies.

To examine the known environmental effects of increased feedstock cultivation and conversion and biofuels use in the United States, we conducted a review of relevant scientific articles, U.S. multidisciplinary studies, and key federal and state government reports. In conducting this review, we searched databases such as SciSearch, Biosis Previews, and ProQuest and used a snowball technique to identify additional studies, asking experts to identify relevant studies and reviewing studies from article bibliographies. We reviewed studies that fit the following criteria for selection: (1) the research was of sufficient breadth and depth to provide observations or conclusions directly related to our objectives; (2) the research was targeted specifically toward projecting or demonstrating effects of increased biofuel feedstock cultivation, conversion, and use on U.S. water supply, water quality, soil quality, air quality and biodiversity; and (3) typically published from 2004 to 2008. In reviewing 62 articles and studies (see app. III), we examined key assumptions, methods, and relevant findings of major scientific articles, primarily on the water quality, water supply, soil quality, and air quality effects.

To examine the findings, assumptions, and limitations of key scientific analyses of the lifecycle greenhouse gas effects of biofuels produced from different feedstocks, we reviewed recent scientific articles in peer-reviewed journals that examined the energy effects of biofuels, including net energy effects and greenhouse gas emissions of biofuels compared with fossil fuels. Specifically, we used a snowball sampling technique, asking experts and relevant stakeholders to identify key studies and then checking in the citations of these articles for other relevant work to identify studies that (1) provided specific estimates of greenhouse gas emissions from ethanol and biodiesel produced from biofuel feedstocks and (2) were published from 2004 to 2009 by U.S.-based researchers. We then examined 12 studies that quantified a change in lifecycle greenhouse gas emissions of biofuels compared with that of fossil fuels as well as 18 studies that found a change in greenhouse gas emissions but did not compare the effects with fossil fuels. We also reviewed 16 additional studies that examined the effects of different inputs, assumptions, and data gaps on lifecycle analysis conclusions. (See app. IV for the 46 scientific studies on the lifecycle greenhouse gas effects of biofuels we reviewed.) In doing this work, we made site visits to DOE's Argonne National Laboratory to interview the scientists who developed the GREET model that is widely used to calculate greenhouse gas emissions and DOE's Oak Ridge National Laboratory to interview scientists about their efforts to develop switchgrass as an energy crop and calculate the greenhouse gas emissions of cellulosic feedstocks. We also reviewed the proposed California Air Resources Board regulation to implement California's low carbon fuel standard.

Based on our review of the methodologies of each of the scientific studies included to assess agricultural and related effects, environmental effects, and greenhouse gas emissions, we determined each to be sufficiently sound to include in this report. We also collaborated with the National Academy of Sciences to identify recognized experts affiliated with U.S.-based institutions, including academic institutions, the federal government, and research-oriented entities for each of the following areas:

- *The effects of increased biofuels production on agriculture.* Experts who published peer-reviewed research articles or texts or significantly contributed to government studies that either (1) analyzed the effects of one or more biofuel feedstocks on U.S. agriculture; (2) estimated how expansion of U.S. biofuels production on agricultural or nonagricultural lands has impacted, is impacting, or will potentially impact food, feed, or fertilizer markets, major agricultural conservation programs, or any associated price and income effects; or (3) examined practices to maintain or increase crop or biofuels feedstock productivity levels while mitigating any adverse effects on environmental quality. We also asked the National Academy of Sciences to identify recognized experts from the private sector.

- *The effects of increased biofuels production on water quality, soil quality, water supply, and air quality.* Experts who have (1) published research analyzing the water resource requirements of one or more biofuel feedstocks and the implications of increased biofuels production on lands with limited water resources, agricultural lands, marginal lands, or highly erodible lands; (2) analyzed the possible effects of increased biofuel production on water, soil, habitat, and biodiversity; or (3) analyzed pollution resulting from biofuels production and use.

- *The lifecycle greenhouse gas effects of biofuels production.* Researchers who have recently published peer-reviewed research that examined the lifecycle greenhouse gas effects of biofuels produced from different feedstocks. Because we were asked to examine the results, assumptions, and limitations of key scientific analyses of the lifecycle greenhouse gas effects of biofuels produced from different feedstocks, we limited our interviews to the researchers who published these scientific studies and, as a result, are most knowledgeable about the models and data used for analysis.

We believe we have included the key scientific studies and have qualified our findings where appropriate. However, it is important to note that, given our methodology, we may not have identified all of the studies with findings relevant to these three objectives. Where applicable, we assessed the reliability of the data we obtained and found them to be sufficiently reliable for our purposes.

Together with the National Academy of Sciences' lists of experts, we identified authors of key agricultural, environmental, and greenhouse gas studies as a basis for conducting semistructured interviews to assess what is known about the effects of the increasing production of biofuels and important areas that need additional research. The experts we interviewed included research scientists in such fields as agricultural economics, environmental and natural resource economics, agronomy, soil science, ecology, air quality, and engineering. We also conducted interviews with cognizant federal agency officials and industry association executives.

To assess federal support for developing a domestic biofuels industry, we reviewed the economic literature on the impacts of various policy tools used to provide federal support and their interactions, including both conceptual and empirical analyses. (See app. V for 10 recent analyses by economists and nonprofit organizations.) We conducted semistructured interviews of cognizant federal officials and academic and government economists and reviewed Treasury data on federal tax expenditures; the R&D tax credit and other tax expenditures generally available to businesses were excluded. We applied conventional economic reasoning in analyzing the incidence of tax credits.

To examine federal support for advanced biofuels R&D, we obtained DOE and USDA data on (1) obligations for biofuels R&D for fiscal years 2005 through 2008 and (2) commitments for grants and loan guarantees for biofuels projects. We also obtained R&D data from EPA but excluded other federal agencies because they obligated only limited funds for biofuel R&D. We did not attempt to determine the market value of proposed federal loan guarantees. To determine what federal agricultural research is underway to support a transition to advanced biofuels feedstock production, we conducted interviews with USDA officials in the Agricultural Research Service; Forest Service; Cooperative State Research, Education, and Extension Service; Natural Resources Conservation Service; Economic Research Service; Office of the Chief Economist; Farm Service Agency; Rural Development mission area; National Agricultural Statistical Service; Office of Budget and Program Analysis; and Risk Management Agency.

To examine the key challenges in meeting the RFS's specified levels, we reviewed relevant literature and federal and industry association reports, and interviewed federal agency officials and executives from industry associations. We also conducted site visits to DOE's National Renewable Energy Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory and USDA's National Center for Agricultural Utilization Research and Eastern Regional Research Center.

In addition, we interviewed executives from cognizant industry associations and nonprofit organizations for each of the objectives. The industry associations include the American Meat Institute, Biotechnology Industry Organization, National Biodiesel Board, National Corn Growers Association, and Renewable Fuels Association, which represent various agricultural, energy, and biofuels industries. The nonprofit organizations include the Environmental Working Group, Natural Resources Defense Council, The Nature Conservancy, and World Resources Institute.

We conducted our work from July 2008 through July 2009 in accordance with generally accepted government auditing standards. These standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Chapter 2: Biofuels Production Has Had Mixed Effects on U.S. Agriculture, but the Effects of Expanded Production Are Less Certain

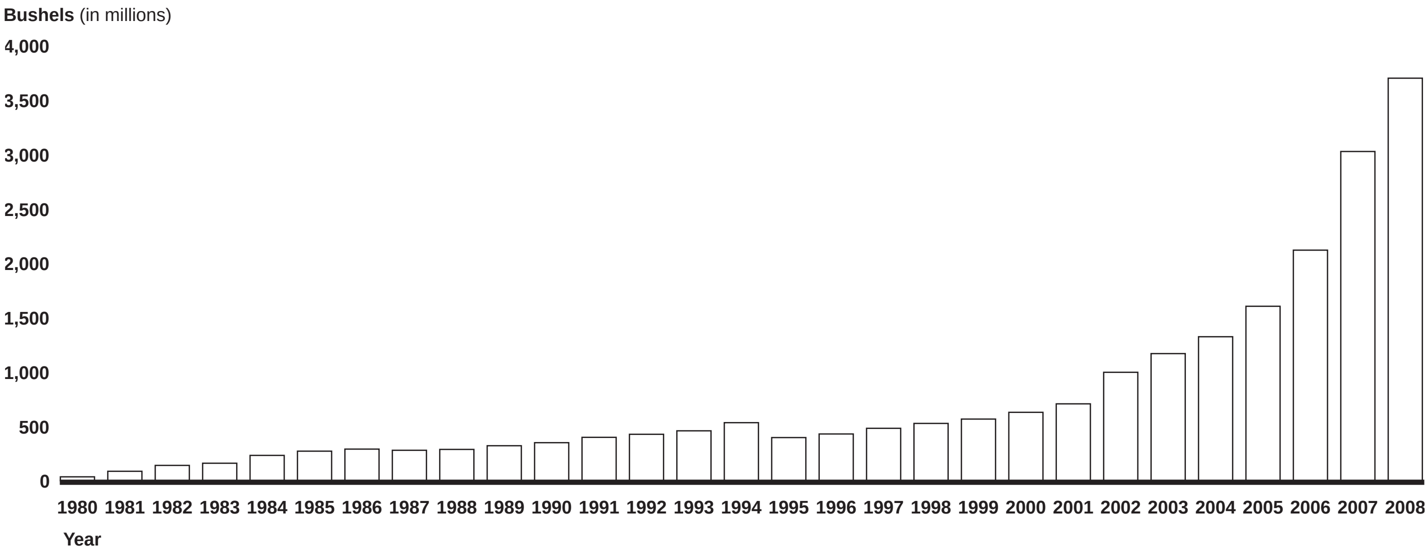
Biofuels production has had mixed effects on U.S. agriculture, including effects on land use, crop selection, livestock production, rural economies, and food prices. For example, the increasing demand for corn for ethanol production has led to higher corn prices, provided economic incentives for some producers to devote additional acres to corn production, and resulted in reduced production of other crops. While higher corn prices have created additional income for corn producers, they have also been driving up feed costs for livestock producers. At the same time, the number of biorefineries producing ethanol or other biofuels has grown considerably, offering new employment opportunities in rural communities as well as a boost to local commerce and tax revenues, although experts' views on the magnitude and permanence of these benefits varies. In addition, the increasing use of corn for ethanol production, among other factors such as high energy costs and tight global grain supplies, has likely contributed to higher retail food prices by increasing the price of corn used for food processing and animal feed. The potential future effects of expanded biofuels production, including production of new energy crops for advanced biofuels, are less certain but could be significant, particularly to the extent that these new crops affect the production of other crops and livestock on agricultural land. Finally, some USDA farm, forest, conservation, and extension programs potentially could reduce risk and provide incentives to encourage farmers to produce cellulosic energy crops (feedstocks) and help reduce the gap with existing supports for producing food and feed crops.

Increasing Corn Ethanol Production Has Had Mixed Effects on Land Use, Crop Selection, and Livestock Production

Increased ethanol production has raised demand for corn and contributed to higher corn prices. This has had several effects on U.S. agriculture, including an increase in acres planted to corn, a reduction in acres planted to other crops, an increase in crop production on lands that were formerly used for grazing or idled, and an increase in feed costs for livestock producers.

In 2007, increased prices for corn led farmers to devote more acreage to corn and less to soybeans and other crops. That year, U.S. farmers planted an estimated 93.5 million acres to corn—a 19 percent increase from 2006—while reducing the area planted to soybeans by 14 percent, and to cotton by 29 percent. According to USDA, a sharp rise in the price of corn, partially attributable to the increased use of corn for ethanol, prompted farmers to make this shift from soybeans and cotton. At the beginning of the 2007 planting season, the price of corn had reached $3.39 a bushel—a 61 percent increase from just 12 months earlier. Moreover, the quantity of U.S. corn used to produce ethanol rose by more than 50 million metric tons from 2002 to 2007. Figure 2 shows the increase in corn used for ethanol by market year, 1980 through 2008.

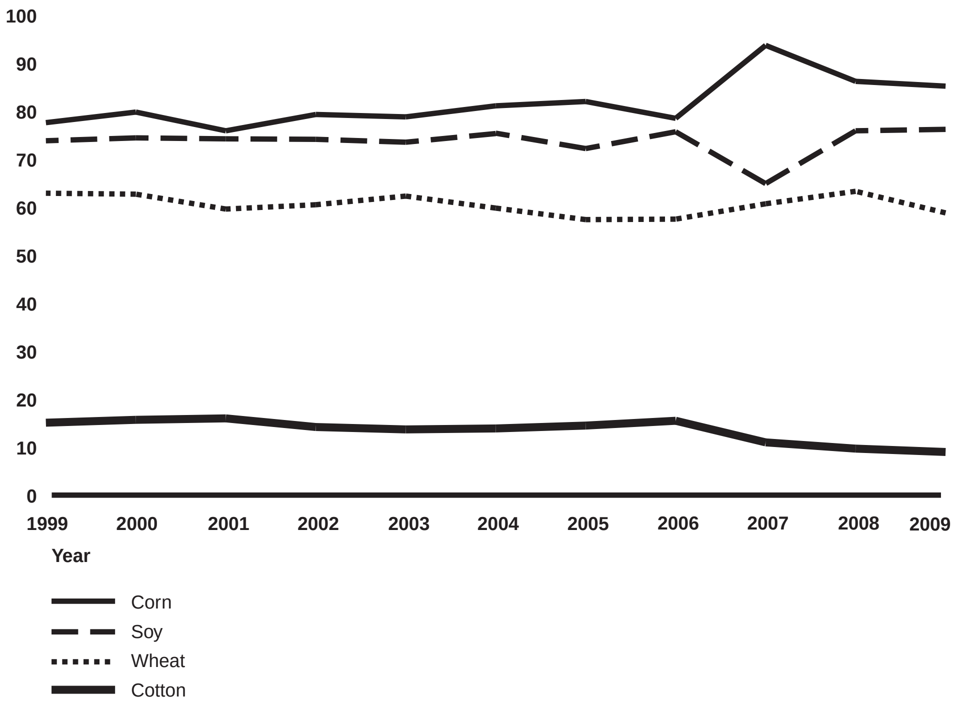
Figure 2: Corn Used for Ethanol by Market Year, 1980-2008



Source: USDA's Economic Research Service.

In 2008, soybean plantings rebounded, as corn acreage declined. Soybean prices rose significantly in 2007 because of the smaller crop—the second smallest soybean crop in a decade—and this prompted some producers to return acres planted in corn in 2007 back to soybeans in 2008. The estimated land area planted to soybeans increased by 17 percent, returning to 2006 levels. Land planted to corn dropped to an estimated 86 million acres in 2008; nevertheless, this level was still 10 percent above 2006 levels and represented one of the largest areas planted to corn since 1949. USDA expects a similar acreage to be planted to corn in 2009 and projects corn acreage to remain above 90 million acres through 2017, with increasing yields per acre. Figure 3 shows the changes in U.S. production—based on planted acres—of corn, soybeans, wheat, and cotton for crop years 1999 through 2009.

Figure 3: U.S. Acres Planted to Corn, Soybeans, Wheat, and Cotton, Crop Years 1999-2009



Source: GAO analysis of USDA's National Agricultural Statistics Service data.

Increased demand and higher prices for corn in recent years also resulted in the cultivation of some land that was formerly used for grazing or idled. Cropland used only for pasture or grazing declined by 41 percent from 2002 to 2007 compared with a 6 percent decline in total cropland, according to USDA's 2007 Census of Agriculture. In addition, the cash rental rates for these pasture and grazing lands increased substantially, in part due to land-use changes to crop production. For example, the average cash rent paid per acre for pasture rose by 41 percent nationwide from 2002 to 2008. In addition, some experts said that some land formerly enrolled in USDA's Conservation Reserve Program (CRP) has recently gone back into crop production, especially corn. CRP is a land retirement program that encourages landowners to take cropland, particularly highly erodible land, out of production and, in most circumstances, establish a natural vegetative cover—usually grasses—on this land. The landowner receives a rental payment from USDA for enrolling land in the program. Some experts expect even more CRP land to go back into production in the near term as contracts expire and if commodity prices remain high.

Moreover, CRP, which as of November 2008 had 34.7 million enrolled acres, is scheduled to reduce its enrollment to no more than 32 million acres by October 1, 2009, as required by the 2008 Farm Bill. USDA officials said they do not track how former CRP land is used once it leaves the program, but USDA is working on a survey to identify reasons why some landowners opt to leave the program.

The conversion of land used for grazing or idled to crop production has mixed effects. Cropland—which produces food, feed, fiber, and energy—can yield relatively high financial returns to crop producers and landowners. In addition, crop exports contribute to the U.S. balance of trade; the United States is the world's leading exporter of several major crops including corn, soybeans, and wheat. Furthermore, crop production generally increases economic activity in rural communities, affecting demand for farm inputs—seed, fertilizer, pesticides, herbicides, farm machinery, and labor—and the services of grain marketing and transportation companies. However, the grazing and idled land, usually planted in grasses, that cropland displaces also has many economic as well as environmental benefits. Grassland provides forage for grazing livestock; provides recreational opportunities, such as for hunting and fishing; reduces soil erosion; improves water quality; provides wildlife habitat; and aids carbon sequestration, which reduces carbon dioxide, a greenhouse gas, in the atmosphere.

Increased use of corn for ethanol has affected livestock producers by increasing prices for feed. In addition, livestock producers face reductions in land available for grazing. Historically, between 50 percent and 60 percent of U.S. corn is used as animal feed, and feed is often the largest cost for livestock producers. According to USDA, from 2006 to 2008, livestock producers saw feed prices nearly double, in part because of increasing use of corn for ethanol.[1] For example, according to USDA, almost one-third of the U.S. corn crop in the 2008 marketing year was used for ethanol production, and the agency estimates that a similar or larger percentage of the 2009 crop will also be used for this purpose. In addition, the amount of land available for grazing cattle has been declining,

[1]Other factors such as drought conditions in some grain-producing countries also contributed to higher feed prices.

according to researchers knowledgeable about the livestock sector.[2] While development and other uses account for part of these losses, conversion of grasslands to cropland, including for the production of crops for biofuels, is also a key factor. In addition, the 2008-09 global recession has hurt U.S. livestock producers by lowering demand for meat and poultry in the United States and abroad. Faced with multiple factors including rising feed costs, declining availability of land for grazing, and decreased domestic and foreign demand for meat, many U.S. livestock producers reduced the size of their herds and flocks in 2008. For example, the national beef cow herd was about 31.7 million head at the end of 2008, the lowest inventory since 1963. USDA projects that the value of U.S. livestock production will decline $11 billion, or 8 percent, in 2009 from the 2008 level. USDA also is forecasting a decline in 2009 and 2010 across all major categories of meat production. Furthermore, a meat industry official said that per-capita meat supplies in the United States in 2009 will be at their lowest level in several decades.

Higher animal feed costs due to increasing corn prices also led some livestock producers to seek alternative feed rations that use less corn. According to officials of livestock producer organizations, in some cases the nutrient or caloric content of these alternative rations is lower, resulting in slower maturation and weight gain in the animal. Another alternative to corn is distiller's grains, a co-product of the ethanol-from-corn process that is rich in protein and is gaining increasing importance as a feed supplement for beef cattle and dairy cows. However, it is less suitable as feed for poultry and hogs because of its high fiber content except in smaller amounts. Also, according to some experts, the increasing use of distiller's grains in the feed ration could raise consumer issues because it could affect the quality and appearance of the meat. Nevertheless, according to some agricultural economists, the increased availability of distiller's grains has reduced to some extent the adverse impact of corn price increases on the livestock sector by increasing the

[2]According to USDA's National Resources Inventory, privately owned grassland decreased by almost 25 million acres from 1982 through 2003, and more recent data indicated that this decline continues, particularly in the Northern Plains states, including North Dakota and South Dakota. GAO, *Agricultural Conservation: Farm Program Payments Are an Important Factor in Landowners' Decisions to Convert Grassland to Cropland*, GAO-07-1054 (Washington, D.C.: Sept. 10, 2007) and *Prairie Pothole Region: At the Current Pace of Acquisitions, the U.S. Fish and Wildlife Service Is Unlikely to Achieve Its Habitat Protection Goals for Migratory Birds*, GAO-07-1093 (Washington, D.C.: Sept. 27, 2007).

supply of a corn substitute. However, a few experts also acknowledged that the price of distiller's grains, like other feed substitutes such as hay, has risen and generally tracks with the price of corn. Poultry producers, who cannot use hay as a substitute or large quantities of distiller's grains, have seen a rapid escalation in feed costs. Increased costs combined with lower demand have forced them to make sustained cutbacks in production, according to livestock industry officials. These officials also said that pork producers can feed soybean meal to their hogs but their total feed costs have remained high, prompting them to breed fewer animals. (See app. VI for further information on economic effects and linkages in food and agricultural markets resulting from increased corn ethanol production.)

Growth in Ethanol Production Has Generally Provided a Boost to Rural Economies

The growth in ethanol production generally has provided a boost to rural economies, particularly in the Corn Belt states.[3] The main benefits have come from increased crop prices and the construction and operation of biorefineries to process corn into ethanol. However, expert views on the magnitude of these benefits and their permanence varies as the ethanol industry is prone to boom and bust cycles because of commodity and energy price volatility. In addition, as discussed above, the growth in ethanol production has generally hurt livestock producers, primarily by driving up feed costs and thereby hurting some sectors of rural economies.

The increases in crop prices, caused partly by ethanol production, have brought benefits to farmers and landowners. For example, corn prices rose from under $2 per bushel in 2005 to $5.47 per bushel in June 2008. The corn futures price also reached a peak that month of $7.08 per bushel. These increases represented historic highs. Furthermore, according to USDA, long-term growth in global demand for agricultural products, in combination with continued U.S. demand for corn for ethanol and European Union demand for oilseeds for biodiesel, will hold prices for corn, oilseeds, and many other crops well above their historical levels through 2018. USDA expects domestic corn use to grow throughout this period, largely reflecting increases in corn use for ethanol production. The agency also expects corn exports to increase due to global economic

[3]The Corn Belt is the area of the United States where corn is a principal cash crop, including Iowa, Indiana, most of Illinois, and parts of Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin.

growth, including increasing demand for feed grains to support growth in meat production.

Because of the increases in crop prices, U.S. farmers set records in 2007 and 2008 for the dollar value of their crop production, according to USDA. Net farm income was $86.8 billion in 2007, more than $29 billion above the average of $57.5 billion (nominal dollars) for the previous 10 years. In addition, USDA estimates that the value of farm assets, including land, machinery, stored crops, and purchased inputs, rose 28 percent from 2005 to 2008. According to USDA, increased crop prices also reduced government outlays by $3.9 billion in 2007 for federal farm programs that provide producers payments when commodity prices fall below specified thresholds. Furthermore, because USDA anticipates that crop prices will remain high for the long term, it projects that government payments to farmers will fall from $12.4 billion in 2008 to an average of less than $10 billion annually from 2009 to 2018.

In addition, the construction and operation of biorefineries to process corn into ethanol has provided additional employment opportunities in local communities and benefited businesses which provide goods and services to these plants. From 1991 through December 2008, the number of U.S. ethanol biorefineries increased from 35 to 172. Construction of a biorefinery generally requires the services of multiple businesses and skilled and unskilled workers, as well as the local purchase of materials, including concrete and plumbing and electricity supplies. While a relatively few firms specialize in ethanol plant construction and generally have their own equipment and skilled workers that travel with them, local construction firms sometimes provide less specialized services such as basic site preparation and plumbing and electrical work.

Once operational, an ethanol biorefinery generally employs dozens of people. For example, an average 100-million-gallon-per-year plant employs about 52 full-time workers, who earn on average $52,000 a year. According to the most recent U.S. Census Bureau data available, the industry had about 4,300 employees in 2006. In addition, an operational biorefinery purchases goods and services from local firms to support its operations. This spending, along with employee salaries, also results in a multiplier effect of additional spending that supports jobs at local businesses, such as restaurants, stores, and gas stations.[4] A 2008 study for the Renewable Fuels Association, a trade association, estimated that a 100-million-gallon-per-year plant provides nearly 1,100 jobs indirectly. However, other sources have estimated that the direct and indirect employment effects of ethanol plants are positive, but substantially lower. For example, a 2009 study by the University of Illinois at Urbana-Champaign estimated a 100-million-gallon-per-year plant creates 97 to 152 jobs indirectly. In another case, a 2007 study done by Iowa State University projected, in part, that by 2016 the U.S. ethanol industry will have created about 9,000 jobs directly and 11,600 indirectly. In addition, according to estimates made by Iowa's Department of Revenue, the operation of an ethanol plant in a town increases the average real household income of its residents by $822. The creation of additional employment opportunities is important for farm households and rural communities. For example, according to USDA, about 90 percent of U.S. farm household income is derived from sources other than the farming operation, such as wages and salaries from off-farm jobs and nonfarm businesses. In addition, according to a March 2009 report by the Rural Policy Research Institute, the nation's rural economy is losing jobs at a rate faster than the rest of the United States. New plants also increase the local tax base, which may provide funding for schools, hospitals, fire protection, and other public services. However, local governments may offer tax abatements for a specified period of years to attract plants to their area.

Expert views on the magnitude of these benefits to rural communities and their permanence vary, and some biorefineries recently have suspended operations or delayed planned construction or expansion projects due to high corn prices, lower fuel demand, and tight credit markets. Some experts noted that the biofuels industry generally has been prone to periods of boom and bust driven by food and energy price volatility. When crop prices are low and energy prices are high, biofuel producers generally have profited and have sought to expand production. However, when these market conditions are reversed, biofuel producers generally have struggled. For example, one of the largest U.S. ethanol producers, VeraSun Energy Corporation, declared bankruptcy in October 2008 and announced the sale of all of its production facilities in February 2009. Other ethanol

[4] We previously reported on the direct and indirect economic impacts of a new renewable energy employer in rural communities. See GAO, *Renewable Energy: Wind Power's Contribution to Electric Power Generation and Impact on Farms and Rural Communities*, GAO-04-756 (Washington, D.C.: Sept. 3, 2004).

producers, such as Pacific Ethanol, Inc., have shut down plants or filed for bankruptcy because of unfavorable market conditions.

Finally, according to livestock industry officials, herd and flock reductions—although initially creating a surge in business for slaughterhouses and meatpackers—have resulted, in the longer term, in many slaughter and meatpacking processors reducing shifts or days of operation, while others were forced to lay off employees, file for bankruptcy, suspend operations, or close. According to these officials, these actions potentially have led to the loss of jobs, economic activity, and tax revenues in some local communities. For example, according to a report by the National Chicken Council, National Turkey Federation, and American Meat Institute, the chicken and turkey industries closed facilities and laid off thousands of employees in 2008 due to historically high corn prices resulting, at least in part, from the use of corn for ethanol. However, the general economic recession affecting the United States is also likely a factor in these plant closures. Furthermore, prices paid to livestock producers for meat may increase in the future due to supply reductions associated with herd and flock downsizing if consumer demand for meat remains unchanged. However, if the current global recession continues or worsens, consumer demand for meat may drop further.

Higher Corn Prices—Driven in Part by Increased Ethanol Production—Have Likely Been a Factor in Recent Food Price Increases

Higher corn prices, resulting in part from increased ethanol production, have likely contributed to domestic and international food price increases. Similar observations have been made in other countries that also are diverting part of their food and feed crop production to biofuels. However, estimates vary widely as to the relative contribution of biofuels production to food price increases. Other factors have also contributed to these price increases, including increased energy costs, higher costs for agricultural inputs, tight global grain supplies, export restrictions, poor grain crops in other countries, and growing world demand for food.

Many experts agreed that the rapid growth in demand for grains to produce biofuels has contributed to rising global and domestic food prices, although opinions varied on the extent of this contribution. Biofuels production has recently been growing by about 15 percent per year worldwide, and more than doubled from 2000 to 2005, to nearly 650,000 barrels per day, or about 1 percent of global transportation fuel use. Moreover, from the end of 2006 to early 2008, world food commodity prices rose by 45 percent, according to the International Monetary Fund, and many world food prices were at record highs in July 2008. In contrast, in the United States, retail food prices rose by 4 percent in 2007 and 5.5

percent in 2008, but these rates were still greater than in prior years. According to USDA, one reason for this smaller rate of increase is that Americans tend to consume highly processed foods in which grain, such as corn or its derivative products, represent a relatively small portion of the processed food cost. This is less true in developing countries where direct consumption of grain is more important.

Estimates vary widely as to the relative contribution of biofuels production to retail and commodity food price increases. For example, in April 2009, the Congressional Budget Office estimated that from April 2007 to April 2008, the rise in the price of corn resulting from expanded production of ethanol contributed from 0.5 to 0.8 percentage points of the 5.1 percent increase in U.S. retail food prices measured by the Consumer Price Index. In another analysis, the U.S. Council of Economic Advisers estimated in May 2008 that U.S. production of corn-based ethanol increased global retail food prices by about 3 percent for a 12-month period from 2007 to 2008. In addition, regarding commodity prices, a June 2008 study prepared for Kraft Foods Global, Inc. by a former USDA Chief Economist estimated that about 60 percent of the increase in the price of corn in marketing years 2006 through 2008 was due to the increased use of this grain for ethanol, although other experts estimated that the impact was from 25 percent to 47 percent.

According to studies we reviewed, the following other factors also contributed to food price increases experienced in 2007 and 2008:

- *Input prices.* Higher oil prices increased the production costs of all goods and services, including prices for agricultural inputs such as fertilizer, diesel, and propane. In general, higher input prices affect food prices through reduced production of food, as suppliers cut back their output.

- *Grain supplies*. Global consumption of grain exceeded production in 7 of the past 8 years, according to USDA. At the same time, by 2007 the global stocks-to-use ratio declined to the lowest level on record since 1970,[5] although government reductions to their reserve stocks also played a role.

[5] The stocks-to-use ratio indicates the level of carryover stock for any given agricultural commodity as a percentage of the total use of the commodity.

- *Export restrictions.* Rapidly rising food prices led some countries to restrict exports of agricultural commodities. In general, these countries wanted to maintain an adequate and reasonably priced domestic food supply to avoid civil unrest. However, according to USDA, these trade disruptions only exacerbated the price increases on world markets.

- *Rising incomes.* In recent years, rising world incomes have led consumers in developing countries, such as China and India, to increase their per capita consumption of staple foods and include more meats, dairy products, and vegetable oils.

- *Exchange rates and speculation.* Historically, commodity prices move with changes in the dollar's exchange rate. For example, depreciation of the U.S. dollar relative to the currency of importing countries makes purchases of U.S. commodities by foreign consumers less expensive, thus stimulating demand and increasing the prices of these commodities, as was the case from 2006 to 2008. In addition, increased purchases of financial instruments to hedge price swings may contribute to greater volatility in commodity prices.

The Effects of Expanded Biofuels Production on Agriculture Are Uncertain but Could Be Significant

Many experts said increased biofuels production, including advanced biofuels, could significantly affect U.S. agriculture by changing land-use patterns. In addition, some experts said crop prices and other aspects of agricultural markets, such as use of inputs, land values, and farming profitability could also be affected. However, the effects are uncertain and will hinge on what energy crop feedstocks are used and whether these feedstocks are grown on existing farmland (crop-, pasture-, and rangeland).[6] Also uncertain is how the continuing world economic recession and increased volatility of agricultural commodity prices, particularly corn prices, will impact the agricultural and biorefining sectors.

Experts' views varied on the effect that diverting an increasing proportion of the U.S. corn crop to the production of ethanol will have on land-use decisions. Some said it would bring even more land not currently cultivated into production, including pasture- and rangeland. Others said it

[6]Pasture, or pastureland, is land used primarily for the production of domesticated forage plants for livestock. In contrast, range, or rangeland, is land where vegetation is naturally occurring and is dominated by native grasses, grasslike plants, and shrubs.

would continue to increase the cropland acreage devoted to corn production and reduce the acreage available for other crops. Still others said that while such changes are possible, the overall shift in agricultural land used to meet the future RFS-specified level for corn ethanol will be relatively modest.

Some experts said that producing new energy crops, such as switchgrass,[7] could increase competition for the use of existing farmland. However, several factors could mitigate this. For example, global food production must double by 2050 in order to meet the needs of the growing world population, according to the United Nations' Food and Agriculture Organization and other sources. Any resulting increases in the demand for highly productive farmland might limit shifts to energy crop production. Also, some experts said that energy crops such as perennial grasses are more suited to marginal land than are most food and feed crops, although they emphasized that yields will be lower on such land. In addition, crop residues could be produced along with food and feed, although residue removal above recommended rates might reduce soil fertility and increase soil erosion and thus affect food production. Furthermore, a few experts noted that some feedstocks chosen for production of advanced biofuels in the future would require little or no agricultural land. These might include municipal waste, forest thinnings, and algae.

A few experts also noted that the commercial production of energy crops is still several years away. Significant challenges involving feedstock production practices, transport infrastructure, ethanol conversion technologies, and market formation must be addressed before new energy crops become economically viable. (See ch. 7 for a further discussion of these factors.) While there are a number of ongoing test or pilot projects to produce advanced biofuels from a variety of crops or other materials, it will be a considerable leap to commercial scale production. Furthermore, there may be little incentive for investors to embrace advanced biofuels at this time. As of early 2009, production in the ethanol industry had stagnated because of relatively low gasoline prices and excess ethanol production capacity. In addition, the U.S. recession, with its tight credit markets, numerous bank failures, and plummeting stock values, has made investors and lenders particularly cautious regarding unproven

[7]Switchgrass is a native prairie grass long used for conservation planting and cattle feed in the United States. Switchgrass is a promising biofuel feedstock crop because it can be grown across a wide range of conditions, can yield great amounts of biomass, establishes deep roots to store carbon in the soil, and does well on marginal lands.

technologies. Finally, future demand and supply projections for crops currently used for biofuels production as well as new energy crops are sensitive to assumptions regarding crude oil prices and U.S. government policies. For example, according to a study by two Purdue University researchers, ethanol production jumps significantly when crude oil prices increase from $40 to $60 a barrel, but the impact on ethanol production would be less pronounced if oil prices were to increase from $140 to $160 per barrel. (See app. II for information on several studies presenting such projections.)

Moreover, while crude oil prices historically have had an impact on the agricultural sector, the RFS created a tighter link between the prices of crude oil and corn, according to some economists. Ethanol's share in the U.S. transportation fuel mix has increased, making up about 5 percent of current U.S. gasoline consumption, while escalating RFS levels guarantee that this share will increase at least in the short term. Price volatility can have damaging effects for crop producers and biorefineries, as well as consumers, all of whom may have difficulty managing increased risk. For example, one large ethanol company filed for bankruptcy protection because it erred in making expensive hedges on the future price of corn. On the other hand, some oil refiners may be benefiting by being able to purchase shuttered ethanol plants. For example, Valero Energy, one of the largest independent U.S. oil refiners, won a bid in March 2009 to purchase eight ethanol plants. If this trend continues, more consolidation in the refining sector may help this set of corn users to weather increased price volatility. Crop and livestock producers, however, would still need to find their own mechanism for managing this volatility.

Although potential growth in biofuel production is uncertain, various estimates suggest that global biofuel production could grow to supply over 5 percent of the world's transportation energy needs. This growth will likely mean an even greater use of crops and agricultural land for producing biofuel feedstocks, putting further pressure on commodity and food prices. In addition, we previously reported on the potential implications of expanded biofuels production on food security, hunger, and international food aid.[8] For example, the diversion of grains to biofuel production contributes to increases in global grain prices, exacerbating

[8]GAO, *International Food Security: Insufficient Efforts by Host Governments and Donors Threaten Progress to Halve Hunger in Sub-Saharan Africa by 2015*, GAO-08-680 (Washington, D.C.: May 29, 2008).

food insecurity in regions such as sub-Saharan Africa by making food less affordable for the poor and the food aid programs that assist them. However, we also reported that rural development opportunities could exist for African communities that are able to produce biofuels.

Some USDA Programs Could Support the Transition to Cellulosic Energy Crop Production for Biofuels

According to USDA officials and experts, some USDA farm, forest, conservation, and extension programs could potentially reduce risk and provide incentives to encourage farmers to produce cellulosic energy crops (feedstocks) for biofuels. At current market prices and under existing subsidy regimes for food and feed crops, returns to production of cellulosic feedstocks are not comparable with those for corn and other agricultural commodities. At present, it is not clear whether or how USDA programs will be designed to reduce the gap or what role increases in biofuels prices will play.

Several USDA officials and experts said a new program, the Biomass Crop Assistance Program (BCAP), may provide a key means to reduce risk to producers of cellulosic feedstocks. The 2008 Farm Bill authorized BCAP to support the establishment and production of cellulosic feedstock and assist landowners with collection, harvest, storage, and transport of the feedstock to a biorefinery.[9] Under this program, producers would enter into multiyear contracts with USDA to obtain payments of up to 75 percent of the cost for planting and establishing a perennial energy crop. They also would be eligible for annual payments for the life of the contract, similar to the payments producers now receive for certain food and feed crops, including corn. In addition, producers could receive separate payments for 2 years if they collect, harvest, store, or transport the feedstock to a biorefinery. Cognizant Farm Service Agency officials told us they will need to carefully consider these three potentially overlapping program payments as they develop the program rules and application process. A few experts said that BCAP payments could help put dedicated energy crops on a level playing field with traditional commodity crops. Farm Service Agency officials expect to issue a notice of proposed rulemaking, including a draft environmental impact statement, in fall 2009.

However, several provisions in the 2008 Farm Bill may affect the Farm Service Agency's ability to effectively develop the BCAP regulations, according to agency officials. For example, it is unclear whether the Farm

[9]Pub. L. No. 110-246 § 9001, 122 Stat. 1651, 2089 (amending 7 U.S.C. § 8111).

Service Agency can pay costs associated with conservation measures under BCAP—such as dedicated wildlife corridors and riparian buffers—in addition to costs specifically cited in the legislation, such as seeds, planting, and site preparation. Also, the 2008 Farm Bill excludes federal- or state-owned land from eligibility, which may have implications for Indian tribe lands held in trust by the U.S. Government and cropland owned by local government entities, such as a school board.

In addition, the 2008 Farm Bill contains a research provision focused on (1) providing grants for enhancing the production of biomass energy crops and the energy efficiency of agricultural operations and (2) developing a best practices database of publicly available information on both the production potential of various biofuel feedstocks and on the best practices for production, collection, harvest, storage, and transportation of those feedstocks. This research is authorized for $50 million annually through 2012 and the Cooperative State Research, Education, and Extension Service would likely carry out the grant program component of this provision once these funds are appropriated.

Lastly, a 2008 Farm Bill provision authorized studies of insurance policies for dedicated energy crops. USDA Risk Management Agency officials said that current methods to design insurance policies for covering pasture, range, and forage lands would be suitable to use for certain dedicated energy crops if farmers were interested in an insurance product. However, these officials also said that developing such products would likely be more complicated for agricultural residues or woody feedstocks.

Producers of biofuel feedstocks may already be considered for USDA conservation programs that the Natural Resources Conservation Service administers—such as the Environmental Quality Incentives Program and the Conservation Stewardship Program—because eligibility is based on land type rather than what is grown on the land. While it is likely that some criteria for production of nonfood biofuel feedstocks would need to be developed or enhanced, officials said that once they have sufficient resources, they do not anticipate difficulty in doing so. However, our past work has found that funding available to these programs has lagged producers' interest in participating.[10] If the land on which producers might grow energy crops is indeed eligible, demand for program participation may further increase.

Currently, energy crops other than corn and soybeans do not represent viable commercial alternatives for farmers when deciding what to plant. As demand for cellulosic-based biofuels develops and raises feedstock prices, returns to energy crop production may approach those for food and feed crops. In the meantime, government subsidies may improve incentives to adopt production systems necessary to grow cellulosic feedstocks. However, the returns for food and feed crops also include the benefits of government subsidies, among them direct and countercyclical payments.[11] Experts said it may not be desirable or necessary to extend similar benefits to dedicated energy crops if biofuels market prices rise sufficiently. Moreover, a USDA official said it is unclear how energy crop subsidies could be designed in light of likely regional variation in prices that would develop.

[10]GAO, *Agricultural Conservation: USDA Should Improve Its Process for Allocating Funds to States for the Environmental Quality Incentives Program*, GAO-06-969 (Washington, D.C.: Sept. 22, 2006), *Conservation Security Program: Despite Cost Controls, Improved USDA Management Is Needed to Ensure Proper Payments and Reduce Duplication with Other Programs*, GAO-06-312 (Washington, D.C.: Apr. 28, 2006), and GAO, *Agricultural Conservation: State Advisory Committees' Views on How USDA Programs Could Better Address Environmental Concerns*, GAO-02-295 (Washington, D.C.: Feb. 22, 2002).

[11]As of the 2008 Farm Bill, direct payments are available for producers with eligible historic base acres of such crops as corn, wheat, grain sorghum, and oilseeds. Countercyclical payments are available for producers with eligible historic base acres when the commodity's effective price is less than the target price. The effective price is the sum of the direct payment rate plus either the national commodity loan rate or the national average farm price for the crop year, whichever is higher.

Chapter 3: Increased Biofuels Production Could Have a Variety of Environmental Effects, but the Magnitude of These Effects Is Largely Unknown

The increased cultivation of corn, its conversion into conventional biofuels, and the storage and use of these fuels could have various environmental effects, including on water supply, water quality, air quality, soil quality, and biodiversity, but future movement toward cellulosic feedstocks for advanced biofuels could reduce some of these effects. Although input requirements have decreased over time, corn is a relatively resource-intensive crop, requiring relatively higher rates of fertilizer and pesticide applications and additional water to supplement rainfall depending on where the crop is grown. As a result, some experts believe that increased corn starch ethanol production may result in the cultivation of corn on arid lands that require irrigation, contributing to additional water depletion, and will lead to an increase in fertilizer and sediment runoff, impairing streams and other water bodies. Furthermore, experts believe that as cultivation of some crops such as corn for biofuels production increases, environmentally sensitive lands that are currently protected because they are enrolled in conservation programs may be moved back into production, thereby increasing cultivation of land that is susceptible to erosion and decreasing available habitat for threatened species. However, it is important to recognize that some of the effects on water quality and habitat may be mitigated by the use of agricultural conservation practices. In the future, farmers may also adopt cellulosic feedstocks, such as switchgrass and woody biomass, which could reduce water and land-use effects relative to corn. In addition, the process of converting feedstocks into biofuels may also negatively affect water supply, water quality, and air quality as more biorefineries move into production. For example, biorefineries require water for processing the fuel and will need to draw from existing water resources, which are limited in some potential production areas. However, the effects will depend on the location and size of the facility and the feedstock used. Finally, the storage and use of certain ethanol blends may pose other environmental problems, such as leaks in underground storage tanks that are not certified to store such blends and increased emissions of certain air pollutants when ethanol is used in most cars; however, less is known about the extent of these effects. According to some experts and officials, focusing on sustainability will be important in evaluating the environmental implications of increased biofuels production.

Cultivation of Corn for Biofuel Has a Variety of Environmental Effects, but a Shift to Cellulosic Feedstocks Could Reduce These Effects

The Biomass Research and Development Board projects that corn acreage will increase in all regions of the United States if corn starch ethanol production reaches the 15 billion gallons per year allowed by EISA for 2015 through 2022, with the largest increases taking place in the Corn Belt and Northern Plains. Although the water requirements of corn production have decreased over time with new seed varieties and agricultural management techniques, increased corn production in these areas could strain the supply of groundwater in places that rely on irrigation and are already facing water constraints. It could also degrade water quality in local streams and waterways as far away as the Gulf of Mexico. In addition, biodiversity and habitat could be affected, as lands set aside for conservation are returned to crop production. In contrast, the cultivation of cellulosic feedstocks has the potential to reduce the environmental effects associated with corn-based biofuel cultivation. However, there is still a significant amount of uncertainty associated with the direction and scale of the potential environmental implications of these feedstocks.

Increased Cultivation of Corn for Ethanol Could Further Stress Water Supplies, but Cultivation of Certain Cellulosic Feedstocks May Require Less Water

Although advances have been made with regard to developing seed varieties for corn that are more drought tolerant, the cultivation of corn for ethanol production can require substantial quantities of water depending on where it is grown and on how much irrigation water is used to grow the corn.[1] According to an Argonne National Laboratory study, the amount of water needed to produce 1 gallon of corn starch ethanol (considering both water used for irrigation and in the conversion process) varies significantly, estimated at 10 to 324 gallons of water per gallon of ethanol for major corn production regions in the United States (see table 1). The upper part of this range generally represents regions that rely heavily on irrigation to grow corn, whereas the lower end reflects water use in those regions that rely primarily on rainfall. Another study examined water use as a function of vehicle miles per gallon associated with a range of transportation fuels. Corn starch ethanol derived from irrigated corn consumes an estimated 1.3 to 62 gallons of water per mile traveled in a vehicle using ethanol, while rainfed corn consumes

[1]Producing one bushel of corn in any of the major corn-producing regions consumes between 19 and 865 gallons of water, on average, based on an evaluation by the Argonne National Laboratory. The amount of water needed depends on precipitation, atmospheric demand (which is a result of solar radiation, wind, humidity, and temperature) and plant growth stage. Greater amounts of water are needed during peak growth stages (July and August for the U.S. Corn Belt), when rainfall may be insufficient to satisfy the needs of a rapidly growing plant. Good soil quality can help keep a plant from stress during dry spells by its moisture-holding capacity.

significantly less water estimated at 0.15 to 0.35 gallons of water per mile traveled.[2] In contrast, the production, transport, and use of gasoline consumes between 3.4 and 6.6 gallons of water per gallon of gasoline, and consumes between 0.07 and 0.14 gallons of water per mile traveled.[3,4]

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

Region	**Corn Belt USDA Region 5** (Iowa, Indiana, Illinois, Ohio, Missouri)	**Great Lakes USDA Region 6** (Minnesota, Wisconsin, Michigan)	**Northern Plains USDA Region 7** (North Dakota, South Dakota, Nebraska, Kansas)
Corn irrigation, groundwater (gallons of water/gallon of ethanol)	6.7	10.7	281.2
Corn irrigation, surface water (gallons of water/gallon of ethanol)	0.4	3.2	39.4
Corn ethanol conversion process (gallons of water/gallon of ethanol)	3.0	3.0	3.0
Total water consumption (gallons of water/gallon of ethanol)	**10.0**	**16.8**	**323.6**

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

Note: The primary corn production regions are in the upper and lower Midwest and include 12 states classified as USDA farm production regions 5, 6, and 7. Together these regions accounted for 89 percent of corn production in 2007 and 2008, and 95 percent of ethanol production in the United States in 2006. The Argonne National Laboratory study estimated the water consumed in corn ethanol production in each of the major ethanol producing regions considering water consumed in both corn cultivation and conversion processing steps. Estimates were based on average consumption of 3.0 gallons of water per gallon of corn ethanol produced in a corn dry mill, average consumptive use of irrigation water for corn in major corn producing regions, and dry-mill yield of 2.7 gallons of ethanol per bushel. In evaluating corn cultivation, the water consumed is based on total amount of irrigation water used for corn production and total corn production for each region. In addition, based on U.S. Geological Survey research the calculation assumes that 30 percent of water recharges local surface and groundwater, and the remaining 70 percent of the water is consumed by evapotranspiration (water lost through evaporation from the soil and plants) and other factors.

[2] King and Webber, "Water Intensity of Transportation," *Environmental Science and Technology* (2008), vol. 42, no. 21, pp. 7866-7872.

[3] Comparatively, biodiesel shows potential benefits over petroleum-based diesel if nonirrigated soy is used. Irrigated soy consumes 0.6 to 24 gallons of water per mile traveled, while rainfed soy consumes .01 to .02 gallons of water traveled per mile traveled. Comparatively, petroleum-based diesel consumes 0.05 to 0.11 gallons. (King and Webber, "Water Intensity of Transportation," *Environmental Science and Technology* (2008), vol. 42, no. 21, pp. 7866-7872.)

[4] See Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, "Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline" (Argonne, Ill.: Jan. 2009).

Estimates of water consumed during the conversion process assumes use of a dry-mill ethanol production facility and considers water lost through evaporation and blowdown (periodic discharge of water used to remove salts and other solids to minimize corrosion, etc.) from the cooling tower and boiler, evaporation from the dryer, as well as water contained in the ethanol and dried distiller's grain co-products, among other factors.

The effects of corn production for ethanol on water supplies are likely to be greatest in water constrained regions of the United States where corn requires irrigation. For example, some of the largest increases in corn acres (1.1 million acres) are projected for the Northern Plains region, where, on average, 40 percent of the corn currently grown is irrigated. (See table 2.) Parts of this region draw heavily on the High Plains (Ogallala) aquifer. The Ogallala aquifer is already a stressed aquifer with known water withdrawals that are greater than the natural recharge that occurs through precipitation. A 1997 U.S. Geological Survey (USGS) report found water levels in the Ogallala aquifer have dropped more than 100 feet in places where agricultural crop irrigation was most intense.[5]

Table 2: Projected Growth in Corn Acreages Related to Increased Corn Ethanol Production of 15 Billion Gallons per Year

(In millions of acres)

	2016 USDA baseline estimate[a]			2016 federal mandate			
U.S. region	**Total cropland**	**Corn acres**	**Continuous corn acres[b]**	**Total cropland**	**Corn acres**	**Continuous corn acres[b]**	**Increase in corn acres**
Appalachian	18.3	4.8	1.2	18.6	5.0	1.3	0.2
Corn Belt	101.0	44.6	8.8	102.6	45.9	9.4	1.3
Delta	15.9	0.7	0.3	16.4	0.8	0.3	0.1
Lake States	40.0	14.5	4.3	40.5	15.1	4.8	0.6
Mountain	20.8	1.2	1.2	20.3	1.3	1.3	0.1
Northern Plains	63.1	16.5	8.2	64.7	17.6	8.6	1.1
Northeast	15.1	3.9	2.0	15.2	4.1	2.0	0.2
Pacific	7.7	0.3	0	7.7	0.4	0	0.1
Southeast	7.5	2.3	1.1	7.6	2.4	1.1	0.1
Southern Plains	27.6	1.1	0.5	27.7	1.2	0.5	0.1
Total	**317.0**	**90.0**	**27.6**	**321.4**	**93.7**	**29.3**	**3.7**

Source: Economic Research Service, USDA.

[a]The 2007 USDA baseline projections for 2016 assumes ethanol production will mature to 12 billion gallons of ethanol per year. The 2016 federal mandate scenario assumed 15 billion gallons of corn-based ethanol per year under the RFS.

[5]USGS, 1997, Groundwater Atlas of the United States: Kansas, Missouri, and Nebraska, HA 730-D.

[b]Acres of cropland planted to corn on a continuous basis, rather than rotating between corn and the planting of other crops, such as soybeans.

The shift to cultivate certain cellulosic feedstocks—such as woody biomass and switchgrass—may require less water. However, effects on water supplies are largely uncertain and will depend on the type of feedstock and where it is grown. For example, agricultural crop residues, such as corn stover, do not require additional water, since they are co-products of already cultivated crops.[6] For cellulosic feedstocks, as with corn or any other crop, the effects on water supply may be minimal if they are planted where they can be grown primarily with rainwater. However, if the crop is irrigated, the implications on water supply could still be significant. While some experts assume that perennial cellulosic feedstocks will be rainfed, other experts and EPA officials pointed out that to achieve maximum yields for cellulosic crops, farmers may need to irrigate. In addition, woody biomass that is planted in such a way to allow for quick growth and maximum production may be more water intensive than some perennial grasses, although there may be opportunities to irrigate these crops with wastewater or saline water sources that would be unsuitable for food crops.[7]

Increased Corn Cultivation for Biofuels Is Likely to Impair Water Quality, but Cultivation of Certain Cellulosic Feedstocks May Have Less of an Effect

Several experts we spoke with identified water quality impairments from the cultivation of corn as among the most significant potential environmental effects of increased corn starch ethanol production. In contrast, the cultivation of certain cellulosic feedstocks may have less of an effect on water quality, although the extent of the effect will depend on a number of factors, including the types of feedstocks grown, where they are grown, and the practices employed to cultivate and harvest them.

Water Quality Effects of Increased Corn Production

Increased fertilizer use can compromise surface and ground water quality. Fertilizer runoff from additional corn cultivation for biofuels production is likely to impair streams and local water bodies, although agricultural conservation practices could mitigate some of these effects. For example, corn requires substantial inputs, including higher

[6]Crop residues are materials left in the field after the crop has been harvested. For example, corn stover is the unharvested portions of the corn plant, including stalks, leaves, and cobs.

[7]According to EPA officials, the long-term impacts of irrigating with wastewater or saline water sources are currently unknown and may be detrimental. Additional controls on runoff will need to be added to protect water quality.

applications of fertilizers as compared to soybeans and other potential biofuel feedstocks.[8] Fertilizer runoff containing nitrogen and phosphorus can lead to overenrichment and excessive growth of algae in surface waters. In some lakes, this has resulted in potentially harmful algal blooms, decreased water clarity, and hypoxia, a condition of reduced oxygen, which impairs aquatic life.[9] Similarly, in marine waters, excessive algae growth can create a hypoxic or dead zone, a region that cannot support fish and other organisms, which require oxygen for survival. The number of reported dead zones around the world increased over the past decade to more than 400.[10] Many of them are along the Gulf of Mexico and the Atlantic Coast, areas that receive drainage from agricultural and urban landscapes, including a large portion of the Corn Belt, where many of the existing and planned ethanol production facilities are located. A 2007 USGS model estimated that 52 percent of the nitrogen and 25 percent of the phosphorus entering the Gulf system is from corn and soybean cultivation in the Mississippi River basin.[11]

Recent studies estimate that nitrogen runoff will increase by 2.5 percent per year in water bodies across the United States and by more than 10 percent per year in the Mississippi River basin if additional corn is grown to meet the up to 15 billion gallons per year of corn starch ethanol allowed by EISA for 2015 through 2022.[12] In addition, an analysis in EPA's May 2009

[8]Corn requires significantly higher applications of nitrogen as compared with soybeans, which are legumes that obtain their own nitrogen from the atmosphere. For example, in crop year 2005, the average annual applications for corn were 138 pounds of nitrogen per acre and 58 pounds of phosphorous per acre for 96 percent and 81 percent of planted acreage in the United States, respectively. In comparison, in crop year 2004, soybeans required, on average, 28 pounds of nitrogen per acre and 69 pounds of phosphorous per acre for 21 percent and 26 percent of total planted acres respectively [NASS 2006, 2005]

[9]The algae themselves do not reduce oxygen; instead, when the algae die, bacteria deplete oxygen during the decomposition process.

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

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

[12]Malcom, S. and M. Aillery. "Growing Crops for Biofuels Has Spillover Effects." *Amber Waves*, USDA Economic Research Service, vol. 7, issue 1, March 2009, pp. 10-15; and Donner, S. and C. Kucharik. "Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River." *Proceedings of the National Academy of Sciences of the United States*, vol. 105, no. 11, 2008, pp. 4513–4518.

notice of proposed rulemaking for the RFS also projected an increase in nitrogen, phosphorus and sediment in the Upper Mississippi River Basin as a result of increased corn production for biofuels. Further, in the Upper Mississippi River basin, surface or subsurface drainage—via ditches or subsurface pipes that move water from wet soils to surface water quickly so crops can be planted—is common and may increase nutrient runoff, further degrading water quality, according to some experts and EPA officials we spoke with. In addition, livestock feeding largely on dried distiller's grains, a co-product of corn starch ethanol production, may produce manure that is especially high in phosphorus, which could also increase nutrient runoff, according to other experts and EPA's proposed rulemaking. Although EPA projects that nutrient runoff as a result of increased corn production may decrease over time with improved crop yields per acre, the nutrient load will be higher than the baseline measurement developed in 2005.

Similarly, increased corn production for ethanol also may increase the contamination of groundwater by nitrates, which are also found in fertilizers. The areas most vulnerable to nitrate contamination are those with high fertilizer use that also depend on irrigation, have permeable soils, and have shallow groundwater. A 2006 USGS study predicted moderate to severe nitrate contamination of shallow groundwater in the High Plains and Northern Midwest, where increased corn cultivation for ethanol is anticipated.[13] This study also predicted elevated nitrate levels of deeper water supplies used for drinking water in these same areas. EPA has determined that levels of nitrate exceeding 10 milligrams per liter in drinking water have an anticipated adverse effect on public health.[14] Some groundwater aquifers in the Corn Belt already have elevated levels of nitrate in groundwater and increased corn production may add to the problem. For example, one study noted that water quality advisories are already common in Columbus, Ohio for elevated levels of nitrates in local waters.

[13]Nolan, B. and K. Hitt. "Vulnerability of Shallow Groundwater and Drinking-Water Wells to Nitrate in the United States." *Environmental Science & Technology*, vol. 40, no. 24, 2006, pp. 7834-7840.

[14]EPA's maximum contaminant level goals for drinking water are set at the level at which no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety. The maximum contaminant level goal for total nitrate and nitrogen is 10 milligrams per liter. This does not mean that less than 10 milligrams per liter poses no risk. Recent studies also indicate levels of nitrate as low as 2.5 milligrams per liter may be associated with several types of cancer.

Increased pesticide use can compromise surface and ground water quality. Increased use of pesticides—including insecticides and herbicides—related to increased corn production will likely affect surface and ground water quality. For example, a 10-year nationwide study by USGS detected pesticides in 97 percent of streams in agricultural and urban watersheds.[15] As would be expected, the highest concentrations of pesticides have been found in the areas of highest use. For instance, application rates of atrazine, a commonly used pesticide for corn production, are highest in the Corn Belt, and atrazine was also the most widely detected pesticide in watersheds in this region, according to a USGS nationwide study. This adversely affected aquatic plants and invertebrates in some of the streams, according to the study, since organisms are vulnerable to short-term exposure to relatively small amounts of certain pesticides. Similarly, increased pesticide use for the cultivation of corn for ethanol production can impair groundwater supplies. For example, the USGS study found pesticides in 61 percent of shallow wells sampled in agricultural areas. Once groundwater is contaminated, it is difficult to clean up.

Increased cultivation of feedstocks for biofuels can increase soil erosion. Increased demand for corn for ethanol could also create incentives for farmers to abandon agricultural conservation practices that would otherwise reduce soil erosion, according to many experts we spoke to. Soil erosion reduces fertility by removing nutrient-rich topsoil. It also contributes to sedimentation, which fills channels and deep areas of lakes, streams, and rivers, affecting aquatic life and recreation. Sediment can also carry contaminants, such as pesticides and fertilizers, to these water bodies. A USDA Economic Research Service study estimates a 2.1 percent increase in rainfall-driven erosion related to increased corn production, with higher erosion effects expected in the Northern Plains, Great Lake States, and Delta regions.[16] Furthermore, the discharge of sediment into streams is a top water quality problem nationwide, as well as in the Mississippi basin, where a large fraction of the increased corn production is anticipated. Moreover, to take advantage of higher corn prices, farmers may shift to planting corn on the same land every year instead of rotating

[15] Gilliom, and others. “The Quality of Our Nation’s Waters—Pesticides in the Nation’s Streams and Ground Water, 1992-2001.” *U.S. Geological Survey Circular 1291*, 2006, p. 172.

[16] Malcom, S. and M. Aillery. “Growing Crops for Biofuels has Spillover Effects.” *Amber Waves*, USDA Economic Research Service, vol. 7, issue 1, March 2009, pp. 10-15.

to other crops such as soybeans—a practice known as continuous corn cultivation. Crop rotation is a common agricultural conservation practice that reduces erosion, helps replenish nutrients in the soil, and helps control pests, reducing the need for fertilizer and pesticides. Based on Biomass Research and Development Board data, an estimated 1.7 million additional acres of continuous corn production is projected for 2016 to meet the up to 15 billion gallons of corn starch ethanol allowed to be included in the Renewable Fuel Standard (see table 2). USDA data indicate that conservation tillage practices, such as no-till, can help reduce soil erosion and sediment runoff.

Expansion of corn and soybean production to marginal lands can further affect water quality. Delivery of sediments, nutrients, and pesticides to water bodies may increase further if production of corn and soybeans expands to marginal lands and lands highly susceptible to erosion. Increased demand for biofuel feedstocks creates incentives for farmers to place such lands back into production. Marginal lands generally have lower productivity soils and are vulnerable to wind and water erosion. Moving these lands back into crop production may require more nutrient and pesticide inputs and increased tillage as compared with more productive lands, potentially leading to further water quality impairments. Increased sediment runoff is also anticipated with increased production of corn and soybeans, especially on marginal and highly erodible lands. Millions of acres of such land are currently enrolled in the Conservation Reserve Program (CRP), which provides annual rental payments and cost-share assistance to producers who contractually agree to retire highly erodible, environmentally sensitive cropland from agricultural purposes. As discussed in chapter 2, farmers are generally required to plant or maintain vegetative covers (such as native grasses) on CRP land, which provides a range of environmental benefits, including improved water quality, reduced erosion, and preserved soil productivity.

Agricultural conservation practices—such as no-till, reduced till, crop rotation, rotation cover crops, and riparian buffer zones—can reduce nutrient and pesticide runoff as well as erosion by retaining additional moisture and nutrients in the soil and disturbing the land less. Additional techniques are also available to reduce the effects of fertilizers, including precision agriculture, controlled-release fertilizers, and practices that match nitrogen fertilizer applications to a crop's nitrogen demand. However, EPA officials noted that despite implementation of these practices to varying degrees, nutrients from agriculture are already a major source of water quality impairment throughout the country, especially in the Corn Belt. Furthermore, a number of irrigation techniques and technologies are available to conserve water and thus reduce runoff. These include subsurface drip irrigation systems, real-time soil moisture and weather monitoring, rainfall harvesting, and use of reclaimed water. See table 3 for a description of some of the agricultural conservation practices that can reduce degradation of surface and ground waters from the increase in cultivation of feedstock for biofuels production.

Table 3: Sample of Agricultural Conservation Practices Available to Reduce the Environmental Effects of Feedstock Cultivation for Biofuels

Agricultural conservation practice	Description	Environmental benefits
Soil erosion prevention		
Crop residue management	Any tillage method that leaves a portion of the previous crop residues (unharvested portions of the crop) on the soil surface.	• Reduces soil erosion caused by tillage and exposure of bare soil to wind and water • Reduces water lost to evaporation • Improves soil quality • Reduces sediment and fertilizer runoff
No-till	Method that leaves soil and crop residue undisturbed except for the crop row where the seed is placed in the ground.	• Reduces soil erosion caused by tillage and exposure of bare soil to wind and water • Reduces water lost to evaporation • Improves soil quality by improving soil organic matter • Reduces sediment and fertilizer runoff
Cover crops	A close-growing crop that temporarily protects the soil during the interim period before the next crop is established.	• Reduces erosion • Reduces nitrate leaching • Integrates crops that store nitrogen from the atmosphere (such as soy), replaces the nitrogen that corn and other grains remove from the soil • Reduces pesticide use by naturally breaking the cycle of weeds, insects, and diseases • Improves soil quality by improving soil organic matter
Nutrient pollution reduction		
Crop rotation	Changing the crops grown in a field, usually in a planned sequence. For example, crops grown in the following sequence corn-soy-corn.	• Integrates crops that obtain nitrogen from the atmosphere (such as soy), replaces the nitrogen that corn and other grains remove from the soil • Reduces pesticide use by naturally breaking the cycle of weeds, insects, and diseases

Agricultural conservation practice	Description	Environmental benefits
Nutrient management	Use of nutrients to match the rate, timing, form, and application method of fertilizer to crop needs.	• Reduces nutrient runoff and leaching
Subsurface fertilizer application	Injection of fertilizer below the soil surface.	• Reduces runoff and gaseous emission from nutrients
Controlled-release fertilizers	Use of fertilizers with water-insoluble coatings that can prevent water-soluble nitrogen from dissolving. Increases the efficiency of the way nutrients are supplied to and are taken up by the plant, regardless of the crop.	• Reduces nutrient runoff and leaching
Controlled drainage	Water control structures, such as a flashboard riser, installed in the drainage outlet allow water level to be raised or lower as needed.	• Minimizes transport of nutrients to surface waters
Irrigation techniques		
Subsurface drip irrigation systems	Irrigation systems buried directly beneath the crop apply water directly to the root zone.	• Minimizes water lost to evaporation and runoff
Reclaimed water use	Water recovered from domestic, municipal, and industrial wastewater treatment plants that has been treated to standards that allow safe reuse for irrigation.	• Reduces demand on surface and ground waters
Multiple benefits		
Wetland restoration	Restoring a previously drained wetland by filling ditches or removing or breaking tile drains.	• Reduces flooding downstream • Filters sediment, nutrients, and chemicals • Provides habitat for wetland plants, amphibians, and birds
Riparian buffer zones	Planting of strips or small areas of land along waterways in permanent vegetation that help control pollutants and promote other environmental benefits.	• Traps sediment • Filters nutrients • Provides habitat and corridors for fish and wildlife
Precision agriculture	A system of management of site-specific inputs (i.e., fertilizer, pesticides) on a site-specific basis such as land preparation for planting, seed, fertilizers and nutrients, and pest control. Precision agriculture may be able to maximize farm production efficiency while minimizing environmental effects. Key technological tools used in this approach include global positioning systems, geographic information systems, real-time soil testing, real-time weather information, etc.	• Reduces nutrient runoff and leaching • Reduces erosion • Reduces pesticide use

Source: GAO.

Water Quality Effects of a Shift to Cellulosic Biofuels

Cultivation of some cellulosic feedstocks can provide certain benefits, including stabilizing soils, reducing soil erosion and nutrient runoff, and increasing nutrient filtration, according to some experts that we spoke to. For example, research indicates that perennial cellulosic feedstocks, such as switchgrass and other native prairie grasses, offer a range of water quality benefits related to their ability to cycle nitrogen more efficiently, sequester carbon, and protect soil from wind and water erosion. The perennial nature of these feedstocks can also reduce the need for most chemical inputs and tillage after crops are established, which can lessen the need for fertilizer application and reduce soil erosion and sedimentation. In addition, use of diverse perennial species can minimize the need for pesticides by promoting greater diversity and an abundance of natural enemies for agricultural pests.[17] Finally, the presence of cellulosic feedstocks across an agricultural landscape can help reduce nutrient and chemical runoff from adjacent farmlands, and provide riparian strips and windbreaks that minimize erosion.

The type, location, and cultivation methods used to grow cellulosic feedstocks will influence the extent to which they can improve water quality. Since potential cellulosic feedstocks have not been grown commercially to date, there is little data on the nutrient and pesticide input needs of these crops. In addition, according to USDA officials, nutrient inputs are likely to be greater on marginal lands with poor soil quality. Furthermore, use of some cellulosic feedstocks, specifically agricultural crop residues, could negatively affect water quality, depending on the agricultural practices employed. Agricultural crop residues—such as corn stover—offer a large and readily available biomass resource for production of cellulosic ethanol. It is a common agricultural conservation practice to leave residue—the portion of the crop which is not harvested—on the field to help protect the soil from wind and water erosion and replenish the soil with nutrients and carbon, among other benefits. If not enough residue is retained on farm fields, there could be increased sediment loadings to waterways. Excess residue removal may also increase the need for fertilizer, potentially leading to further water quality degradation, according to some experts. Further, an analysis conducted for EPA's proposed rulemaking identified the need for different conservation systems and conservation practice standards to produce cellulosic feedstocks in a sustainable manner.

[17]According to USDA officials, perennial grasses will probably have lower input requirements than corn, but incentives to increase yields will narrow any gap. Compared to other crops, the difference in input requirements ultimately may be quite small.

Biofuels Production Can Affect Soil Quality and Productivity

Promotion of biofuel production in a way that maintains soil quality over the long term is a critical environmental consideration about which several experts have expressed concern. Soil is a central, fundamental resource for all crops, including biofuel feedstock production, and ultimately determines crop productivity. Soil quality is directly affected by soil organic matter (which includes decomposed crop residue and living microorganisms), soil structure and compaction, and soil microbial communities. In particular, soil carbon, a central component of soil organic matter, supports nutrient cycling, improves soil structure, enhances water exchange and aeration, and sustains microbial life in the soil.

The effects of biofuel feedstocks cultivation on soil quality will depend on which feedstock is planted and how it is cultivated. For example, planting perennial feedstocks, such as switchgrass, can help store soil carbon, stabilize soils, and reduce erosion, largely because of the deep root systems of many perennial plants. In addition, some cultivation methods can help maintain and potentially improve soil quality. Specifically, use of conservation tillage practices, such as no-till or planting cover crops, can protect soil from erosion and help restore, maintain, or build soil organic matter.

Overuse of agricultural residues as feedstocks for biofuel production would also likely have adverse effects on soil quality, according to several experts we interviewed. Considerable uncertainty exists regarding how much, if any, residue can be removed for biofuels production while maintaining soil and water quality. In addition to protecting the soil from wind and water erosion, crop residues left on the field help maintain soil quality and replenish the soil with carbon and nutrients. If too much residue is removed for use as a feedstock for biofuels, soil productivity may be compromised, according to these experts. USDA, DOE, and some academic researchers are attempting to develop new projections on how much residue can be removed without compromising soil quality, but sufficient data may not be available to inform their efforts, and it may take several years to make such projections. In the interim, USDA and DOE are developing some tools to help estimate safe residue removal rates, but efforts are still under way. When completed, these residue removal assessment tools will consider the broad variance of local conditions such as soil type, climate, and management practices.

Habitat and Biodiversity May Be Compromised with Increased Biofuel Feedstocks Cultivation

The increased cultivation of corn and soy-based feedstocks to meet increases in corn and soy-based biofuels production could have significant effects on wildlife habitat and biodiversity, according to experts we spoke with. As mentioned above, a portion of the land that may be cultivated for additional crop production is expected to come from environmentally sensitive lands currently enrolled in conservation programs, such as the CRP. According to experts we spoke with, these lands provide contiguous habitat available for native wildlife in many parts of the country. Moving these lands back into production could lead to effects on available habitat, and subsequently, biodiversity. In addition, the effects of more intensively farmed monocultures—production or growth of a single crop—over a wide area have been shown to lead to a decline in biodiversity and biodiversity-based benefits, such as pest suppression. For example, a recent study found that increased corn plantings can result in lower landscape diversity, altering the supply of natural predators to the soybean aphid, a major food crop pest.[18]

According to some experts that we spoke to, cellulosic biofuel feedstocks that require few inputs and include a diverse mix of native and perennial species could promote greater biodiversity than input-intensive corn and soybean monocultures. Furthermore, some research suggests that cellulosic feedstocks may be grown on marginal lands that have been removed from agricultural production with fewer environmental effects. For example, a 2006 study—in which diverse native prairie grass species were grown on a site with degraded soils similar to lands often set aside in conservation programs—demonstrated that such perennial grasses could generate promising feedstock yields with low nutrient and irrigation inputs.[19] According to some experts we spoke to, crop choice and cultivation methods will influence the extent of biodiversity benefits of cultivating cellulosic biofuel crops. For example, the cultivation of monocultures of cellulosic biofuel feedstocks, such as switchgrass, may be economically favorable to the cultivation of diverse native prairie grasses. However, according to some experts, these kinds of monocultures may not provide the same biodiversity benefits, and the characteristics that make

[18] Landis, D., M. Gardiner, W. van der Werf, and S. Swinton. "Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes." *Proceedings of the National Academy of Sciences of the United States of America*, vol. 105, no. 51, 2008, pp. 20552-20557.

[19] Tillman D., J. Hill, and C. Lehman. "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science*, vol. 314, issue 5805, 2006, pp. 1598-1600.

the plant good for crop production, such as being fast growing, also increase its potential to invade natural environments. For instance, a recent study found that some monocultures of cellulosic feedstocks may be invasive in certain regions of the United States and have the potential to affect plant biodiversity in these regions.[20, 21] In addition, some USDA officials said that cultivation of new feedstock across large areas within the landscape will likely create new disease and insect problems for which there are limited control strategies.

The Process of Converting Feedstocks into Biofuels Has Environmental Consequences, but the Effects Vary

The processing of feedstocks into biofuels at biorefineries may have significant effects on water supplies in some parts of the United States. However, according to officials, existing water quality regulations over effluents discharged by these facilities are expected to reduce the effects of pollutants. These facilities may also affect air quality, but the effects will depend on location, feedstock, and the pollution control technologies deployed.

Effects on Water Supply from Biorefineries Can Be Significant in Some Locations

Although research indicates that the amount of water consumed in the corn ethanol conversion process has declined over time and is small compared to the amount of water consumed to grow irrigated corn, it may have significant effects on local water supplies. Specifically, from 1998 through 2007, water consumption at corn ethanol biorefineries dropped 48 percent—from 5.8 to 3.0 gallons of water per gallon of ethanol—with improved equipment and energy efficient design, according to a 2009 Argonne National Laboratory study.[22] Nevertheless, at this rate, the current average water needs for a single 100-million-gallon-per-year corn ethanol plant is almost the same as the annual water needs for a city with

[20]Barney, J.N. and J.M. DiTomaso. "Nonnative Species and Bioenergy: Are We Cultivating the Next Invader?" *Bioscience*, vol. 58, no. 1, 2008, pp. 64-70.

[21]An invasive species is a nonnative species whose introduction does or is likely to cause economic or environmental harm or harm to human, animal, or plant health. For example, an invasive plant may outcompete and displace native grasses and broadleaf plants that serve as a primary source of forage for animals.

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

approximately 8,200 people—approximately 300 million gallons, according to an EPA estimate.[23] In addition, a recent report by the National Research Council found that siting of some ethanol plants is occurring where water resources are already under duress.[24] As figure 4 shows, many existing and planned ethanol facilities that require 0.1 to 1.0 million gallons of water per day are located on the High Plains aquifer, where current water withdrawals are much greater than the aquifer's recharge rates (about 0.02 to 0.05 foot per year in most areas of the northern parts of the aquifer which include parts of Nebraska, Kansas, South Dakota, Colorado and Wyoming). [25] Furthermore, ethanol conversion requires high-quality water, which can include groundwater, surface water, or municipal water supply sources.[26] Because rural communities frequently rely on groundwater aquifers, which may take lifetimes to recharge, for their drinking water supplies, if several ethanol plants are built near one another or draw from the same aquifer, they could reduce the drinking water available to the surrounding communities. Finally, according to EPA, most estimates of water consumption in ethanol production do not consider water discharged as a result of pre-treating water prior to use in the conversion process.

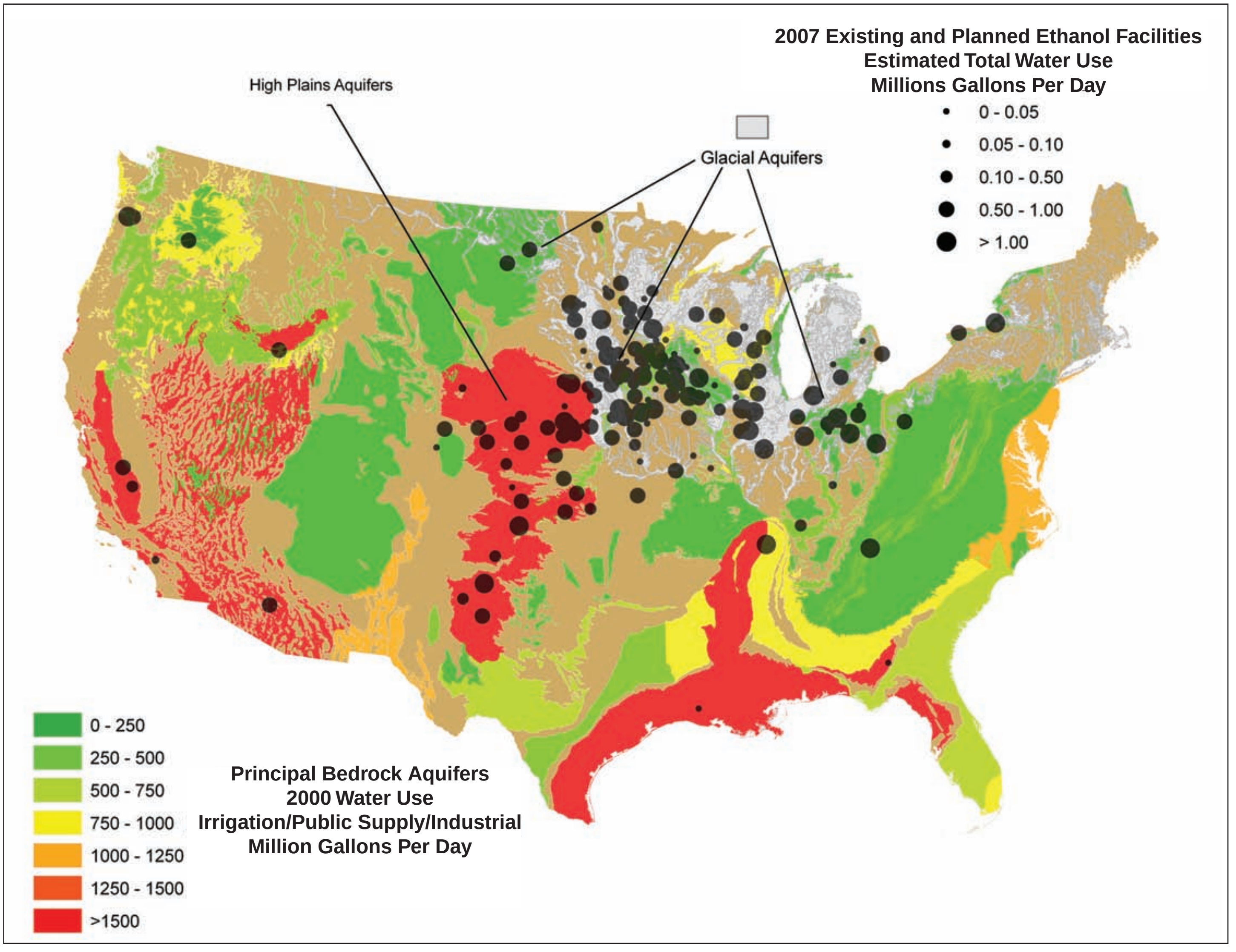
[23]Average water consumption in the United States is 100 gallons per day per person, according to EPA.

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

[25]McMahon, P.B., J.K. Böhlke, and C.P. Carney. Vertical Gradients in Water Chemistry and Age in the Northern High Plains Aquifer, Nebraska, 2003: U.S. Geological Survey Scientific Investigations Report 2006–5294, 2007.

[26]Among the problems with using low-quality water in the biofuel conversion process, boilers lose heat capacity and may be spoiled if using water with high total dissolved solids.

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



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

For conversion of cellulosic feedstock, the amount of water consumed will depend on the process and on technological advancements that improve the efficiency with which water is used. For example, according to a 2009 Argonne National Laboratory study, water consumed in the biochemical conversion process for cellulosic feedstock using advanced technology is estimated at 5.9 gallons of water per gallon of ethanol, while thermochemical gasification processes for cellulosic feedstock may only require 1.9 gallons of water per gallon of ethanol or other fuel.[27] According to the study, water required in the conversion process for cellulosic feedstock may also be reduced as technology improves, as has occurred in corn ethanol biorefineries.

Water Pollutants Discharged by Biorefineries Are Regulated under the Existing Permitting Process

While effluent from ethanol and biodiesel refineries may contain pollutants that could negatively affect water quality, discharges of these effluents are regulated under the requirements of the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) program. Effluents from refineries can be applied to land, treated on site, discharged to local wastewater treatment facilities, or discharged to water bodies. Under the act, refineries that discharge pollutants into federally regulated waters are required to obtain a federal NPDES permit from EPA or a state agency authorized by EPA to implement the NPDES program. These permits generally allow a point source, such as a refinery, to discharge specified pollutants into federally regulated waters under specific limits and conditions. According to EPA officials, the greatest potential pollutants are discharges of contaminated water from the reverse osmosis treatment used in ethanol refineries and the glycerin that is used in biodiesel refineries.[28] According to EPA officials and state officials we spoke with, the NPDES permitting process is generally being effectively applied to discharges from refineries.[29] For ethanol refineries, these permits cover blowdown (water containing salts built up in cooling towers and boilers), as well as discharges from the reverse osmosis process. The concentrated salts in discharges to streams and lakes from reverse osmosis are an area of concern due to their potential aquatic toxicity and other water quality effects, according to EPA officials. In addition, at small

[27]Thermochemical gasification is a process where the entire biomass input is converted in a syngas (an intermediate mixture of carbon monoxide and hydrogen) that can then be refined into a number of biofuel products, including ethanol, diesel, methane, or butanol, among other fuels.

[28]Reverse osmosis is a filtration process used to purify fresh water by, for example, removing the salts from it. This process is used to treat the water supply for the ethanol plant.

[29]EPA Region 7 has developed guidance manuals for the construction and operation of ethanol and biodiesel facilities: "Environmental Laws Applicable to Construction and Operation of Ethanol Plants; 2007" and "Environmental Laws Applicable to Construction and Operation of Biodiesel Production Facilities, 2008." These guidance manuals can be viewed at http://www.epa.gov/sustainability/energy.htm.

biodiesel refineries, biological oxygen demand from glycerin can be a problem in effluent released into local municipal wastewater facilities because it may disrupt the microbial processes used in wastewater treatment, according to EPA officials.[30] However, according to EPA, in larger biorefineries, glycerin is less of a concern because it often is extracted from the effluent and refined for use in other products, including cosmetics and animal feed. In the future, it is likely that new technologies will make recovery of glycerin economically feasible in smaller facilities, according to USDA.

Air Quality Effects of Biorefineries Will Depend on the Location and Size of the Facility and the Feedstock Used

Certain air pollutants—known as criteria pollutants under the Clean Air Act—are released into the air during most industrial manufacturing and refining processes, including the conversion of feedstocks into ethanol. These pollutants, which pose risks to human health and welfare, include particulate matter, nitrogen dioxide, carbon monoxide, ozone, lead, and sulfur dioxide.[31] In addition, ethanol refineries can emit volatile organic compounds, which are a precursor to ozone, a criteria pollutant. (See table 4 for details on the public health and environmental effects of common pollutants that can be released by ethanol refineries.) In addition to criteria pollutants, ethanol refineries emit hazardous air pollutants, such as acetaldehyde, which are known or suspected to cause serious health effects, including cancer, or adverse environmental effects such as damaging crops or trees.

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

[31]Under the Clean Air Act, EPA has established, and regularly reviews, national ambient air quality standards (NAAQS) for six air pollutants also known as “criteria” pollutants: ozone, particulate matter (PM2.5 and PM10), lead, nitrogen dioxide (NO2), carbon monoxide (CO), and sulfur dioxide (SO2). Additionally, EPA monitors volatile organic compounds, which are known ozone precursors. The volatile organic compounds emitted from ethanol plants might include, but are not limited to, acetaldehyde, acrolein, formaldehyde, and methanol. Some volatile organic compounds are hazardous air pollutants, such as acetaldehyde, and are regulated as such under section 112 of the Clean Air Act.

Table 4: Potential Air Pollutants Associated with Ethanol Refineries and Their Related Health and Environmental Effects

Pollutant	Health effects	Environmental effects
Particulate matter	Aggravation of respiratory and cardiovascular disease, decreased lung function and increased respiratory symptoms, and premature death.	Impairment of visibility, effects on climate, and damage and/or discoloration of structures and property.
Sulfur dioxide	Aggravation of asthma and increased respiratory symptoms. Contributes to particle formation with associated health effects.	Contributes to the acidification of soil and surface water and mercury methylation in wetland areas. Contributes to particle formation with associated environmental effects. Causes injury to plants and suppresses crop yield.
Oxides of nitrogen (NOx)	Aggravation of respiratory disease and increased susceptibility to respiratory infections. Contributes to ozone with associated health effects.	Contributes to the acidification and nutrient enrichment (eutrophication, nitrogen saturation) of soil and surface water. Contributes to ozone with associated environmental effects. Can adversely affect plants and crop yields.
Carbon monoxide (CO)	Reduces the ability of blood to carry oxygen to body tissues including vital organs. Aggravation of cardiovascular disease.	None known.
Volatile organic compounds	Cancer (from some toxic air pollutants) and other serious health problems. Contributes to ozone formation with associated health effects.	Contributes to ozone formation with associated environmental effects.
Ozone (O_3)[a]	Aggravation of respiratory and cardiovascular disease, decreased lung function and increased respiratory symptoms, increased susceptibility to respiratory infection, and premature death.	Damage to vegetation such as effects on tree growth and reduced crop yields.

Source: EPA.

[a]Ozone is a secondary pollutant formed by a chemical reaction of volatile organic compounds and NOx in the presence of sunlight.

Biorefineries that emit more than threshold quantities of criteria and hazardous air pollutants are subject to Clear Air Act permitting requirements. If a biorefinery's emissions meet or exceed specific statutory or regulatory thresholds prior to its construction or any subsequent major modifications, the proposed facility or modification undergoes a New Source Review.[32] Under New Source Review, permitting authorities review a proposed facility or modification to ensure that it will operate within emissions limits and utilize the requisite pollution control technologies. In addition, these biorefineries must obtain an operating permit and must comply with any applicable national emission standards

[32]A major modification is a physical or operational change that would result in a significant net increase in emissions.

for hazardous air pollutants.[33] According to EPA regional officials, emissions from many of the existing and planned facilities in their region do not meet or exceed applicable thresholds, and are not subject to a New Source Review.[34,35] These EPA officials and some state officials said they have experienced relatively few permit compliance issues with biorefineries once they are operational; however, these officials said the number of new permit applications has been small, in part due to the recent economic downturn.

According to some experts we spoke with, as biofuels production increases, the effects on air quality from conversion processes will depend on the location of the biorefinery and the feedstock used. For example, according to some experts, many facilities are currently located in close proximity to where biofuel feedstocks are cultivated—in rural areas that do not traditionally have problems with ambient air quality. However, some state and EPA officials expressed concern that with increased production and the availability of a more diverse group of biofuel feedstocks in a variety of geographic locations, future biorefineries may be located closer to urban areas that already have impaired ambient air quality, thereby exacerbating existing problems. In addition, according to some experts and state officials we spoke with, when looking at the total air emissions from biofuels it is important to also consider the additional emissions that may be generated by the transport of feedstocks to the biorefinery as well as the transport of fuel from the facility for blending with gasoline prior to distribution.

In addition, EPA regional officials expressed concern regarding elevated ambient levels of some hazardous air pollutants that may result from increased ethanol production, especially in areas with high concentrations of ethanol refineries. For example, acetaldehyde, a hazardous air

[33]A Title V operating permit contains all existing federal Clean Air Act requirements, including reporting and monitoring requirements, applicable to the source in one document. These operating permits contain any applicable new source performance standards and national emission standards for hazardous air pollutants.

[34]EPA Region 7 serves the states of Iowa, Kansas, Missouri, and Nebraska. About 44 percent of existing U.S. ethanol production capacity is located in these states as of March 2009.

[35]According to EPA, the standards for biorefineries are less stringent given their size than for larger petroleum facilities on a per unit of production basis, and the result is that as more and more biorefineries are built to displace gasoline, there will be a steady increase in nationwide emissions due to biofuel production.

pollutant, forms during the ethanol conversion process and is also emitted when ethanol is used as fuel.[36] A 2008 study by the Nebraska Department of Environmental Quality showed that some ethanol refineries may have difficulties meeting national emission standards for some hazardous air pollutants, including acetaldehyde. Further, EPA's May 2009 notice of proposed rulemaking regarding the RFS included an analysis that found the production and distribution of biofuels could increase acetaldehyde emissions by almost 14 percent by 2022 when compared to business as usual estimates. According to EPA regional officials, EPA is planning a pilot study to monitor ambient acetaldehyde in localities with high concentrations of ethanol production in order to develop better estimates of acetaldehyde emissions in the ethanol conversion process.

In contrast, at this time, according to some experts and EPA regional officials we spoke with, little is known about the potential air quality effects of converting cellulosic feedstocks to biofuels, primarily because commercial-scale cellulosic biorefineries have not been completed and put into use. While some studies projecting potential emissions generated from the cultivation and conversion of biofuels show promise,[37] some experts we spoke with believe that predictions of potential emissions reductions from the conversion of cellulosic feedstock are speculative until facilities have been demonstrated at the commercial scale.

[36]Acetaldehyde is mainly used as an intermediate in the synthesis of other chemicals. It is ubiquitous in the environment and may be formed in the body from the breakdown of ethanol. Acute (short-term) exposure to acetaldehyde results in effects including irritation of the eyes, skin, and respiratory tract. Symptoms of chronic (long-term) intoxication of acetaldehyde resemble those of alcoholism. Acetaldehyde is considered a probable human carcinogen based on inadequate human cancer studies and animal studies that have shown nasal tumors in rats and laryngeal tumors in hamsters.

[37]See Hill, J., S. Polasky, E. Nelson, D. Tilman, H. Huo, L. Ludwig, J. Neumann, H. Zheng, and D. Bonta. "Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline," *Proceedings of the National Academies of Sciences*, vol. 106, no. 6, 2009, pp. 2077-2082; and Wu, M., Y. Wu, and M. Wang. "Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment," *Biotechnology Progress*, no. 22, 2006, pp. 1012-1024.

Storage and Use of Certain Ethanol Blends May Result in Further Environmental Effects that Have Not Yet Been Measured

As the percentage of ethanol used in motor fuels increases, the risk of leaks in the existing fuel storage and delivery infrastructure also increases because some of these tanks are not currently certified for storing such blends. These leaks could result in contamination of groundwater and surface water. Furthermore, the potential effects of increased biofuels use on air quality will depend on the ability of the existing fleet of vehicles to adapt to fuel blends with an increased percentage of ethanol.

Current Fuel Storage and Delivery Infrastructure May Be Inadequate to Prevent Leaks and Potential Groundwater Contamination from Certain Ethanol Blends

Ethanol is highly corrosive and poses a risk of damage to pipelines, rail or tanker trucks, underground storage tanks (UST), and above-ground storage tanks (AST), which could in turn lead to releases to the environment that may also contaminate groundwater, among other issues.[38] According to EPA officials, aside from UST systems specifically designed to store fuel containing 85 percent ethanol, a large number of the 617,000 federally regulated UST systems currently in use at approximately 233,000 sites across the country are not certified to handle fuel blends that contain more than 10 percent ethanol.[39] These officials stated that the expected life span of USTs is typically 30 years. This, combined with the lack of information on how many of these tank systems are ethanol compatible and where they are installed, makes it difficult for EPA to gather data on the level of leakage risk posed by a switch to different blends of ethanol. Officials also commented that substantial turnover in ownership further complicates the challenge of determining what type of UST system is in the ground without removing it.

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

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

Moreover, according to EPA officials, most tank owners do not have records of all the UST systems' components, such as the seals and gaskets. Glues and adhesives used in UST piping systems were not required to be tested for compatibility with ethanol until recently. Thus there may be many compatible tanks with incompatible system components, increasing the potential for equipment failure and fuel leakage, according to EPA officials, and EPA continues to work with government and industry partners to study the compatibility of UST system components with various ethanol blends. In 2000, 39 states, territories and tribes identified leaking USTs as one of the top 10 causes of groundwater contamination in state assessment reports. When leakage occurs from USTs storing ethanol-blended fuels, the contamination may pose greater risks than petroleum. Studies show that ethanol causes benzene, a soluble and carcinogenic chemical in gasoline, to travel longer distances and persist longer in soil and groundwater than it would in the absence of ethanol, potentially reaching a greater number of drinking water supplies.[40,41]

[40]When ethanol is present, the ethanol is consumed by microorganisms in the soil first. This decomposition takes up nutrients and oxygen needed to break down benzene and related compounds. As a result the benzene plume extends a greater distance.

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

Use of Certain Ethanol Blends in Vehicles Is Expected to Increase Emissions of Certain Air Pollutants, but Research Is Ongoing to Better Establish the Magnitude of These Emissions

In addition to emissions from biorefineries, research indicates that there is some concern regarding tailpipe emissions from vehicles and small nonroad engines using certain blends of ethanol.[42,43] In modeling done as part of its proposed rulemaking, EPA estimated that nitrogen oxide emissions are projected to increase due to the use of fuel blends with 10 percent ethanol, and the use of fuel blends with 85 percent ethanol will lead to more significant increases in ethanol, acetaldehyde, and formaldehyde emissions. Furthermore, while some vehicles are designed to handle fuel blends of up to 85 percent ethanol, some conventional vehicles may not be equipped to handle blends containing greater than 10 percent ethanol, according to an Oak Ridge National Laboratory study.[44] Specifically, the study reported that the use of these intermediate ethanol blends by vehicles may have an effect on the pollution control systems and emissions of some vehicles, particularly older vehicles.[45] While EPA has conducted some research to quantify the emissions effects of ethanol blends of 10 percent and 85 percent, research on intermediate blends has been limited and efforts are under way to determine the magnitude of their

[42]The Clean Air Act Amendments of 1990 require areas with the worst air quality to use reformulated gasoline, which includes oxygenate additives that increase the oxygen content of the fuel and reduce emissions of carbon monoxide in some engines. In recent years, ethanol has been increasingly used as the primary oxygenate in gasoline.

[43]Small nonroad engines include leaf blowers, line trimmers, generator sets, lawn mowers, and small tractors.

[44]Before approving the use of intermediate ethanol blends, EPA would assess potential impacts on vehicle emissions.

[45]Vehicles have pollution control systems—known as catalytic converters—that are located between a vehicle's engine and tailpipe. Catalytic converters work by facilitating chemical reactions that convert exhaust pollutants such as carbon monoxide and nitrogen oxides to normal atmospheric gases such as nitrogen, carbon dioxide, and water. As the catalytic compound breaks down over time, the converter loses its capacity to reduce pollutant emissions.

potential effect.[46] For example, DOE's National Renewable Energy Laboratory and Oak Ridge National Laboratory and EPA are conducting long-term studies on the effects of intermediate ethanol blends on emissions from vehicles in the existing fleet and small nonroad engines. Preliminary results have shown that, in vehicles, fuel blends greater than 10 percent ethanol generally reduce emissions of some criteria pollutants and some hazardous air pollutants, although acetaldehyde emissions increased.[47] The National Renewable Energy Laboratory, the Oak Ridge National Laboratory, and EPA are expected to report on the effects of intermediate ethanol blends on the full useful life of the existing fleet of vehicles in 2010, including effects on pollution control systems and emissions.[48] While the potential effects of intermediate ethanol blends on tailpipe emissions and catalytic systems are important, EPA emissions data indicate that tailpipe emissions of certain pollutants have decreased substantially over time (see table 5). As a result, while there may be some adverse effects, particularly in areas with existing air pollution problems, the effects of increased pollution from motor vehicles as a result of ethanol use may be relatively small. EPA plans to further analyze the potential air quality effects of increased renewable fuel use as a part of the final rulemaking for the RFS.

[46] A 2007 review of available literature by a team of researchers at Oak Ridge National Laboratory found that limited data existed on the use of intermediate ethanol blends in conventional gasoline vehicles in the United States. A study contracted by the Australian Department of Environment found nitrogen oxide emissions increases and accelerated long-term degradation of the vehicle's pollution control system with 20 percent ethanol fuel blends. See Bechtold, R., J. Thomas, S. Huff, J. Szybist, T. Theiss, B. West, M. Goodman, and T.A. Timbario. "Technical Issues Associated with the Use of Intermediate Ethanol Blends (>E10) in the U.S. Legacy Fleet: Assessment of Prior Studies." Oak Ridge National Laboratory, DOE, August 2007; Orbital Engine Company, "Market Barriers to the Uptake of Biofuels Study: A Testing Based Assessment to Determine Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Passenger Vehicle Fleet." Report to Environment Australia, March 2003; and Orbital Engine Company, "Market Barriers to the Uptake of Biofuels Study: Testing Gasoline Containing 20% Ethanol." Phase 2B-Final Report to the Department of the Environment and Heritage of Australia, May 2004.

[47] Acetaldehyde emissions increased with fuel blends containing 20 percent ethanol by an average of 0.81 milligrams per mile when compared to regular gasoline. Increases for blends containing 10 percent and 15 percent ethanol were 0.38 milligrams per mile and 0.70 milligrams per mile, respectively.

[48] The full useful life of a vehicle is considered to be 100,000 to 150,000 miles.

Table 5: Criteria Pollutants and Related Emissions from Stationary and Mobile Sources, 1990 and 2007 (thousands of short tons)

	Year	Carbon monoxide (CO)	Nitrogen oxides (NOx)	Sulfur dioxide (SO_2)	Volatile organic compounds	Particulate matter (PM2.5)[a]
Highway vehicles	1990	110,255	9,592	503	9,388	323
	2007	41,610	5,563	91	3,602	114
Nonroad equipment	1990	21,447	3,781	371	2,662	300
	2007	18,762	4,164	396	2,650	276
Total U.S. emissions	**1990**	**154,188**	**25,527**	**23,077**	**24,108**	**7,560**
	2007	**88,254**	**17,025**	**12,925**	**18,423**	**5,450**

Source: GAO analysis of EPA data.

[a]PM2.5 includes particulate matter at most 2.5 micrometers in diameter.

Focus on Sustainability Will Be Important in Evaluating Environmental Implications of Increased Biofuel Production

Experts from government, academia, and the private sector have stated that to better understand the environmental implications of different fuel choices, an increased focus on sustainability is needed. While there are no standard criteria, nor a single working definition for sustainability, the Biomass Research and Development Board described sustainable renewable energy production as systems that are not only productive, but also environmentally, economically, and socially viable now and for future generations. Some experts and agency officials said that sustainability is a useful concept for understanding these effects and evaluating policy options because it takes into account a wide variety of potential effects. Several efforts are under way to evaluate biofuels using this broad concept. For example, the Biomass Research and Development Board has drafted a proposed set of scientific sustainability criteria that cover the critical elements of a sustainable biofuels system.[49] Each criterion has a corresponding set of measurable indicators. For example, one of the environmental criteria is “soil quality and land productivity,” and its corresponding indicators are feedstock yield, soil loss, and soil organic matter content. Although some data are available, reliable science-based methods to predict likely outcomes from measurable indicators must still be developed, according to USDA.

Furthermore, some experts and officials we spoke with highlighted the importance and need for lifecycle analysis of the environmental effects of biofuels—throughout feedstock cultivation, harvest, transport, fuel

[49]Criteria have been developed to help measure environmental, economic, and social benefits and consequences, as well as the impacts on energy diversification and security.

production, storage, and use. EPA is undertaking some of these analyses and included a partial assessment of water and air effects in the preamble of the May 2009 RFS proposed rulemaking. In addition, EPA has stated that it has clear authority and responsibility under other statutes, such as the Clean Water Act and the Federal Insecticide, Fungicide and Rodenticide Act, to evaluate the environmental impacts of a biofuel's lifecycle. However, EISA does not require EPA to determine what fuels are eligible for consideration under the RFS based on their lifecycle environmental effects even though a fuel's lifecycle greenhouse gas emissions determine eligibility (see ch. 4). Moreover, beginning in 2022, EPA must establish the renewable fuel standard based in part on the impact of the production and use of renewable fuels on the environment. According to the experts we spoke with, any comprehensive analysis of the costs and benefits of gasoline compared with the various types of biofuels will require a complete analysis of environmental effects as well.

Conclusions

Ethanol, biodiesel, and advanced cellulosic biofuels are being promoted for their potential contributions to reducing net greenhouse gas emissions, achieving greater national energy security by decreasing the transportation sector's use of imported petroleum, and developing rural economies by raising domestic demand for U.S. farm products. Although EPA's May 2009 proposed rulemaking included a partial analysis of water and air effects of biofuels production, EISA does not require EPA to determine what renewable fuels are eligible for consideration under the RFS based on their lifecycle environmental effects, apart from lifecycle greenhouse gas emissions. Given the significant environmental effects that could occur at every step of the biofuels production process—feedstock cultivation, harvest, transport, conversion to biofuel, storage, and end use—and the potential for biofuels production to further exacerbate existing environmental problems, we believe that any assessment of biofuel feedstock will be incomplete without a full consideration of all the related potential environmental implications associated with each type of feedstock. Furthermore, for policymakers to be fully informed about the effects of their decisions, these implications must be compared to the environmental effects of gasoline and other transportation fuel options. While we recognize the challenge EPA faces in assessing the variety of environmental effects that increased biofuels production can cause and given that, at a minimum, the agency will be required to undertake such an assessment in 2022, we believe developing a strategy to assess these effects now is an important first step in ensuring that future fuel choices will not lead to additional environmental degradation.

Matter for Congressional Consideration

In addition to the currently required lifecycle greenhouse gas emissions analysis, the Congress may wish to consider amending EISA to require that the Administrator of the Environmental Protection Agency develop a strategy to assess the effects of increased biofuels production on the environment at all stages of the lifecycle—cultivation, harvest, transport, conversion, storage, and use—and to use this assessment in determining which biofuels are eligible for consideration under the renewable fuel standard. This would ensure that all relevant environmental effects are considered concurrently with lifecycle greenhouse gas emissions.

Agency Comments and Our Evaluation

In commenting on a draft of this report, EPA addressed the Matter for Congressional Consideration to consider amending EISA to require EPA to develop a strategy to assess the effects of increased biofuels production on the environment at all stages of the lifecycle and to use this assessment in determining which biofuels are eligible for consideration under the RFS. EPA commented that this matter might be best addressed by the recently created Executive Biofuel Interagency Working Group co-chaired by EPA, USDA, and DOE, which has been tasked to promote the environmental sustainability of biofuel feedstock production, among other things. EPA also commented that it has clear authorities and responsibilities under other environmental statutes that may regulate aspects of a biofuel's lifecycle and is required by Section 204 of EISA to evaluate the environmental effects of biofuels and submit a report to the Congress.

We acknowledge that EPA has the authority under other statutes to mitigate the environmental effects of biofuels and believe that the evaluation currently required by section 204 of EISA will provide a good foundation for the analysis we are suggesting. However, we believe that our matter for congressional consideration would require EPA to not only assess the lifecycle effects of biofuels, but to actually use these assessments to determine which biofuels are eligible for consideration under the renewable fuel standard.

Chapter 4: Researchers Disagree on How to Account for Indirect Land-Use Changes in Estimating the Lifecycle Greenhouse Gas Effects of Biofuels Production

Twelve recent scientific studies have used greenhouse gas or economic forecasting models to estimate the total emissions of carbon dioxide and associated gas during a biofuel's lifecycle—growing, harvesting, and transporting the feedstock; producing the biofuel; and using it in a vehicle—and comparing these results with greenhouse gas emissions of fossil fuels.[1] Overall, the estimated lifecycle greenhouse gas emissions of biofuels compared with fossil fuels in these studies ranged from a 59 percent reduction to a 93 percent increase in greenhouse gas emissions for corn starch ethanol, a 113 percent reduction to a 50 percent increase for cellulosic ethanol, and a 41 percent to 95 percent reduction for biodiesel. More specifically, studies that did not include indirect land-use changes in their lifecycle analysis generally reported that conventional corn starch ethanol can achieve some net greenhouse gas reduction benefits and cellulosic ethanol can likely achieve more reduction benefits as compared with fossil fuels. However, the three studies that addressed indirect land-use changes in their methodologies each reported that biofuels had a net increase in greenhouse gas emissions relative to fossil fuels. In addition, 9 other scientific studies assessed the greenhouse gas emissions of various biofuels feedstocks using various other metrics, such as the carbon payback period—the amount of time needed to compensate for the carbon debt generated from clearing new lands to grow biofuel feedstocks.

Many of the lifecycle analysis researchers we interviewed stated there is general consensus on the approach for measuring the direct effects of increased biofuels production, but disagreement among researchers about assumptions and assessment methods for estimating the indirect effects of global land-use change. EPA is required to assess significant greenhouse gas emissions from land-use change because only biofuels that achieve certain lifecycle emission reductions relative to petroleum fuels are eligible for consideration under the RFS. In particular, researchers disagree about what nonagricultural lands will be converted to replace land used to grow biofuels crops so that world production of food, feed,

[1]Researchers have generally used Argonne National Laboratory's GREET model to estimate fuel-cycle energy use and emissions associated with alternative transportation fuels and advanced vehicle technologies. In addition, some researchers have used (1) the University of Missouri's and Iowa State University's FAPRI model to estimate international crop expansion, (2) the FASOM model developed by Texas A&M University and others to estimate domestic crop expansion, (3) NASA's MODIS satellite-based data to estimate the percentage of each land type converted to cropland, and (4) Purdue University's GTAP general equilibrium model to predict the amount and types of land needed in a region to meet demands for both food and fuel production.

and fiber crops is maintained, and about future productivity trends in both existing and new farmland. Although research for measuring indirect land-use changes as part of the greenhouse gas analysis is only in the early stages of development, EISA directed EPA to promulgate a rule to determine the lifecycle greenhouse gas emissions of biofuels included in the RFS, including significant emissions from land-use changes for each feedstock. Many researchers told us that the lack of agreement on standardized lifecycle assessment methods, combined with key information gaps in several areas—such as feedstock yields, domestic and international land-use data, and data on above-ground biomass and soil carbon for a variety of land cover crops worldwide—greatly complicate EPA's ability to promulgate this rule. On May 26, 2009, EPA published a proposed rule in the *Federal Register*.

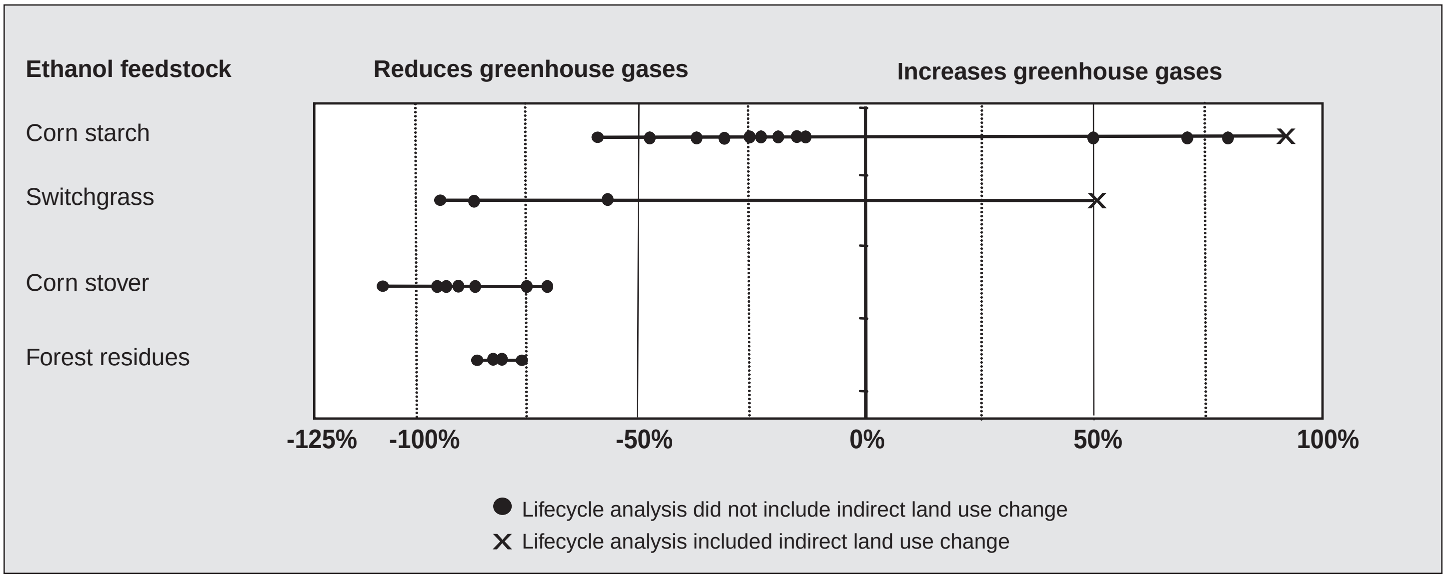
Estimates of the Lifecycle Greenhouse Gas Emissions of Biofuels Have Significantly Differed

Twelve recent scientific studies that compared the estimated lifecycle greenhouse gas emissions of using ethanol with using gasoline generally showed a modest greenhouse gas reduction benefit for conventional corn starch ethanol and greater benefits for cellulosic ethanol (see fig. 5). For example, a 2006 Argonne National Laboratory study estimated that, for the entire fuel cycle, corn starch ethanol generated 21 percent to 24 percent less greenhouse gas emissions than gasoline, while cellulosic ethanol produced from corn stover generated 86 to 89 percent less greenhouse gas emissions than gasoline.[2] Updated data presented in 2008 showed that such feedstocks as forest residues, corn stover, switchgrass, and fast-growing trees reduced greenhouse gas emissions relative to gasoline from 75 percent to 112 percent.[3] In comparison with gasoline, the estimated greenhouse gas emissions ranged from a 59 percent decrease to a 93 percent increase for corn starch ethanol and from a 113 percent decrease to a 50 percent increase for ethanol emissions from cellulosics, including switchgrass, corn stover, and forest residues.

[2]Argonne National Laboratory, *Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States* (Argonne, IL: Nov. 2006).

[3]*Life-Cycle Analysis of Biofuels: Issues and Results*, presentation by Dr. Michael Wang, Center for Transportation Research, Argonne National Laboratory, at an American Chemical Society forum for Congressional staff (August 2008). The reduction of greenhouse gas emissions exceeded 100 percent in one study because some feedstocks create a net carbon benefit by sequestering more carbon than is released when combusting the fossil fuels used to produce the biofuel.

Figure 5: Estimated Lifecycle Greenhouse Gas Emissions of Ethanol as Compared with Gasoline



Source: Figure based on data from 12 key studies conducted by DOE, USDA, and academic researchers.

In addition, we examined 9 other scientific studies that estimated the greenhouse gas impacts of biofuels using different metrics to report their results than the studies shown in figure 5. For example, 3 of these 9 studies estimated the greenhouse gas emissions of biofuels based on a carbon payback period—defined as the amount of time needed to overcome greenhouse gas releases incurred when new lands are cleared to grow biofuel feedstocks—while 2 studies in this group used a net energy metric, such as net energy input per unit output. Other studies in this group reported the greenhouse gas impacts from biofuels in terms of overall greenhouse gas emissions reductions or increases without quantifying these reductions relative to fossil fuels. These 9 scientific studies reported both positive and negative greenhouse gas impacts for biofuels.

Assumptions about Agricultural and Energy Inputs, Co-Products, and Land-Use Changes Determine Research Results

The results of the 21 scientific studies we reviewed vary primarily because researchers made different assumptions about the agricultural management practices and biorefinery energy inputs required to produce biofuels, allocated these energy inputs to co-products in a number of ways, and considered direct and indirect land-use impacts to different extents. (See app. IV for a list of key studies on the lifecycle greenhouse gas effects of biofuels and app. VII for a summary of the assumptions and conclusions of 17 researchers about lifecycle greenhouse gas emissions of biofuels production.)

Assumptions about Agricultural and Biorefinery Energy Inputs Can Strongly Affect the Results of Biofuel Lifecycle Assessment Models

Several researchers told us that different assumptions about agricultural inputs and practices related to biofuel production can strongly affect lifecycle analysis results. For example, assumptions about fertilizer production and its rate of application are important because corn farming requires intensive application of nitrogen-based fertilizer. One study estimated that 70 percent of greenhouse gas emissions in corn production are related to nitrogen fertilizer, which requires fossil energy to produce and results in emissions of nitrous oxide, a greenhouse-gas, from the farmed soil.[4] Also, most researchers told us that certain agricultural and production efficiencies could reduce greenhouse gas emissions from corn starch ethanol. For example, such farming practices as planting cover crops that bind the fertilizer's nitrogen in the soil might mitigate nitrogen leaching and greenhouse gas emissions and improve soil organic levels.[5] Similarly, the no-till land management practice might improve soil organic levels and increase carbon sequestration rates in comparison with conventional tillage. In addition, the lifecycle analysis is affected by decisions on what type of land to bring into feedstock production, the energy requirements of harvesting machinery, and the energy associated with transporting feedstocks to biorefineries.

[4]Kim S. and Dale B. "Effects of Nitrogen Fertilizer Application on Greenhouse Gas Emissions and Economics of Corn Production." *Environmental Science and Technology*, vol. 42, no. 16 (2008): pp. 6028-6033.

[5]Using a winter cover crop, such as wheat, in the cropping system, could reduce soil emissions of nitrous oxide compared to continuous corn cultivation without a cover crop. See Kim S., and Dale B. "Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel." *Biomass and Bioenergy*, 29 (2005) pp. 426-439.

Researchers have also made varying assumptions on the amounts and types of energy used to power biorefineries. For example, estimates of the lifecycle greenhouse gas emissions of corn ethanol as compared with gasoline have varied from a 3 percent increase when coal was used as the process fuel to a 52 percent decrease when wood chips were used.[6] For cellulosic ethanol biorefineries, some studies that assume coal will be used for power showed increased greenhouse gas emissions compared with other studies that assume lignin (the noncellulose portion of the feedstock) will be used as a source of power.[7] Furthermore, the models vary based on whether they measure biorefinery energy use with regional data or measure it at a specific biorefinery, and some studies vary based on whether they use energy data for dry mill processing or more energy-intensive wet mill processing.

Assumptions about Allocating Energy to Co-Products Can Substantially Affect the Results of Biofuel Lifecycle Analyses

The same energy that a biorefinery uses to make ethanol or biodiesel also creates economically valuable co-products, including distiller's grains produced with corn ethanol using dry mill processing, soy meal produced by soybean crushing facilities, glycerin produced with biodiesel by biorefineries, and electricity produced by ethanol biorefineries that use cellulosic and sugarcane feedstocks. To analyze the energy use and greenhouse gas emissions, the energy used by a biorefinery to produce co-products needs to be subtracted out. Because future cellulosic biorefineries could be designed to co-produce electricity along with ethanol by burning the lignin in cellulosic feedstocks to generate heat or steam, this potential energy offset for producing cellulosic ethanol also needs to be taken into account. Researchers have used different approaches for addressing biofuels co-products. Some researchers did not include co-products as a factor in their analysis while other researchers have allocated the energy use attributable to these products through (1) a displacement method that assumes that co-products from ethanol production substitute for other products that require energy for their

[6]See Wang M., Wu M., and Huo H. "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," *Environmental Research Letters*, 2 (2007).

[7]See Pimentel D., Patzek T. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research*, vol 14, no. 1 (2005): pp. 65-76; Schmer M.R., Vogel K.P., Mitchell R.B., and Perrin R.K. "Net Energy of Cellulosic Ethanol from Switchgrass." *Proceedings of the National Academy of Sciences*, vol. 105, no. 2 (2008): pp. 464-469; and Argonne National Laboratory, *Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States* (Argonne, IL: Nov. 2006).

production, (2) a mass-based method that distributes energy among all products according to their mass output shares, and (3) an economic revenue shares method that distributes energy based on the revenue shares of each product. Several researchers told us that the methods used to allocate energy to these co-products is one of the largest variables in energy studies, and the variation can lead to widely different results.[8] A recent Argonne National Laboratory study examining the implications of selecting one method over others found that co-product method selection has significant effects on the biofuel greenhouse gas results, particularly for corn ethanol and biodiesel—for corn starch ethanol from 19 percent to 46 percent of the greenhouse gas emissions could be allocated to the distiller's grain co-product depending on the method used, and for cellulosic ethanol from 2 percent to 31 percent could be allocated to co-generated electricity depending on the method used.[9]

Land-Use Changes May Be the Most Important and Difficult Variable to Account for when Assessing the Lifecycle Greenhouse Gas Emissions of Biofuels

Some researchers believe that land-use changes are the most significant factor in determining the greenhouse gas effects of certain types of biofuels. The land-use changes resulting from biofuel production are either direct or indirect. Direct land-use change examines the immediate effects of displacing the existing use of land to grow feedstocks for biofuel production. For example, as corn ethanol production increases, farmers could grow more corn on land previously used for another type of crop, such as soybeans. Indirect land-use change is significantly more difficult to measure because it examines what nonagricultural lands may be converted to replace agricultural land used to grow biofuels crops to maintain world production of food, feed, and fiber crops. For example, assessments of indirect land-use change attempt to measure the impact of increased biofuel production in the U.S. on agriculture patterns in other countries, such as those in tropical regions where land not currently used for agriculture might be cleared to produce corn and other agricultural commodities. Such land-use changes may result in more greenhouse gases being released than were saved through the replacement of gasoline with ethanol.

[8]In a 2006 survey of published and gray literature examining the greenhouse gas effects of ethanol, Farrell found that calculations about the net energy calculations for ethanol were most sensitive to co-product allocation. See Farrell A.E. "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, vol. 311, issue 5760 (2006): pp. 506-508.

[9]Wang M., Huo H., and Arora S. "Methods of Dealing with Co-Products of Biofuels in Life-Cycle Analysis," forthcoming in the *Energy Policy Journal*.

To date, only a few studies have attempted to account for the effects of indirect land-use change. One study estimated that (1) corn starch ethanol resulted in a 93 percent increase in greenhouse gas emissions relative to gasoline when indirect land-use changes were included and (2) converting corn fields to grow switchgrass would trigger land-use changes that would result in a 50 percent increase in greenhouse gas emissions as compared with gasoline.[10] In addition, two other studies stated that biofuels production could increase greenhouse gas emissions if corn starch ethanol production required expanding agricultural production on other native habitats or if cellulosic feedstocks accelerated land clearing by adding to the agricultural land base needed for biofuels.[11] These studies quantified the carbon debt, which determines the greenhouse gas releases that biofuels must overcome to provide greenhouse gas benefits. The time needed to overcome this carbon debt is referred to as the payback period. One of these studies estimated this payback period to be about 86 to 840 years for biodiesel, depending on the tropical ecosystem being converted, and about 93 years for corn ethanol produced on newly converted U.S. central grasslands. The studies also reported that the expansion of biofuels into production in tropical ecosystems would always lead to net carbon emissions for decades to centuries, but expanding into degraded or already cultivated land could reduce greenhouse gas emissions and provide carbon savings. However, while all three studies incorporated land-use change effects, other researchers have criticized these studies for either (1) not recognizing cultural and political interactions as well as other factors that also lead to land-use change, (2) using economic models that do not include all land-use factors in the modeling, (3) making certain assumptions about the type of land being converted and agricultural practices used to plant the biofuel feedstocks, or (4) making assumptions regarding crop productivity of existing and new crop land that may not reflect technology potentials. [12] Other researchers told us that indirect

[10]Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J, Tokgoz S., Hayes D., and Yu T.H. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science*, vol. 319 (2008): pp. 1238-1240. Supporting online material was published on *Science Express* (Feb. 7, 2008).

[11]See Fargione J., Hill J., Tilman D., Polasky S., and Hawthorne P. "Land Clearing and the Biofuel Carbon Debt," *Science*, vol. 319, issue 5867 (2008): 1235-1238; and Gibbs H.K, Johnston M, Foley J.A, Holloway T., Monfreda, C., Ramankutty N., and Zaks, D. "Carbon Payback Times for Crop-Based Biofuel Expansion in the Tropics: The Effects of Changing Yield and Technology." *Environmental Research Letters*, vol. 3 (2008): 1-10.

[12]For example, the development of hybrid seeds could offset some of the potential increase in cultivated land.

land-use changes could be significant but said that their effects cannot be estimated because current models, methods, and data are inadequate.

Two of these studies also estimated that biodiesel achieved a 41 percent to 95 percent decrease in greenhouse gas emissions relative to diesel fuel.[13] However, these studies did not consider the possible effects of biofuel production on land-use decisions and any new greenhouse gas emissions that may be released. Other researchers told us that converting rainforests, peatlands, savannas, or grasslands to biodiesel crops would likely lead to increased greenhouse gas emissions. For example, in a 2006 study, researchers did not consider land-use changes and reported greenhouse gas emission decreases for soybeans compared with diesel fuel, but in a 2008 study, some of these researchers found greenhouse gas increases when land-use changes were considered.[14] While these researchers did not quantify the results as a percent change compared with fossil fuels, they found that clearing certain land for crop-based biofuels would release more carbon dioxide than the greenhouse gas reductions from displacing fossil fuels would provide.

Despite the differences regarding how to quantify land-use change, the researchers we interviewed generally believe that certain cellulosic feedstocks, such as corn stover, wood waste, or municipal waste, would not cause significant indirect land-use changes and could decrease greenhouse gas emissions compared with fossil fuels, even though some researchers said over-harvesting agricultural residues could increase soil erosion and adversely affect water quality, requiring mitigation.

[13] Hill J., Nelson E., Tilman D., Polasky S., and Tiffany D. “Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels.” *Proceedings of the National Academy of Sciences*, July 25, 2006, vol. 103, no. 30, pp. 11206-11210; and McCarl, B.A., “Bioenergy in a Greenhouse Mitigating World.” Choices, 23(1), pp. 31-33, 2008.

[14] Fargione J., Hill J., Tilman D., Polasky S., and Hawthorne P. “Land Clearing and the Biofuel Carbon Debt,” Science, vol. 319, issue 5867 (2008): pp. 1235-1238, and Hill J., Nelson E., Tilman D., Polasky S., and Tiffany D. “Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels.” Proceedings of the National Academy of Sciences, vol. 103, no. 30 (2006): pp. 11206-11210.

Shortcomings in Forecasting Models and Data Make It Difficult to Determine Lifecycle Greenhouse Gas Emissions

Researchers told us there is a lack of consensus within the scientific community about whether biofuels reduce greenhouse gas emissions, citing in particular uncertainties about how to link biofuels production with indirect land-use change. Underlying this lack of consensus are limitations to current forecasting models, a lack of standardized assumptions and metrics, and a lack of current data on the type of land that would be brought into production to replace acreage used to grow biofuel feedstocks.[15] Many researchers told us that limitations to current lifecycle models and key information gaps challenge EPA's ability to promulgate a rule defining fuels eligible for consideration under the RFS.

Models for Assessing Lifecycle Impacts Are Currently Limited

Several researchers have cited a need for better and more sophisticated models and analyses of lifecycle impacts. Many researchers we interviewed said a primary limitation in conducting lifecycle analyses is how to link biofuels production with indirect land-use change. The complexity of commodity markets, national policies and other factors influencing land use makes modeling the indirect effects of rising demand for biofuel feedstocks highly uncertain. For example, some researchers said the current models do not consistently (1) identify where the biofuel feedstocks are grown, (2) include marginal or unused land in the modeling, and (3) characterize the carbon content of the soil before and after the biofuel feedstocks are planted. Moreover, researchers said that none of the models alone can accurately quantify international aspects of land-use change, since they essentially have to perform economic modeling of the whole world as well as conclusively prove cause and effect—that land in Brazil, for example, is being converted because of U.S. biofuel production. In addition, some models use profit maximization as the decision rule to predict how people will respond to changes in prices, but these models do not necessarily predict how people make decisions or how economic and social policy in the various nations affect land-use decisions in those countries.

Some researchers cited the need for more research to address information gaps, such as limited data on land use, feedstock yield and agricultural inputs data, and conversion data at cellulosic biorefineries. Specifically, researchers said there are gaps in the research for direct land-use change,

[15] The International Organization of Standardization has developed lifecycle analysis standards. However, researchers use different assumptions and system boundaries in their analyses, which influence final results.

such as variations in the different ecosystems being studied.[16] In addition, researchers identified data gaps in the amount of carbon in the biomass that is lost when, for example, a forest is converted into farmland. Researchers also cited a lack of real data for different feedstock yields because, for example, some feedstocks have not been widely grown for harvest on a large scale under typical farm conditions, and actual yields and fertilizer application rates may differ with large scales and on-farm conditions. Researchers also said limited information exists on the costs and efficiencies of cellulosic materials in a biorefinery, since the first biorefineries are just beginning to be built and have not yet produced substantial real-world data.

Some Efforts Are Being Made to Address Lifecycle Modeling and Data Concerns

International efforts are ongoing to address the need to standardize lifecycle models and metrics. For example, the International Organization of Standardization has published lifecycle analysis protocols. However, some researchers have noted that these standards still do not contain guidelines for some important assumptions, such as indirect land-use impacts. The Global Bioenergy Partnership is also working to formulate a methodological framework to measure greenhouse gas emission reductions from biofuels.

In addition, in April 2009, the California Air Resources Board adopted a regulation that will implement California Executive Order S-01-07, the Low Carbon Fuel Standard, which calls for the reduction of greenhouse gas emissions from California's transportation fuels by 10 percent by 2020. As with the federal RFS, the California Low Carbon Fuel Standard is also attempting to measure the greenhouse emissions for the full lifecycle, including both the direct emissions associated with producing, transporting, and using fuels, as well as the indirect emissions that may be caused by land-use change when certain biofuel feedstocks are grown. The California Air Resources Board's regulation identifies carbon intensity values for gasoline and some biofuels produced under different process and input pathways, including 11 different pathways to produce ethanol from corn, and values for cellulosic ethanol from farmed trees, agricultural waste, and forest waste are under development. In the draft regulation, the

[16]For example, while USDA's National Resources Inventory surveys land use, natural resource conditions, and trends on domestic nonfederal, nonforest lands, it does not analyze comprehensive land use data gathered at the same locations every year. Also, these survey data cannot be readily integrated with data from USDA's survey of producers or agricultural census because of differences in land use definitions.

carbon intensity values for corn ethanol vary based on location, type of processing facility, and wet or dry co-product, but each corn pathway includes the same carbon intensity value for land-use change. The preliminary results show that certain transportation fuels that substitute for gasoline could meet the Low Carbon Fuel Standard, including some conventional corn starch ethanol using the dry mill conversion process and some corn starch ethanol produced in California, as well as ethanol from sugarcane produced in Brazil. Others would not, including corn ethanol produced in the Midwest or using the wet mill conversion process. However, some associations have criticized the California rule for the lack of precision in measuring the indirect effects of biofuels. For example, the Truman National Security Project, a group of retired military and intelligence officers, criticized the global trade analysis model used to develop the draft rule for its variability depending on the assumptions used by the individuals conducting the research.

Although research for measuring indirect land-use changes as part of the greenhouse gas analysis is only in the early stages of development, EISA requires that EPA develop a regulation for determining the lifecycle greenhouse gas emissions of biofuels included in the RFS, including those emissions caused by land-use changes. To be eligible for consideration under the RFS, conventional corn starch ethanol from biorefineries built after December 19, 2007, must generally reduce lifecycle greenhouse gas emissions by at least 20 percent relative to petroleum fuels. Advanced biofuels and biomass-based diesel must generally reduce lifecycle greenhouse gas emissions by at least 50 percent, and advanced biofuels made from cellulosic biomass must generally reduce emissions by at least 60 percent relative to baseline petroleum fuels.

On May 26, 2009, EPA published a Notice of Proposed Rulemaking in the *Federal Register* that proposes a regulatory structure to implement the RFS and methods for calculating the greenhouse gas impact of biofuels and announced that key components of its lifecycle greenhouse gas emissions analysis would be peer reviewed. The four peer review analyses, which EPA has posted on its Web site, were completed in late July 2009: (1) methods and approaches to account for lifecycle greenhouse gas emissions from biofuels production over time, (2) model linkages, (3) international agricultural greenhouse gas emissions and factors, and (4) satellite imagery.

Several DOE and USDA researchers we interviewed have expressed concern that the lifecycle models and data are not sufficiently mature for EPA to account for indirect land-use change in estimating biofuels greenhouse gas emissions. Some of these researchers also said that EPA has not made its approach to address indirect land-use change by combining elements of the GREET, FAPRI, FASOM, and GTAP models sufficiently transparent so that others can closely examine key assumptions in EPA's analyses and possibly replicate EPA's simulations. One DOE researcher noted that if secondary effects are to be included, they should be addressed on a consistent basis for all fuel pathways and uncertainties in understanding causal effects should be recognized. In addition, the National Biodiesel Board has expressed concern that the production from many biodiesel refineries, particularly ones using soybean and other vegetable oil feedstocks, may not qualify as biomass-based diesel under EPA's proposed RFS regulation because of the indirect land-use changes that result when soybeans are grown as an energy crop.

On May 5, 2009, the President announced the formation of an Executive Biofuel Interagency Working Group, co-chaired by the Secretaries of Agriculture and Energy and the Administrator of EPA. The working group is tasked with, among other things, identifying new policy options to promote the environmental sustainability of biofuels feedstock production, taking into consideration land use, habitat conservation, crop management practices, water efficiency, and water quality, as well as lifecycle assessments of greenhouse gas emissions.

Conclusions

EISA requires EPA to determine lifecycle greenhouse gas emissions from different biofuels and to define those fuels that would count toward the annual volume in the RFS because they sufficiently reduce emissions compared with gasoline. However, researchers have used markedly different assumptions and models to analyze the lifecycle greenhouse gas emissions of corn starch and cellulosic biofuel feedstocks. Also, no commonly recognized standards exist to assess, in particular, indirect land-use changes associated with increased biofuels production, and researchers are limited by uncertain data in key areas. As a result, researchers have reported widely varying results on the aggregate quantity of greenhouse gas emissions for corn starch ethanol, cellulosic ethanol, and biodiesel as compared with gasoline and diesel. Such current scientific uncertainty makes it difficult for EPA to precisely determine whether a biofuel generated from corn starch or from cellulosic feedstocks would meet the greenhouse gas reduction requirements under the RFS. Without this information, EPA may be hampered in its ability to accurately define some feedstocks as acceptable or unacceptable fuels under the RFS.

Recommendation for Executive Action

To improve EPA's ability to determine biofuels greenhouse gas emissions and define fuels eligible for consideration under the RFS, we recommend that the Administrator of EPA and the Secretaries of Agriculture and Energy develop a coordinated approach for identifying and researching unknown variables and major uncertainties in the lifecycle greenhouse gas analysis of increased biofuels production. This approach should include a coordinated effort to develop parameters for using models and a standard set of assumptions and methods in assessing greenhouse gas emissions for the full biofuel lifecycle, such as secondary effects that would include indirect land-use changes associated with increased biofuels production.

Agency Comments and Our Evaluation

USDA, DOE, and EPA each commented on our recommendation for determining biofuels' lifecycle greenhouse gas emissions. Specifically, USDA agreed with the general premise implicit in the recommendation, but cited the need to ensure that coordinated scientific discussions do not lead to standard methods that become codified in regulations that would inhibit the adoption and use of new information and improved or more appropriate methods as they become available. We agree with USDA's concern that the RFS regulation should not codify standard methods that might inhibit the development of better information or methods for assessing lifecycle greenhouse gas emissions. However, we believe that a coordinated approach for identifying and researching unknown variables and major uncertainties will benefit EPA's lifecycle analysis because only three scientific studies have examined the effects of indirect land-use changes and USDA and DOE provide substantially greater funding in support of biofuels R&D. DOE noted that EPA already consults with DOE on these matters and added that DOE would welcome the opportunity to become more engaged in this process if requested to do so by the EPA Administrator. EPA stated that the agency has worked closely with USDA and DOE in developing the lifecycle assessment methodology for its proposed rule, and with the European Union and other international governmental organizations and scientists on modeling, including the impact of indirect land-use change. We note that while EPA has obtained information from USDA and DOE, its lifecycle analysis methodology was not transparent because EPA did not share its methodology with outside scientific groups before its Notice of Proposed Rulemaking for the RFS regulation was published. We believe the recently completed peer review of EPA's methodology, including key assumptions and its analytical model, will improve the transparency of EPA's lifecycle analysis. Furthermore, the indirect effects of land-use change on lifecycle greenhouse gas emissions are not well understood, and additional research is needed to address unknown variables and major uncertainties.

Chapter 5: Federal Tax Expenditures, the RFS, and an Ethanol Tariff Have Primarily Supported Conventional Corn Starch Ethanol

The federal government supports the development of a domestic biofuels industry primarily through tax credits, the RFS, and a tariff on ethanol imports. Since 1978, the Volumetric Ethanol Excise Tax Credit (VEETC) and its predecessor have provided a tax incentive for blending ethanol with gasoline. In December 2007, the Energy Independence and Security Act (EISA) expanded the RFS by substantially increasing the required annual volumes of renewable fuels, including up to 9 billion gallons of conventional corn starch ethanol in 2008 and up to 15 billion gallons of conventional corn starch ethanol in 2015. As a result, the VEETC's annual cost to the Treasury in forgone revenues could grow from $4 billion in 2008 to $6.75 billion in 2015 for conventional corn starch ethanol, even though the 2008 Farm Bill reduced the VEETC from 51 cents to 45 cents per gallon of ethanol starting in 2009. The United States also imposes a tariff on ethanol imports, which qualify for the VEETC, by imposing a tariff of 54 cents per gallon plus 2.5 percent of the ethanol's value.

Two of these tools—the VEETC and the RFS—can be duplicative with respect to their effects on ethanol consumption. We and others have found that the VEETC does not stimulate the use of additional ethanol under current market conditions because conventional ethanol use in transportation fuel in 2009 is unlikely to exceed 10.5 billion gallons—the portion of the required 11.1 billion gallons of biofuels that the RFS allows to come from conventional corn starch ethanol. In light of this situation, some recent studies have suggested that the VEETC be terminated or phased out or be revised by, for example, modifying it to provide a stimulus when crude oil prices are low but reducing its size when crude oil prices rise.

Advanced biodiesel and cellulosic biofuels have high production costs that have limited their ability to compete in fuel markets. To stimulate domestic production of these biofuels, the Congress has provided larger federal tax credits—$1.00 per gallon to biodiesel producers or blenders and $1.01 per gallon to cellulosic biofuels producers—which, to date, have predominantly supported biodiesel production. In addition, the RFS requires the use of at least 1 billion gallons of biomass-based diesel in and beyond 2012 and at least 16 billion gallons of cellulosic biofuels in 2022.

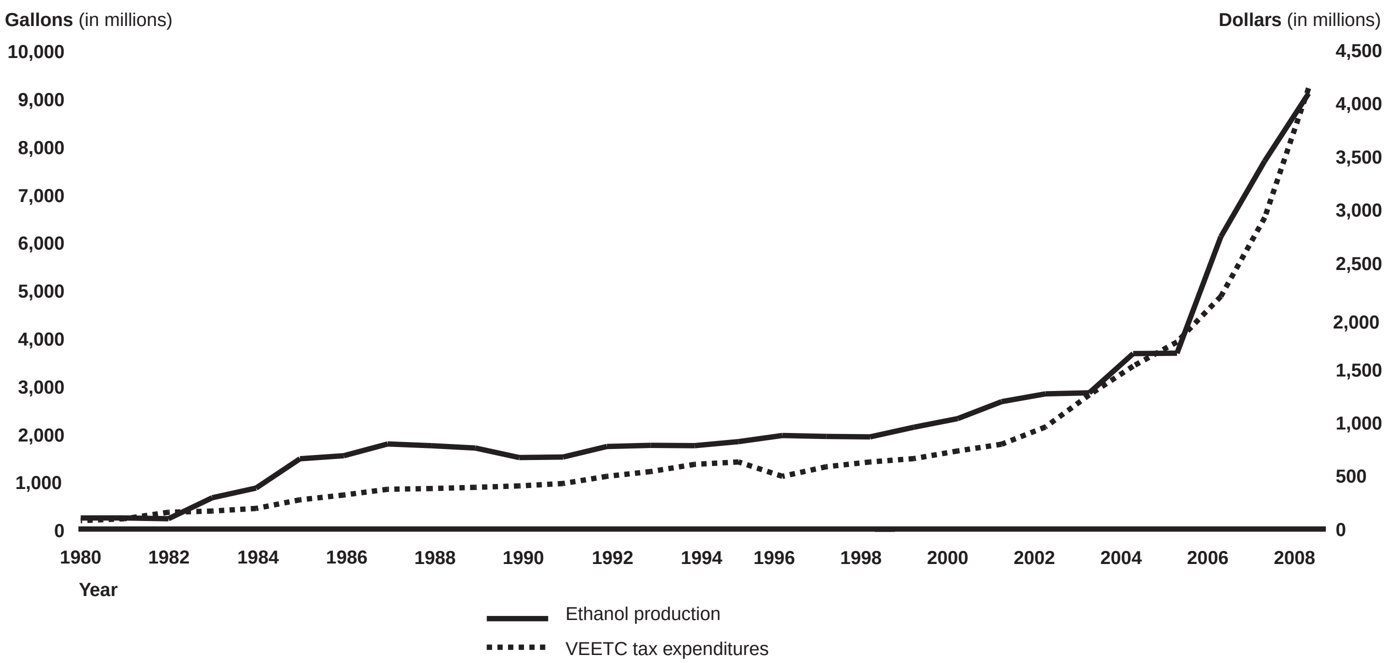
The VEETC Provides a Tax Credit to Companies that Blend Ethanol with Gasoline

The VEETC and its predecessor excise tax exemption for ethanol have historically been important federal tools to establish and expand the domestic ethanol industry, which has predominantly used conventional corn starch because of lower production costs. To stimulate the production of ethanol for blending with gasoline, the Energy Tax Act of 1978, among other things, established an excise tax exemption at the equivalent of 40 cents per gallon of ethanol. The American Jobs Creation Act of 2004 changed this original excise tax exemption to an excise tax credit called the VEETC and extended it through December 31, 2010.[1] The 2008 Farm Bill subsequently reduced the VEETC from 51 cents to 45 cents per gallon for ethanol, starting the year after at least 7.5 billion gallons of ethanol were produced or imported.

As shown in figure 6, both domestic ethanol production and federal tax expenditures through the VEETC have risen sharply in recent years. A key reason for this growth is that 25 states have banned the use of methyl tertiary butyl ether (MTBE) as an oxygenate blended into gasoline to meet Clean Air Act standards because of concerns about ground water contamination, leading to ethanol's substitution. About 9.2 billion gallons of ethanol were produced domestically in 2008, resulting in an estimated $4 billion in tax credits for ethanol blenders, according to Treasury. If reauthorized and left unchanged, the VEETC's annual cost to the Treasury in forgone revenues could be as much as $6.75 billion for conventional corn starch ethanol in 2015 and each year thereafter. Typically, petroleum refineries or gasoline wholesalers blend the biofuels with gasoline (motor fuel blenders) and receive the 45-cent-per-gallon tax credit. Economists have found that some of the benefit of this tax credit gets passed forward to motor fuel purchasers in the form of lower prices at the pump and some gets passed backward to biorefineries that produces the ethanol (ethanol producers) in the form of higher prices paid for ethanol.

[1] Producers may alternatively take this credit as an income tax credit to the extent the credits exceed the tax imposed on taxable fuel under 26 U.S.C. § 4081.

Figure 6: Domestic Ethanol Production and Federal Tax Expenditures, 1980-2008



Source: Renewable Fuels Association and the Department of the Treasury.

Note: The VEETC replaced the federal ethanol excise tax exemption in 2004. Domestic ethanol production is reported by calendar year and tax expenditures are reported by fiscal year.

The VEETC was important in helping to create a profitable corn starch ethanol industry when the industry had to fund investment in new facilities. It is less important now for sustaining the industry because most of the capital investment has already been made—ethanol production can now be profitable as long as the revenue that producers receive is sufficient to cover operating costs and depreciation. Corn starch ethanol refining is a mature industry because the process technology for making it is well understood—the process for making corn starch ethanol is similar to making alcoholic beverages, and the industry has developed the appropriate yeasts and enzymes. Furthermore, domestic biorefinery capacity is approaching the 15-billion-gallons-per-year maximum allowed for corn starch ethanol under the RFS in 2015.[2] Corn starch ethanol consumption received a boost as a substitute for MTBE, providing a

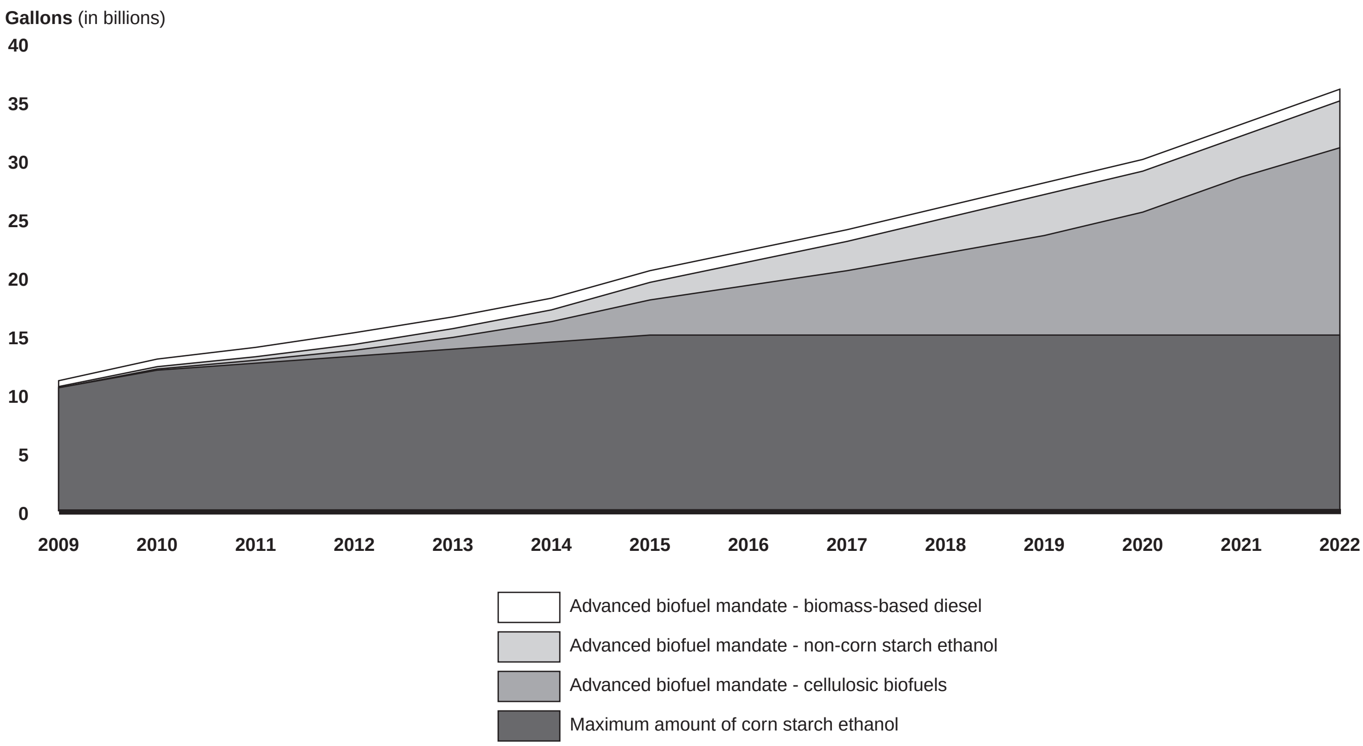
[2]EPA's proposed rulemaking on lifecycle greenhouse gas emissions will affect decisions whether to construct new corn starch ethanol biorefineries because biorefineries built after December 19, 2007, must reduce emissions by at least 20 percent to qualify under the RFS.

consistent demand for ethanol. As a result, ethanol consumption (primarily from corn starch) grew from about 2 billion gallons in 2002 to about 9.5 billion gallons in 2008. As of January 2009, the domestic corn starch ethanol industry has 11.5 billion gallons of refining capacity with an additional 1.8 billion gallons of capacity under construction, according to the Renewable Fuels Association.

RFS Biofuels Volume Requirements Rise Annually

The Energy Policy Act of 2005 established the RFS, which required that 4 billion gallons of renewable fuels be blended with gasoline in 2006, rising to 7.5 billion gallons in 2012. In December 2007, EISA substantially expanded the RFS by requiring that U.S. transportation fuels contain 9 billion gallons of renewable fuels in 2008 rising to 36 billion gallons in 2022 (see fig. 7). The RFS allows conventional corn starch ethanol—the predominant U.S. biofuel because of its relatively low production cost—to account for at most 10.5 billion gallons of the RFS's annual requirement in 2009 rising to at most 15 billion gallons in 2015 and remaining at this level through 2022. The RFS requires that, in 2022, at least 21 billion gallons of advanced biofuels must be blended, including at least 16 billion gallons of cellulosic biofuel and at least 1 billion gallons of biomass-based diesel.

Figure 7: Annual Biofuels Use under the RFS, 2009-2022



Source: EISA.

To ensure compliance with the RFS, EPA annually sets a blending standard—10.21 percent for 2009—that represents the amount of biofuels that each obligated party (gasoline refiners, importers, or blenders, with certain exceptions) must meet.[3] To demonstrate compliance with EPA's blending standard, each obligated party acquires a sufficient amount of renewable identification numbers (RIN)—a unique identification number that a producer or importer assigns to each gallon of biofuel.[4] RINs are

[3]The yearly blending standard is calculated as a percentage by dividing the amount of renewable fuel that the RFS requires to be used in a given year by the amount of gasoline expected to be used during that year, including certain adjustments and exemptions specified by the EISA. The percentage exceeds 10 percent in part because the numerator includes the combined RFS for ethanol and biodiesel while the denominator excludes biodiesel.

[4]A RIN consists of a 38-character code that includes the year the biofuel is produced or imported, the equivalence value for that type of biofuel, and a company and a facility identification.

valid for both the calendar year in which they were generated and the following calendar year. Obligated parties with more RINs than needed to meet that year's blending standard can either hold the extra RINs for use in the following year or sell them to another party that needs additional RINs to comply with the blending standard.

EISA allows the Administrator of EPA, after consulting with USDA and DOE and holding a public notice and comment period, to reduce the amount of biofuels required to be blended in gasoline in whole or in part if the Administrator determines that (1) its implementation would severely harm the economy or environment of a state, a region, or the United States or (2) that there is an inadequate domestic supply. In April 2008, Texas requested that EPA waive 50 percent of ethanol produced from grain under the RFS because the RFS was unnecessarily having a negative impact on Texas's economy and, specifically, increased ethanol production was contributing to higher corn prices that were adversely affecting its livestock industry and food prices. EPA denied the waiver because it determined that the evidence did not support a finding that the RFS would harm the economy of a state, region, or the country and the RFS would have no impact on ethanol production volumes or on corn, food, or fuel prices.[5]

The United States Imposes a Tariff on Ethanol Imports

In addition to the VEETC and the RFS, the federal government levies a tariff on imported ethanol to support the domestic corn starch ethanol industry. Since 1980, the United States has placed a duty of 54 cents per gallon plus a tariff that is 2.5 percent of ethanol's value. The tariff on imported fuel ethanol gives the domestic ethanol industry a price advantage relative to ethanol imports. Prior to 2006, U.S. ethanol imports were less than 200 million gallons a year. In 2008, even though crude oil prices peaked above $130 per barrel, making ethanol price competitive with gasoline, ethanol imports only grew to 500 million gallons.

The United States has provided an exception to the tariff for Caribbean Basin Initiative countries which can export ethanol duty free to the United States if at least 50 percent of the feedstock is grown in member countries. Alternatively, Caribbean Basin Initiative countries can export volumes of up to 7 percent of U.S. ethanol consumption duty free if more than 50

[5]The RFS did not affect ethanol production volumes in the spring and summer of 2008 because domestic ethanol consumption exceeded the RFS's required amount.

percent of the feedstock comes from nonmember countries—Brazilian and European ethanol imports often come through Caribbean Basin Initiative countries. Imports of ethanol have recently been well below the 7 percent cap, however.

The RFS and the VEETC Can Be Duplicative for Total Ethanol Consumption

The RFS establishes an annual floor for the amount of renewable fuels to be blended into U.S. transportation fuels. Economists consider the RFS to be "binding" when the RFS mandate causes biofuels consumption to be higher than it would otherwise be. In these circumstances, the VEETC does not affect the level of ethanol consumption and is a duplicative policy tool for increasing ethanol consumption. Because the RFS would ensure that the same amount of ethanol was used by blenders with or without the VEETC, we and others have found that removing the VEETC would not adversely affect the demand for corn for ethanol and the income of corn producers, which depend on the total level of ethanol consumption. Alternatively, the RFS is considered nonbinding if consumption exceeds the blend volumes in the RFS, which could occur if crude oil prices rise significantly. From 2006 through 2008, the RFS was not binding because U.S. corn starch ethanol consumption outpaced the annual RFS levels that the Energy Policy Act of 2005 had established. Specifically, in 2007, ethanol consumption rose to about 6.8 billion gallons, as compared with the 4.7 billion gallons of biofuels specified in the RFS. In 2008, ethanol consumption reached 9.5 billion gallons, exceeding the RFS level of 9 billion gallons of biofuels.[6] However, because EISA substantially increased biofuels requirements through 2022, the RFS is now more likely to be binding in the future.

When the RFS is binding, removal of the VEETC would not affect ethanol consumption but would eliminate the tax credit benefit to motor fuel blenders, motor fuel purchasers, and ethanol producers. Because the VEETC lowers the effective price (actual price minus the tax credit) that blenders pay for ethanol, blenders may be able to retain some of this lower effective price, but some or all of it may be passed forward to motor fuel purchasers in the form of lower (blended) motor fuel prices—as much as 4.5 cents for a gallon of E10 gasoline. Alternatively, some of this lower effective price may be passed backward to ethanol producers in the form

[6] U.S. biofuels consumption has been limited primarily to corn starch ethanol because of its lower production costs.

of higher ethanol prices.[7] However, economists do not expect corn growers to benefit from the VEETC when the RFS is binding because the total amount of ethanol consumption is limited to the RFS's specified level. If the VEETC were eliminated, then motor fuel blenders would lose their tax credits, motor fuel purchasers may pay higher prices at the pump, and ethanol producers may receive less for ethanol.[8]

The RFS is not binding when ethanol consumption exceeds the RFS level. While consumption up to the RFS level would otherwise occur, some of this additional consumption above the RFS level is likely to result from the VEETC's ethanol price-lowering effects. In these circumstances, the VEETC directly benefits blenders by lowering their effective price for ethanol and could lead to lower prices at the pump for purchasers and higher prices received by ethanol producers. This in turn can lead to higher corn prices, which benefit corn growers and nongrower owners of corn-producing land, while hurting other corn purchasers, including cattle, dairy, hog, and poultry ranchers and farmers and consumers. If the VEETC were removed in these circumstances, blenders' demand for ethanol could fall. In turn, this would cause the price of ethanol received by ethanol producers to fall, lowering their demand for corn, and subsequently leading to lower corn prices. Throughout the marketing chain, those who had benefited from the VEETC would lose their benefits.

[7]With a binding RFS, much of the VEETC's benefit may go to ethanol producers if the retail price of blended motor fuels is affected more by the price of gasoline than by the price of ethanol, as is the case of E10.

[8]The VEETC, in the form of forgone federal tax revenues, pays part of the cost of a binding RFS. Without the VEETC, the entire cost would be borne by ethanol purchasers—blenders or motor fuel purchasers, or both—or others to whom the purchasers may be able to pass on the cost, such as workers at blending refineries. Because the cost of tax expenditures is often hidden, placing the cost on market participants can make the RFS cost more transparent.

The Relationship between Crude Oil and Corn Prices Will Primarily Determine Whether the RFS Is Binding

Whether the RFS is binding or not primarily depends on the relationship between crude oil prices and corn prices, because those prices determine whether it is cheaper to produce gasoline or ethanol. Relatively high oil prices and relatively low corn prices (as might result from a bumper corn crop that exceeded forecasts) tend to favor ethanol consumption by increasing the cost of producing gasoline and lowering the cost of producing ethanol, respectively. Specifically, the RFS is less likely to be binding when oil prices are high relative to corn prices and more likely to be binding when oil prices are low relative to corn prices. Similarly, other factors that influence gasoline and ethanol production costs could affect the extent to which each is consumed and whether or not the RFS is binding.

Many analysts believe that under current market conditions, with crude oil prices well below the peaks they reached last year, the RFS for 2009 is binding. As evidence, some point to the prices that blenders are paying for RINs. When a blender uses more renewable fuel than is required by EPA's blending standard for that year, the extra RINs associated with that fuel can be sold to other blenders, who can use them to comply with the RFS. The sale prices for these RINs have been relatively high, implying that they are scarce, and, therefore, that the RFS is likely binding because few blenders are using more ethanol than the 2009 blending standard requires.

Economists have disagreed about the circumstances necessary to make the RFS nonbinding in 2009—one economist told us that crude oil prices would have to reach $80 per barrel while another said $120 per barrel.[9] A third economist stated that relative gasoline and ethanol prices in June 2009 approached the point that blenders would choose to blend more ethanol than the RFS requires because crude oil reached $70 on the spot market. Whether or not the RFS will remain binding in the next few years depends heavily on future oil and corn prices, which are hard to forecast. In addition, as corn starch ethanol consumption increases in future years under the RFS, higher oil prices will be needed to make the RFS nonbinding for a given level of corn prices. If oil prices continue to show the volatility that they have in the past 2 years, then periods in which the

[9]The crude oil price that would make the RFS nonbinding in 2009 will vary with corn prices, which are affected by such factors as the weather and export and livestock demand for corn. USDA data show the current ratio of corn stocks to a year's corn use is low by historical standards, suggesting the potential for volatile corn prices.

RFS is binding and nonbinding may alternate, leading the VEETC to have different effects.[10]

Some Recent Studies Have Proposed that the VEETC Be Revised

Since December 2007, when EISA substantially expanded the RFS for biofuels, several studies have examined the interaction of the RFS, the VEETC, and the import tariff (see app. V). Three economists who have studied this interaction stated that because the RFS is currently binding, the VEETC does not increase ethanol consumption and the benefits of the 45-cent- per-gallon tax credit mainly go to ethanol consumers in the form of lower fuel prices. They noted that some benefits likely accrue to ethanol blenders but no benefits accrue to corn growers or ethanol producers. A fourth economist stated that with a binding RFS, most of the VEETC's benefits go to consumers when oil prices are low and go to ethanol producers when oil prices are high.

Some of these recent studies have proposed that the VEETC be revised by (1) eliminating it, (2) phasing it out as the corn starch ethanol industry further matures, or (3) increasing the amount of the tax credit when oil prices are low and decreasing it when they are high. Three of the economists told us that when the RFS is binding it is as effective in stimulating ethanol consumption as the combination of the RFS and the VEETC, making taxpayer funds unnecessary. They also prefer the RFS over the VEETC as a way to stimulate ethanol consumption. One of the economists noted that the RFS is preferable because it is more transparent about how much the government wants to stimulate ethanol consumption than the combination of the RFS and the VEETC. The economist added that motor fuel blenders would likely lose if the VEETC was removed, but the exact impacts would depend on supply and demand elasticities. Others noted that the RFS alone costs taxpayers less than the VEETC, although one economist stated that eliminating the VEETC would increase the cost of E10 gasoline by at most 4-1/2 cents per gallon. The economists noted that ethanol blenders continued to receive the VEETC in June 2008—when gasoline prices exceeded $4 per gallon and ethanol prices reached $3 per gallon. Alternatively, two of the recent studies that examined federal biofuels supports did not reach conclusions or make recommendations about future federal supports.

[10]Crude oil prices on the spot market rose to $137 per barrel in July 2008 before dropping to $35 per barrel in January 2009 in response to lower demand because of the global economic recession. Crude oil prices on the spot market rose to $72 per barrel in June 2009.

Other Federal Biofuels Tax Expenditures Support Biodiesel and Cellulosic Biofuels Producers

High costs for producing advanced biodiesel and cellulosic ethanol have limited their ability to compete in fuel markets. The federal government has provided tax credits through the following tax incentives to stimulate production of these biofuels and assist small producers:

The Biodiesel Tax Credit and the Small Agri-Biodiesel Producer Credit: The Biodiesel Tax Credit provides a $1 per gallon tax credit for producing or blending biodiesel or agri-biodiesel.[11] The Small Agri-Biodiesel Producer Credit provides a 10-cent-per-gallon credit for the first 15 million gallons of agri-biodiesel produced for businesses. This credit is limited to agri-biodiesel producers with a production capacity of less than 60 million gallons per year. Together, these tax credits for biodiesel production—including biodiesel exports—increased from $30 million in fiscal year 2005 to $200 million in fiscal year 2008 according to Department of the Treasury estimates. Both are scheduled to expire on December 31, 2009. In 2008, U.S. biodiesel production totaled 690 million gallons, according to the National Biodiesel Board.

Biodiesel producers and blenders are eligible for these tax credits regardless of whether the biodiesel is consumed in the United States or is exported. In October 2008, the Congress closed the so-called "splash and dash" loophole for biodiesel that allowed biodiesel to be imported into the United States, blended with small amounts of diesel to claim the Biodiesel Tax Credit, and then exported for final use to a third country—often the European Union, which provides tax credits for biodiesel consumption. However, biodiesel produced in the United States for export is eligible to claim both tax credits. While no accurate data exist on the import and export of biodiesel, two economists estimated that between January and August 2008 at least 285 million gallons—or about 65 percent of domestic biodiesel production during this period—were exported. In June 2008, the European Commission initiated an antidumping investigation and, in March 2009, the European Commission imposed provisional antidumping and antisubsidy duties on U.S. biodiesel imports. The duty rates vary by producer.

Annual RFS levels for biomass-based diesel begin with 500 million gallons in 2009 and rise to at least 1 billion gallons in 2012 and each year

[11] Agri-biodiesel is defined as biodiesel produced from virgin agricultural products such as soybean oil or animal fats, as opposed to biodiesel produced from previously used agricultural products such as recycled fryer grease.

thereafter.[12] To qualify as biomass-based diesel under the RFS, a biorefinery's production must generally achieve at least 50 percent less lifecycle greenhouse gas emissions than baseline petroleum fuels. Production that does not qualify as biomass-based diesel might be able to qualify for the RFS's allocation of advanced biofuels that is not designated for biomass-based diesel or cellulosic biofuels. If not, it would then compete with conventional corn starch ethanol.

- *Cellulosic Biofuel Producer Tax Credit and Special Depreciation Allowance for Cellulosic Biofuel Plant Property:* The Cellulosic Biofuel Producer Tax Credit provides a $1.01 per gallon tax credit for cellulosic biofuel produced after December 31, 2008. The value of this credit is reduced by the value of other tax credits, including the VEETC and the Small Ethanol Producer Tax Credit, so that the maximum combined credit a cellulosic biofuel producer may claim is $1.01 per gallon.

  The Special Depreciation Allowance for Cellulosic Biofuel Plant Property allows qualified cellulosic biofuel plant owners to take a depreciation deduction of 50 percent of the adjusted basis of the plant in the year it is put in service. There have been no expenditures associated with either of these tax incentives. Both incentives are scheduled to expire on December 31, 2012.

- *The Small Ethanol Producer Tax Credit:* The Small Ethanol Producer Credit provides a 10 cent per gallon credit for the first 15 million gallons of ethanol produced each year by businesses with a production capacity of less than 60 million gallons annually. According to Department of the Treasury estimates, expenditures for income tax credits for ethanol have remained flat at around $40 million for fiscal years 2005 through 2008 with one exception in fiscal year 2006 when the expenditure was $50 million.[13] To date, the small ethanol producer credit has primarily gone toward corn starch ethanol because no cellulosic ethanol has been commercially produced, but small producers of cellulosic ethanol are also eligible for this tax credit. This tax credit is scheduled to expire on December 31, 2010.

[12]Biodiesel refineries have about 2.7 billion gallons of annual production capacity.

[13]The Department of the Treasury reports expenditures for the Small Ethanol Producer Credit and other ethanol income tax credits together, so this total may include expenditures on other ethanol income tax credits.

Conclusions

The RFS requires rapidly increasing levels of biofuels to be blended into U.S. transportation fuels through 2022 and allows the use of up to 15 billion gallons of conventional corn starch ethanol in 2015 and annually thereafter. Under current market conditions, the VEETC does not stimulate additional ethanol consumption above the required level, making it duplicative to the RFS with respect to ethanol use. As long as the RFS is binding, the VEETC benefits motor fuel blenders, ethanol consumers, and ethanol producers, but does not affect corn growers' income. At the same time, by increasing ethanol use through 2015, the RFS has increased the VEETC's cost to the Treasury in forgone revenues because blenders are given a tax credit of 45 cents for each gallon of ethanol they blend with gasoline. The cost of this tax credit could reach $6.75 billion in 2015 and each year thereafter for corn starch ethanol. Furthermore, the conventional corn starch industry is mature because the technology is well-understood and biorefineries have the capacity to produce 11.5 billion gallons of ethanol each year. The VEETC was more important in helping to create a profitable industry when the industry had to fund facilities investment than it is now for sustaining the industry when most of the capital investment has already been made. The 2008 Farm Bill reduced the VEETC from 51 cents to 45 cents per gallon while establishing a $1.01 per gallon tax credit for advanced cellulosic biofuels. While proposals have been made to reduce, phase out, or modify the VEETC, the direct and indirect effects on motor fuel blenders and other market participants are uncertain. Moreover, fluctuations in crude oil prices, such as that experienced in the past 2 years, create additional uncertainties as to whether the RFS will be binding in future years, with possible implications for the VEETC. The Congress is expected to review the VEETC next year because it will be terminated on January 1, 2011, unless renewed.

Matter for Congressional Consideration

Because the RFS allows rapidly increasing annual amounts of conventional biofuels through 2015 and the conventional corn starch ethanol industry is mature, the Congress may wish to consider whether revisions to the VEETC are needed. Options could include maintaining the VEETC, either reducing the amount of the tax credit or phasing it out, or modifying the tax credit to counteract fluctuations in crude oil prices.

Chapter 6: Federal Biofuels R&D Primarily Supports Developing Cellulosic Biofuels

Cellulosic ethanol is a primary focus of federal biofuels R&D. DOE and USDA, the largest sponsors of biofuels R&D, obligated about $500 million in this area in fiscal year 2008. The Energy Independence and Security Act (EISA) of 2007 and the 2008 Farm Bill authorized significant new biofuels spending for 2009 and beyond, and the American Recovery and Reinvestment Act of 2009 provided DOE with $800 million for biofuels R&D. Many experts identified important R&D areas for stimulating cellulosic biofuels production.

Federal Biofuels R&D Programs Are Growing and Focus on Cellulosic Ethanol

Federal agencies obligated about $505.5 million for biofuels R&D in fiscal year 2008 (see table 6).[1] DOE obligated $463.2 million in fiscal year 2008, primarily on cellulosic ethanol R&D. USDA obligated an estimated $39.3 million on bioenergy and renewable energy R&D in fiscal year 2008. EPA's Office of Research and Development obligated about $3 million for biofuels R&D related to EPA's regulatory responsibilities in fiscal year 2008. Each of these agencies significantly increased biofuels R&D obligations between fiscal years 2005 and 2008.

Table 6: Federal Agencies' Obligations for Biofuels R&D, Fiscal Years 2005-2008

Dollars in millions

	Fiscal year			
Agency	**2005**	**2006**	**2007**	**2008**
DOE	$117.8	$95.0	$213.6	$463.2
USDA	26.7	30.0	35.1	39.3
EPA	0.3	0.3	0.7	3.0
Total	**$144.8**	**$125.3**	**$249.4**	**$505.5**

Sources: DOE, USDA, and EPA.

Note: Obligated amounts may differ from appropriated amounts because they account for deobligations, recast funds, carryover funds, and rescissions. USDA obligations data for fiscal year 2008 are estimates, as are obligations data for fiscal years 2005-2008 for DOE's Office of Science.

[1]This total includes USDA obligations for all renewable energy programs because USDA could not break-out the total by focus or technology. USDA obligations data for fiscal year 2008 are estimates, as are obligations data for fiscal years 2005-2008 for DOE's Office of Science.

DOE's Obligations for Biofuels R&D Have Grown Substantially

DOE's obligations for biofuels R&D have increased almost fourfold since fiscal year 2005, when it obligated $117 million on biofuels R&D. About 75 percent of DOE's fiscal year 2008 obligations for biofuels R&D supported the Office of Energy Efficiency and Renewable Energy's Biomass Program (about 70 percent primarily focused on cellulosic ethanol) and Vehicle Technologies Program (about 5 percent). About 25 percent of DOE's fiscal year 2008 obligations for biofuels R&D supported basic research through the Office of Science.

- *Biomass Program:* Biofuels R&D obligations by the Biomass Program more than quadrupled between fiscal years 2005 and 2008—from about $76 million to $327 million—with the percentage of funding going to cellulosic ethanol increasing to about 70 percent by fiscal year 2008. In particular, these funds support the Integrated Biorefineries Program with a goal of developing commercial-scale integrated biorefineries to demonstrate how these biorefineries can use a wide variety of cellulosic feedstocks and operate profitably once construction costs are covered. In February 2007, the Biomass Program awarded up to $385 million over 5 years, subject to annual appropriations, that would provide, at most, 40 percent of the costs for each of six pilot integrated cellulosic biorefinery projects. Subsequently, two projects withdrew, and DOE now plans to invest up to $272 million in the remaining four projects, subject to annual appropriations, between fiscal years 2007 and 2011 (see table 7).

Table 7: Integrated Biorefinery Projects Receiving DOE Funding

Dollars in millions

Project company and location	Technology, feedstock, and production capacity	Potential DOE and industry funding over 5 years[a]
Abengoa Bioenergy Biomass of Kansas, LLC Hugoton, Kansas	*Technology:* Thermochemical and biochemical processing *Feedstock:* 700 tons/day of corn stover, wheat straw, milo (sorghum) stubble, switchgrass, and other opportunity feedstocks *Production capacity:* 11.4 million gallons/year of ethanol and sufficient energy to power the operation and sell excess energy to the co-located dry-grind ethanol production plant	DOE: $76.3 Industry: $114.2
BlueFire Ethanol, Inc. Riverside and San Bernardino Counties, California	*Technology:* Concentrated acid processing followed by fermentation of sugars to ethanol *Feedstock:* 700 tons/day of sorted green waste and wood waste from landfills *Production capacity:* 19 million gallons/year in the unit in which DOE will be participating	DOE: $40.0 Industry: $61.8

Project company and location	Technology, feedstock, and production capacity	Potential DOE and industry funding over 5 years[a]
POET Project Liberty, LLC Emmetsburg, Iowa	*Technology:* Integrating production of ethanol into a dry grind corn mill process *Feedstock:* 700 metric dry tonnes/day of corn fiber, corn stover *Production capacity:* 125 million gallons/year, of which roughly 25 percent will be from lignocellulosics	DOE: $80.0 Industry: $123.5
Range Fuels, Inc. near Soperton, Georgia	*Technology:* Conversion through catalytic upgrading of syngas to ethanol and methanol *Feedstock:* 2500 tons/day of unmerchantable timber and forest residues *Production capacity:* 20 million gallons/year from first unit and about 100 million gallons/year of ethanol and about 20 million gallons/year of methanol from the commercial unit	DOE: $76.0 Industry: $280.0

Source: DOE.

[a]DOE's potential funding is subject to review and annual appropriations.

- *Vehicle Technologies Program:* The Vehicle Technologies Program's biofuels-related obligations increased from about $9 million in fiscal year 2005 to about $22 million in fiscal year 2008. Its primary projects currently are an intermediate ethanol blends test program, which is co-led by the Biomass Program, and an ethanol optimization program. The intermediate blends test program is studying the emissions, driveability, materials compatibility, and emissions control system durability for E15 and E20 ethanol blends. The ethanol optimization program is conducting R&D on the design of flexible-fuel vehicles that will run optimally on fuels of any ethanol blend.

- *Office of Science:* Obligations for biofuels R&D at the Office of Science increased from about $33 million in fiscal year 2005 to about $114 million in fiscal year 2008. The Office of Science primarily supports basic biofuels research through its Offices of Basic Energy Sciences and Biological and Environmental Research and three Bioenergy Research Centers. Most of the Office of Science's biofuels obligations in fiscal year 2008 supported the three Bioenergy Research Centers—individually led by Oak Ridge National Laboratory, the University of Wisconsin, and Lawrence Berkeley National Laboratory. The Office of Science plans to provide each with a total of up to $125 million between fiscal years 2008 and 2013, subject to annual appropriations, to accelerate basic research in the development of cellulosic ethanol and other biofuels.

In addition, DOE's Office of the Chief Financial Officer administers DOE's loan guarantee program for categories of energy projects that provide a reasonable prospect of repayment and that commence construction by September 30, 2011, including leading edge biofuel projects that will use technologies performing at the pilot or demonstration scale that the Secretary determines are likely to become commercial technologies and will produce transportation fuels that substantially reduce lifecycle greenhouse gas emissions compared with other transportation fuels. DOE is currently reviewing loan guarantee applications for several biofuel projects but, to date, has not approved any.

USDA's Obligations for Biofuels R&D Have Gradually Risen

USDA obligated an estimated $39 million in fiscal year 2008 for bioenergy and renewable energy R&D, including biofuel, wind, solar, and geothermal energy projects. USDA's obligations increased from about $27 million in fiscal year 2005 to about $39 million in fiscal year 2008. Most of these funds supported the Agricultural Research Service, USDA's chief scientific research agency, for R&D focused on developing technologies for the sustainable production and harvest of biomass feedstocks and the production of biofuels at or near the farm. The goals of this R&D are to identify (1) varieties and hybrids of bioenergy feedstocks with optimal traits, (2) optimal practices and systems that maximize the sustainable yield of high-quality bioenergy feedstocks, and (3) enabling commercially preferred biorefining technologies. For example, the renewable energy assessment program is assessing the maximum sustainable harvest of corn stover while maintaining soil organic matter.

USDA's Cooperative State Research, Education, and Extension Service, which will become the National Institute of Food and Agriculture on October 1, 2009, supports land grant university research, conducts outreach and education activities, and co-administers a Biomass Research and Development Initiative competitive grant process with DOE.

USDA guaranteed loans for biofuels projects grew from $13.3 million in fiscal year 2005 to $88.3 million in fiscal year 2007 but declined to $16.5 million in fiscal year 2008 for four biofuels related projects. USDA's Rural Development program provides loan guarantees primarily through the Business and Industry Guaranteed Loan Program and the Rural Energy for America Program. The Rural Business Cooperative Service, within Rural Development, and the Commodity Credit Corporation, within the Farm Service Agency, administer grant, loan guarantee, and payment programs to expand ethanol, biodiesel, and advanced biofuel production capacity.

EPA's R&D Addresses the Full Biofuels Lifecycle

Obligations by EPA's Office of Research and Development for biofuels R&D increased from $340,000 in fiscal year 2005 to about $3 million in fiscal year 2008. This R&D, which supports EPA's mission and regulatory responsibilities, focused on the biofuels lifecycle in fiscal year 2008. Specifically, this R&D includes (1) improving the characterization of greenhouse gas emissions; (2) assessing the environmental and human health risks associated with existing and future feedstock, conversion technology, and fuel pathways; (3) assessing the risks associated with genetically engineered plants and microbes; (4) assessing the environmental implications of increased biofuel concentrations stored in tanks including impacts on leak prevention, detection, and remediation of releases, and implications for protection of ground water; (5) verifying emerging biofuels tank leak detection systems; (6) assessing the environmental implications of using animal manures and municipal solid waste as a feedstock; and (7) characterizing risks and updating EPA's Integrated Risk Information System, particularly related to air emissions resulting from increased biofuels consumer use.

The Congress Has Authorized and Appropriated Additional Funding for Biofuels R&D

The research and energy titles of the 2008 Farm Bill reauthorized existing programs and created several new initiatives to promote biofuels use, develop advanced biofuels, and increase advanced refinery capacity. Some of these provisions provide mandatory funding, while others authorized the use of discretionary funds through fiscal year 2012. For example, USDA's former Bioenergy Program was revised to provide payments to support and expand production of advanced biofuels, with mandatory funding of at least $300 million through fiscal year 2012. The act also created the Biomass Crop Assistance Program, directing the Secretary of Agriculture to support the establishment of eligible perennial crops for bioenergy production and biofuels production through contracts using such sums as necessary from Commodity Credit Corporation funds through 2012. In addition, the act authorized (1) grants, contracts, and financial assistance for biofuels research, including at least $118 million in mandatory funding through fiscal year 2012; (2) competitive grants and loan guarantees for the construction or retrofit of biorefineries for advanced biofuels production for $320 million to $920 million through fiscal year 2012; and (3) a R&D program to encourage using forest biomass for energy and grants for energy efficient research and extension projects.

The American Recovery and Reinvestment Act of 2009 appropriated $800 million to DOE for biomass-related projects. In addition, the Omnibus Appropriations Act of 2009 appropriated $217 million for DOE's biomass and biorefinery systems R&D program.

Experts Identified R&D Areas for Improving Cellulosic Biofuels Production

Many experts cited the importance of R&D in the following areas for stimulating cellulosic biofuels production:

- *Long-term R&D on energy crops to improve plant and tree characteristics.* Long-term R&D on certain food, feed, and fiber crops has led to improved yields and quality. For example, researchers are examining ways to improve physiological characteristics of the feedstocks, including greater ability to accumulate carbon through photosynthesis; a more conducive molecular structure for conversion into fuel; pest resistance; and greater drought, salt, and cold tolerance.

- *Reducing environmental impacts.* Several experts cited the importance of examining the impacts of feedstock cultivation on soil quality, water quality and quantity, wildlife, and greenhouse gas emissions by using such tools as remote sensing and decision tools that consider biophysical, economic and social factors at scales ranging from field to farm to watershed. Real-world data will improve projections and estimates that would help land managers and policy makers to better predict the outcomes of certain production and management practices and weigh their potential advantages and disadvantages.

- *Conducting large-scale field trials.* DOE's and USDA's Regional Feedstock Partnership initiated 38 herbaceous crop and corn stover removal field trials in 2008 to help develop best practices for producing, harvesting, and managing energy crops. For example, USDA and DOE are using field trial data to develop a computer tool to maximize the amount of corn stover that can be removed without materially reducing soil organic matter or increasing soil erosion. However, DOE's manager for the partnership program stated that the 5-acre research plots used by the Regional Feedstock Partnership are too small to collect and integrate sufficient data on nutrient, carbon, and water cycles. The manager cited the importance of large-scale field trial data for developing cropping and harvesting approaches and estimating likely yields and environmental impacts. In addition, USDA's Renewable Energy Assessment Project is conducting field trials assessing the impact of biomass removal—primarily corn stover but also cotton residues and switchgrass—on long-term soil productivity at multiple locations across the nation.

Chapter 7: Significant Challenges Must Be Overcome to Meet the RFS's Increasing Volumes of Biofuels

The domestic biofuels industry faces multiple challenges to meet the RFS's increasing volumes of biofuels, particularly those volumes related to cellulosic biofuels. At least 16 billion gallons of the 21-billion-gallon requirement for advanced biofuels must be met from cellulosic feedstocks; yet cellulosic ethanol currently costs at least twice as much to produce as conventional corn starch ethanol. Collecting, transporting, and storing the leaves, stalks, and even tree trunks of cellulosic biomass needed by cellulosic biorefineries presents numerous logistical difficulties that increase costs. Also, cellulosic conversion technology needs further development to reduce processing costs. Scientists are currently working to do so through improved pretreatment processes and biochemical and thermochemical refining technologies.

An immediate challenge that may limit the use of ethanol produced from either corn starch or cellulosic feedstocks is the lack of infrastructure for distributing and using the growing volumes of ethanol. Specifically, because the Clean Air Act limits the ethanol content in gasoline to 10 percent for most U.S. vehicles and the current economic slowdown has reduced U.S. gasoline demand, the nation may reach the blend wall—the point where all of the nation's gasoline supply is blended as E10 and extra volumes of ethanol cannot be readily consumed—as early as 2011. If EPA and vehicle manufacturers find that the current U.S. vehicle fleet cannot use higher ethanol blends, additional ethanol consumption will be limited to specially designed vehicles known as flexible-fuel vehicles because they can use either gasoline or E85—a blend of 85 percent ethanol and 15 percent gasoline. However, expanding E85 consumption will depend on substantial investment in the ethanol distribution infrastructure and consumer purchases of flexible-fuel vehicles. Alternatively, if advances are made in thermochemical refining technology, biorefineries could produce products that are compatible with the existing oil refining, distribution, and storage infrastructure and the existing vehicle fleet—and therefore avoid blending wall issues. While the RFS requires more modest use of biodiesel beginning in 2009, this industry faces its own set of challenges, including the cost of feedstocks and a limited U.S. market for its product.

Farmers and Other Suppliers Face the Challenge of Identifying and Developing Productive and Profitable Cellulosic Feedstocks

Various potential cellulosic feedstocks are being explored for commercial use. A 2005 study, sponsored by DOE and USDA, identified more than 1.3 billion dry tons per year of biomass potential in the United States—an amount sufficient, according to the study, to produce biofuels that could replace 30 percent of U.S. crude oil consumption by around 2030 and still meet food, feed, and export demands.[1] The study identified two broad sources of biomass potential:

- *From agricultural lands.* 998 million sustainable dry tons are estimated to be potentially available annually, assuming extensive development, including 428 million dry tons from annual crop residues; 377 million dry tons of perennial crops; 87 million dry tons of grains used for biofuels; and 106 million dry tons of animal manures, process residues, and other miscellaneous feedstocks.

- *From forest lands.* 368 million sustainable dry tons of biomass feedstock are estimated to be available annually, including 145 million dry tons from forest products industry residues, 64 million dry tons from logging and site-clearing residues, 60 million dry tons from fuel treatment operations to reduce fire hazards, 52 million dry tons in fuel wood, and 47 million dry tons in urban wood residues (yard and tree trimmings, packaging materials, and construction and demolition debris).[2]

Despite the vast availability of potential cellulosic feedstocks, uncertainties remain over how much of it will be profitable for either a farmer to grow or a supplier to harvest. The chemical composition of fuel ethanol does not change whether it is made from corn starch or cellulosic sources. In general, to operate profitably an ethanol refinery needs a year-round supply of large volumes of low-cost feedstocks that are of consistent quality. As a result, the relative cost, consistency, volume, and accessibility of a feedstock is critical in determining whether it is ultimately sought by an ethanol refinery. In this context, farmers and

[1]Oak Ridge National Laboratory, prepared for DOE and USDA, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (April 2005).

[2]The Billion-Ton study may have overestimated the amount of feedstock that can be economically harvested because it did not calculate costs associated with harvesting potential feedstocks with existing technology. The study also included woody biomass from federal forest lands, but EISA subsequently excluded such biomass from qualifying under the RFS. An updated study is expected to be published later this year.

suppliers face multiple challenges in identifying and developing productive and profitable cellulosic feedstocks, including the following:

- *The production, yield, and marketing of dedicated energy crops are uncertain.* Switchgrass is considered a promising biofuel feedstock and offers the potential to expand the geographic range of biofuel refineries due to its productivity on poor soil and low fertilizer and water needs. Yet, because switchgrass is a perennial crop that requires time to establish, farmers may face a 2- to 3-year period before switchgrass fields mature and potentially become economically productive.[3] In addition, although switchgrass has frequently produced more than 10 tons of dry matter per acre on test plots, yields could vary widely depending on such factors as land quality, weather conditions, weeds, and overall management. Furthermore, it will take time to develop the means to produce switchgrass on a large scale and to develop markets for this and other new feedstocks. Finally, potential feedstock producers would also have to consider less tangible factors, such as complexity, convenience, and ability to conserve soil and habitat. For example, advanced feedstock crops could require different planting and harvest schedules, which could interfere with other tasks on the farm or with family obligations.

- *The use of agricultural residues may be limited.* In contrast to dedicated energy crops, agricultural residues, such as corn stover, are already produced in substantial quantities and located nearby existing ethanol refineries. However, the amount of residues that farmers will be able and willing to remove from their fields is unknown. Agricultural residues are vital for preventing soil erosion and improving soil fertility. The amount of agricultural residues that can be safely removed will vary by field and region and is the subject of ongoing research. There are also practical considerations that could make corn stover harvesting unprofitable or make farmers unwilling to harvest remaining residues. For instance, corn stover harvesting may compete with other crop harvesting operations and complicate their collection. Also, weather and soil conditions may not allow timely field drying of corn stover for safe storage. Corn stover can also become contaminated with dirt and other materials during harvesting,

[3]The Tennessee Biofuel Initiative includes a demonstration pilot refinery that is scheduled to begin producing ethanol from switchgrass by the end of 2009. The university entered into 3-year contracts with switchgrass producers to help reduce the financial uncertainty that farmers face when deciding to grow switchgrass and ensure feedstock availability for the refinery.

which can limit its consistency and therefore its desirability as an ethanol feedstock.

- *Feedstock demand for certain residues may conflict with current uses and restrictions*. Mill residues such as bark, sawdust and shavings, are generally dry, consistent and concentrated—all desirable feedstock characteristics sought by ethanol refineries. However, mill waste is currently used for fuel, particleboard and mulch. Similarly, other potential feedstocks, including willow, poplar, pines, and cottonwood, have already been established and are being commercially harvested, primarily for pulpwood and other wood products. As a result, ethanol refineries would have to compete with other markets for these higher-valued feedstocks. Growers of new stands of woody biomass face time lags even longer than for perennial herbaceous crops before trees mature and potentially become economically productive. For example, hybrid poplar trees require 8 to 15 years of growth to reach their first harvest. Finally, biomass harvested from federal forest lands generally cannot be counted toward RFS specified levels. The Energy Independence and Security Act (EISA) excludes forest-related slash and precommercial tree thinning—the trimming or removal of trees in a stand of trees to improve the growth of the remaining trees—harvested from federal forest lands.

- *EISA and the 2008 Farm Bill provide different definitions of renewable biomass.* EISA requires that, for purposes of RFS-specified levels, cellulosic biofuels be derived from renewable biomass and provides a more limited definition of this term than the 2008 Farm Bill. For example, EISA's definition of renewable biomass excludes municipal waste and residues or other woody crops on federally managed forest land. Also, with regard to planted crops and crop residues, EISA defines renewable biomass as planted crops and crop residue harvested from agricultural land cleared or cultivated prior to its enactment that is either actively managed or fallow and nonforested. In contrast, the 2008 Farm Bill contains no similar exclusions or restrictions in its definition of renewable biomass. The different definitions could cause confusion over where biomass may be grown or harvested. Some government and academic projections assume that biofuels made from feedstock on federal forest lands will count toward the RFS, and they include these feedstocks in their projections of the amount of feedstock that will potentially be available for biofuel production.[4] Some USDA, DOE, and EPA officials told us that these inconsistencies have complicated rule formulation and could make it more difficult to meet the RFS's advanced biofuel requirements. Without clarification of the renewable biomass definition and how it affects land eligibility, stakeholders and program officials may be unsure about how to most efficiently and effectively reach individual program outcomes, meet interagency goals such as those in the National Biofuels Action Plan, and achieve RFS's specified levels. This could reduce the focus on and investment in a feedstock source that some experts consider among the most favorable options, provided an economical conversion process can be demonstrated. On the other hand, agency officials also expressed concern that if renewable biomass is defined too broadly, this could permit feedstock production on lands that now provide a carbon sink or other environmental benefits, thus potentially increasing greenhouse gas emissions.

Cellulosic Feedstocks Pose Unique Logistical Challenges for Biorefineries

Additional challenges for the cellulosic biofuel industry lie in the feedstock supply chain. Specifically, cellulosic feedstocks do not have the established and efficient harvest, storage, and transportation infrastructure long since developed for corn. In contrast to corn kernels that currently compose most of the biomass used in domestic ethanol refineries, cellulosic feedstocks are less energy dense, bulkier, and more difficult and costly to transport. They are also harder to dry and store and lack established feedstock quality standards sought by ethanol refineries. According to DOE officials, cellulosic ethanol currently is estimated to cost at least twice as much to produce as conventional corn starch ethanol and the uncertainty of the biomass feedstock supply chain and associated risks are major barriers to procuring capital funding for start-up cellulosic biorefineries.[5] The Biomass Research and Development Board estimates that supply chain costs for cellulosic ethanol refineries constitute as much as 20 percent of the projected cost of finished cellulosic ethanol and states that harvesting and collecting feedstocks from cropland or out of forest, feedstock storage, feedstock preprocessing, and feedstock transportation

[4] The Biomass Research and Development Board's November 2008 report, which models and projects potentially available feedstock amounts, does not consider materials from federal lands as eligible.

[5] The 2008 Farm Bill established a $1.01 per gallon tax credit through 2012 for cellulosic biofuels producers and reduced the VEETC, which is available for conventional corn starch ethanol, to 45 cents per gallon.

from the field to the refinery need to become more cost effective to meet the RFS.[6]

The industry faces several challenges in harvesting and collecting feedstocks, including operations to get cellulosic feedstock from its production source into storage. For example, as noted contamination of corn stover with dirt and other material can foul baling equipment. In addition, the contaminants can complicate feedstock grinding that occurs during preprocessing and the unneeded weight can increase transportation costs to the ethanol refinery. Also, weather and soil conditions may not allow farmers to leave the stover in the field long enough to dry to prevent spoilage during storage. In response to these issues, DOE has funded R&D to evaluate machinery capable of simultaneously segregating and processing both corn ears and stover in one pass, which could minimize these harvesting and collection problems. To date, few such machines are commercially available. As with corn stover, specialized machinery would need to be developed to harvest, handle, and collect large volumes of cellulosic feedstocks, regardless of whether they are agricultural residues, dedicated perennial energy crops, forest residues, or other feedstocks.

After harvesting and collection, adequate storage facilities are also needed because cellulosic feedstocks generally have a narrow harvest window and are subject to spoilage, while ethanol refineries require a large, steady, and year-round supply of a consistent-grade feedstock. Cellulosic feedstocks also require preprocessing steps, such as grinding, to minimize quality variability so that feedstocks have the proper moisture content, bulk density, fluid thickness (viscosity), and quality needed by an ethanol refinery. Finally, cellulosic feedstock suppliers face additional transportation costs associated with their feedstock. The low bulk density of cellulosic feedstocks would require additional deliveries to an ethanol refinery compared with a refinery that uses corn. Researchers at the National Renewable Energy Laboratory (NREL) forecast that cellulosic feedstock producers would generally need to be located within 50 miles of a cellulosic ethanol refinery to minimize feedstock transportation costs.

[6] Biomass Research and Development Board, *National Biofuels Action Plan* (Washington, D.C., October 2008).

High Costs and the Limitations of Current Conversion Technology Are Key Challenges to Making Cellulosic Biofuels Competitive with Other Fuels

Cellulosic conversion technology—whether through biochemical or thermochemical processes—needs more R&D and commercial development and is expensive relative to the cost of producing ethanol from corn starch. According to NREL researchers, producing cellulosic ethanol through biochemical conversion is difficult because it requires a complex chemical process to convert the plant material into simple sugars to use for ethanol.

The total project investment for a 50-million-gallon-per-year cellulosic ethanol biorefinery using a biochemical conversion process is estimated to be $250 million, as compared with a total project investment of $76 million for a similar capacity corn starch ethanol plant, according to NREL.[7] Because of these biorefinery capital costs and higher costs for collecting and transporting the feedstock, additional pretreatment steps, and enzymes to break down the sugars, the cost of producing a gallon of cellulosic ethanol is about twice that of producing a gallon of corn starch ethanol. Currently, while some small U.S. biorefineries are processing cellulosic feedstocks using biochemical or thermochemical conversion technologies, no commercial-scale facilities are operating. However, as of January 2009, 25 cellulosic ethanol projects with a combined projected production capacity of up to 376 million gallons per year were under development and construction in the United States, according to the Renewable Fuels Association.

To date, federal funding for R&D on processing cellulosic feedstocks into a biofuel has focused mainly on biochemical processes that use enzymes and microorganisms similar to a corn starch ethanol biorefinery to break down the sugars in cellulosic feedstocks to make ethanol. Less federal R&D funding has been spent on developing advanced thermochemical conversion processes, which use heat and chemical catalysts to break down cellulosic feedstocks. Thermochemical conversion processes can achieve higher fuel yields from a given feedstock than biochemical processes by converting more of the biomass into fuel. They also offer the potential to convert biomass into products that oil refineries can use as direct replacements for petroleum-based fuels, in contrast to ethanol. Federal R&D on thermochemical conversion technologies has focused on gasification and fast pyrolysis:

[7] Total project investment figures are in 2007 dollars and include plant construction, equipment, installation, site development, and other costs such as startup costs and permits.

- The gasification process heats the biomass at very high temperatures (about 800 degrees Celsius) with a controlled amount of oxygen to produce a mixture called synthesis gas, or syngas. With additional cleanup and conditioning, the syngas can then be used as a fuel itself to generate steam or electricity or used as a feedstock for Fischer-Tropsch synthesis, in which the syngas undergoes a catalytic reaction and can be converted into ethanol, diesel fuel, jet fuel, or other biofuels.

- The fast pyrolysis process, based on centuries-old technology used to make charcoal, heats biomass at high temperatures (about 400 to 500 degrees Celsius) in the absence of oxygen. About 60 percent to 70 percent of the conversion yield is an intermediate product referred to as bio-oil or pyoil. However, oil refineries currently cannot use pyoil as a petroleum substitute or hydrocarbon fuel because of its instability, inability to mix with petroleum, acidity, and corrosiveness. NREL, ARS, and industry scientists are conducting R&D on chemical catalysts to improve pyoil's stability and refinability by lowering its oxygen content and acidity. In addition, about 12 percent to 15 percent of the conversion yield of fast pyrolysis process is biochar, a carbon-rich charcoal similar in appearance to potting soil.[8] Injecting biochar in agricultural lands has been proposed as a way to both increase the soil's carbon content and reduce greenhouse gas emissions into the atmosphere. USDA is conducting research to quantify the effects of adding biochar into soils on crop productivity, soil quality, carbon sequestration, and water quality.[9] Finally, about 13 percent to 25 percent of the conversion yield is syngas, which can be used as a fuel for heat or power generation. Alternatively, the syngas from fast pyrolysis can also be used as a feedstock for Fischer-Tropsch synthesis and converted into different liquid fuels.

Researchers at NREL and USDA's Eastern Regional Research Center told us the pyrolysis conversion process offers two additional benefits. First, this technology can be used on a small, distributive scale that reduces feedstock transportation and storage costs. Because of its energy density per unit volume, the resulting pyoil is more economical to transport.

[8]The slow pyrolysis process, which heats biomass in the absence of oxygen over a longer time period, produces more biochar relative to pyoil than fast pyrolysis. The distribution of products on a weight basis for slow pyrolysis is about 30 percent liquid, 35 percent char, and 35 percent gas.

[9]Biochar may enable the removal of more corn stover and other agricultural residues from fields than can currently be removed and therefore increase the productivity of feedstock crops.

Second, pyrolysis converts more of the available biomass into fuels than biochemical conversion and is generally less energy intensive than either biochemical conversion or gasification. As a result, it is likely to have a smaller carbon footprint than the other conversion processes. Furthermore, the process could actually achieve net greenhouse gas reductions if the biochar successfully increases the soil's carbon content when it is injected in agricultural lands. However, researchers at both laboratories told us that pyrolysis R&D funding has been limited. NREL has primarily participated in a cooperative R&D agreement involving DOE's Pacific Northwest National Laboratory and UOP, a subsidiary of Honeywell. The Eastern Regional Research Center recently entered into a cooperative R&D agreement with Siemens Energy & Automation, Inc., and UOP to improve pyrolysis oil production technology.

Blending Limits and Transportation Pose Challenges to Expanded Ethanol Consumption

In 2008, U.S. biorefineries produced and distributed more than 9.2 billion gallons of ethanol. This ethanol was blended with gasoline to make either E10, which most vehicles can use as an oxygenate additive, or E85, which has a more limited market, primarily in the upper Midwest. Because the current economic slowdown has reduced U.S. gasoline demand, the nation may reach the blend wall—the point where all of the nation's gasoline supply is blended as E10 and extra volumes of ethanol cannot be readily consumed—as early as 2011. The United States may reach the blend wall limit solely with existing ethanol production from corn starch. This could greatly restrict the growth of the cellulosic biofuels industry, because ethanol is likely to be the first biofuel produced from cellulosic sources, rather than bio-oil or jet fuel.

One option to avoid the blend wall is to determine whether higher ethanol blends—E12, E15, or E20—can be used in the gasoline distribution and storage infrastructure and vehicles without adversely affecting the integrity of storage tank systems or vehicle equipment and performance. E10 is the highest ethanol blend that may currently be used in most U.S. vehicles. Before a higher ethanol blend could be marketed, EPA would have to approve a waiver to the Clean Air Act that would classify the blends as substantially similar to gasoline.[10] Similarly, automobile manufacturers would have to determine that a higher ethanol blend than E10 has no long-term effects on vehicle equipment and performance. Without this determination, they might void their warranty protection for existing vehicles that use a higher blend of ethanol. In addition, there are concerns that higher blends, or even E10, could damage non-auto engines, such as boat engines and small engines for equipment like lawn mowers and small tractors, and underground storage tank systems that were not rated to handle these higher blends. Also, leak detection technologies used in underground storage tank systems were developed for use with petroleum fuel and would need to be tested for performance with higher ethanol blend fuels.

DOE's NREL and Oak Ridge National Laboratory are collaborating with EPA to conduct a short-term emissions study using 20 cars to test 31 fuels, including ethanol blends. The study is expected to be completed by December 2009. In addition, under DOE's Intermediate Blends Test program, the two laboratories have initiated a project to test the long-term effects of using E15 and E20 blends by comparing them with vehicles that use unblended gasoline. Specifically, the laboratories are testing 32 cars over their full useful lives to assess emission control catalyst durability. The cars will run 120,000 miles with stops for all required vehicle maintenance and emission testing at 60,000; 90,000; and 120,000 miles. Smaller programs conducted in collaboration with the automotive and petroleum industries are examining fuel system materials compatibility and evaporative emissions, and they plan to initiate a study of vehicle cold start and drivability. Researchers expect to publish test results by June 2010.

A second option to avoid the blend wall is to increase E85 consumption by providing the infrastructure needed to distribute, store, and dispense E85, while also increasing the number of vehicles, called flex-fuel vehicles, that can run on E85. Expanding ethanol consumption will be costly because of the following:

[10]Section 211(f)(1)(A) of the Clean Air Act Amendments of 1990 provides that fuel and fuel additives marketed in the United States for use in light-duty vehicles must be "substantially similar" to the fuels used by EPA for federal emissions test procedures. Any fuel or fuel additive with more than 2.7 percent oxygen (by weight) is not considered to be substantially similar although EPA may grant a waiver of the substantially similar requirement if certain standards are met. EPA has granted waivers allowing ethanol concentrations of up to 10 percent of the volume of gasoline—or 3.5 percent oxygen by weight.

- Ethanol is transported primarily on the freight rail system, which is more costly than shipping by pipeline. According to NREL, the overall cost of transporting ethanol from refineries to fueling stations is estimated to range from 13 cents per gallon to 18 cents per gallon, as compared to the overall cost of transporting petroleum fuels via pipelines from refineries to fueling stations of about 3 cents to 5 cents per gallon. While ethanol cargo currently represents a relatively small share of overall rail volume, DOE and ethanol industry experts are concerned about the limited capacity of the freight rail system for transporting greater amounts of biofuels if production increases significantly. For example, in an April 2009 study, the National Commission on Energy Policy reported that few blending terminals have the off-loading capacity to handle large train shipments of ethanol.[11] In 2006, we reported that replacing, maintaining, and upgrading the existing aging rail infrastructure is extremely costly, and while railroad officials plan to make substantial investments in infrastructure, the extent to which these investments will increase capacity as freight demand increases is unclear.[12]

  Ethanol is not transported through the petroleum product pipeline system because of concerns that, for example, it will attract water in the pipes, rendering it unfit to blend with gasoline, according to DOE officials. Our June 2007 report found that even if ethanol could be shipped by existing pipelines, no pipelines exist to transport it from the Midwest, where it is mainly produced, to major markets on the East and West coasts.[13] Alternatively, existing petroleum pipelines could be used in certain areas to transport ethanol if ongoing efforts by operators to identify ways to modify their systems to make them compatible with ethanol or ethanol-blended gasoline are successful. A 2006 NREL report estimated the current costs of constructing pipelines at roughly $1 million per mile, although the costs can vary dramatically based on right-of-way issues, the number of required pumping stations, and other considerations.

[11] National Commission on Energy Policy, *Task Force on Biofuels Infrastructure* (Washington, D.C., April 2009).

[12] GAO, *Freight Railroads: Industry Health Has Improved, but Concerns about Competition and Capacity Should Be Addressed*, GAO-07-94 (Washington, D.C.: Oct. 6, 2006).

[13] See GAO, *Biofuels: DOE Lacks a Strategic Approach to Coordinate Increasing Production with Infrastructure Development and Vehicle Needs*, GAO-07-713 (Washington, D.C.: June 8, 2007).

- Ethanol is corrosive, so gasoline stations will need to install dedicated tank systems for storing E85 and specialized pumps and equipment for dispensing it. EPA estimates that the cost of installing E85 refueling equipment will average $122,000 per facility—which may be a significant impediment for many potential retailers. Liability concerns are also a challenge to increasing the number of E85 pumps. According to the Biomass Research and Development Board, one of the most significant hurdles to retail ethanol expansion is the current lack of Underwriters' Laboratory certification for pumps dispensing blends of E15 or higher because large operators of fuel pumps, ranging from the Postal Service to large retailers, will be reluctant to sell E85 or potentially other approved intermediate blends.

  In October 2008, we reported that the lack of E85 fueling stations greatly reduced the ability of the federal vehicle fleet to achieve its nationwide energy objectives for using alternative fuels.[14] We concluded that until alternative fuel, particularly E85, is more widely available, federal agencies will likely continue to expend time and resources on acquiring flexible-fuel vehicles that can run on E85 with limited success in displacing petroleum, possibly missing opportunities to displace petroleum through other means, such as through the purchase of conventional hybrids (vehicles that are powered by both an internal combustion engine and an electric motor) or natural-gas-powered vehicles.

- Only about 8 million flexible-fuel vehicles out of more than 250 million in the nationwide vehicle fleet can use E85. However, many flexible-fuel vehicles are using E10 because a ready supply of E85 does not exist outside the upper Midwest. Fueling stations offering E85 are concentrated in the upper Midwest—15 states have less than 10 such fueling stations and 7 states have none. As of February 2009, only about 1,900 fueling stations nationwide offered E85, compared with nearly 168,000 gas stations.

[14]GAO, *Federal Energy Management: Agencies Are Acquiring Alternative Fuel Vehicles but Face Challenges in Meeting Other Fleet Objectives*, GAO-09-75R (Washington, D.C.: Oct. 22, 2008).

The Biodiesel Industry Faces Feedstock and Market Challenges

The domestic biodiesel industry faces several challenges that limit its potential market.[15] Specifically, the biodiesel industry faces high feedstock costs.[16] The cost for soybean oil, the most common feedstock for U.S. biodiesel production, and other plant oils is high because the biodiesel industry competes with food and animal feed markets for these oils. These high feedstock costs have prompted the biodiesel industry to look to other feedstock sources, including animal fats, recycled greases, and nonfood-grade corn oil. The biodiesel industry also faces substantial production overcapacity. According to the National Biodiesel Board, as of September 2008, the annual production capacity from 176 existing U.S. biodiesel refineries totaled 2.61 billion gallons—yet actual U.S. biodiesel production reached 700 million gallons from October 1, 2007, to September 30, 2008, leaving the capacity utilization at many of these facilities extremely low.

In contrast to the U.S. ethanol industry, the nation's biodiesel refining capacity is relatively dispersed. While many biodiesel refineries are located in the Midwest, substantial refineries are located in the South and on the West Coast. Yet, as with the U.S. ethanol industry, biodiesel cannot be blended at oil refineries and transported through product pipelines because of contamination concerns. Rather, biodiesel is transported by railroad cars and tanker trucks to fueling stations, which are expensive and slower than using pipeline and, in turn, add to product cost. In addition, for biodiesel to penetrate the light-duty vehicle fleet beyond the B5 or B10 blending levels,[17] additional biofuel-capable vehicles must be produced and marketed to consumers. There are limited numbers of fueling stations carrying B20, because its physical properties may require the retrofit of storage tank systems and dispensing equipment.

Furthermore, while the RFS requires use of at least 500 million gallons of biodiesel in 2009, the National Biodiesel Board has expressed concern that the production from many biodiesel refineries, particularly ones using soybean and other vegetable oil feedstocks, may not qualify as biomass-based diesel under EPA's proposed RFS regulation because biomass-based diesel under the RFS must generally achieve at least a 50 percent

[15] The Emergency Economic Stabilization Act of 2008 (Pub. L. No. 110-343 § 202 (2008)) provides that all biodiesel fuels are eligible for a $1 per gallon biodiesel tax credit beginning January 1, 2009.

[16] Biodiesel production results in glycerol (glycerin) as a co-product. Rising biodiesel production has created a need to find new uses for it.

[17] B5 is a blend of 5 percent biodiesel and 95 percent petroleum-based diesel.

reduction in lifecycle greenhouse gas emissions as compared with petroleum fuels. A new biodiesel feedstock for the future is algae. DOE and private companies are increasing their funding of R&D to develop technologies that can cost effectively use algae to produce biodiesel.

Conclusions

The RFS allows the use of up to 15 billion gallons per year of conventional biofuel by 2015 and requires at least 21 billion gallons of advanced biofuels—with at least 16 billion gallons of this amount coming from cellulosic feedstocks—in 2022. Yet, at present, the distribution infrastructure and vehicle types necessary to transport and use increased ethanol production do not exist. In addition, the United States will reach the blend wall limit as early as 2011 solely with existing ethanol production from corn starch, which could greatly restrict the growth of the cellulosic biofuels industry. Thermochemical processing technologies, such as pyrolysis, have the potential to produce advanced biofuels that can be used in the nation's existing fuel distribution and vehicle infrastructure and therefore avoid future blend wall issues. However, DOE and USDA have not focused substantial R&D resources on developing these technologies. Furthermore, EISA and the 2008 Farm Bill define renewable biomass differently regarding feedstocks and land eligibility, creating difficulties for agencies to formulate rules, implement program activities, and effectively execute the interagency *National Biofuels Action Plan*. This may also create uncertainty for biofuels producers and could potentially reduce the nation's ability to increase advanced biofuels feedstock production and realize their benefits.

Recommendations for Executive Action

To minimize future blend wall issues and associated ethanol distribution infrastructure costs, we recommend that the Secretaries of Agriculture and Energy give priority to R&D on process technologies that produce biofuels that can be used by the existing petroleum-based distribution and storage infrastructure and the current fleet of U.S. vehicles.

To address inconsistencies in existing statutory language, we recommend that the Administrator of the Environmental Protection Agency, in consultation with the Secretaries of Agriculture and Energy, review and propose to the appropriate congressional committees any legislative changes the Administrator determines may be needed to clarify what biomass material—based on type of feedstock or land—can be counted toward the RFS.

Agency Comments

USDA and DOE commented on our recommendation for giving priority to R&D for producing biofuels that can be used by the existing petroleum-based infrastructure. Specifically, USDA agreed that this is an important goal which its R&D should address, but cited other similarly important R&D goals that its scientists are simultaneously pursuing, such as the development of feedstocks with physical and chemical properties that make them effective for conversion, and the creation of productive methods that are environmentally sound and economically advantageous for producing large quantities of feedstocks. In its comments, DOE stated that it has already expanded in this direction, noting for example that its $480 million funding opportunity announcement for integrated biorefinery operation, which closed on June 30, 2009, included green diesel and green gasoline. DOE also cited a new solicitation to fund consortia to accelerate development of advanced biofuels under the American Recovery and Reinvestment Act supports infrastructure-compatible fuels and algae-based fuels.

USDA, DOE, and EPA commented on our recommendation for clarifying what biomass material can be counted toward the RFS. USDA agreed with the recommendation that the executive agencies should consult on a definition and propose any legislative changes to the appropriate congressional committees, stating that the department supports the 2008 Farm Bill's definition. DOE stated that the department would welcome the opportunity to participate in deliberations about how to clarify the biomass definition if requested to do so by the EPA Administrator, adding that the department supports an expansion of biomass eligibility to include materials that do not come from federal lands classified as environmentally sensitive and that can be grown and harvested in a sustainable manner. EPA stated that the agency is working with USDA to identify inconsistencies and interpret how biomass is treated under EISA and the 2008 Farm Bill.

Appendix I: Key Studies on the Agricultural and Related Effects of Biofuels and on the Transition to Advanced Biofuel Feedstock Production

Abbott, P.C., Hurt, C., and Tyner, W.E. “What’s Driving Food Prices?” Farm Foundation, 2009.

Anderson, D.P., Outlaw, J.L., Bryant, H.L., Richardson, J.W., et al. “The Effects of Ethanol on Texas Food and Feed,” Agricultural and Food Policy Center, Texas A&M University, April 2008.

Babcock, B.A. “Breaking the Link Between Food and Biofuels,” Center for Agricultural and Rural Development, Iowa State University, Briefing Paper 08-BP 53, July 2008.

Baker, J.M., Ochsner, T.E., Venterea, R.T., and Griffis, T.J. “Tillage and Soil Carbon Sequestration: What Do We Really Know?” *Agriculture. Ecosystems and Environment*, vol. 118 (2007); 1-5.

Biomass Research and Development Board, “The Economics of Biomass Feedstocks in the United States: A Review of the Literature,” October 2008.

Biomass Research and Development Board, “Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research,” December 2008.

Cassman, K.G. “Ecological Intensification of Cereal Production Systems: Yield Potential, Soil Quality, and Precision Agriculture,” *Proceedings of the National Academy of Sciences*, vol. 96 (1999); 5952-5959.

Collins, K. *The Role of Biofuels and Other Factors in Increasing Farm and Food Prices: A Review of Recent Developments with a Focus on Feed Grain Markets and Market Prospects*, June 2008. Report prepared for Kraft Foods Global, Inc.

Congressional Budget Office, *The Impact of Ethanol Use on Food Prices and Greenhouse Gas Emissions*, April 2009.

De La Torre Ugarte, D., English, B.C., and Jensen, K. “Sixty Billion Gallons by 2030: Economic and Agriculture Impacts of Ethanol and Biodiesel Expansion,” *American Journal of Agricultural Economics*, vol. 89, no. 5 (2007): 1290-1295.

English, B.C., De La Torre Ugarte, D., Jensen, K., Hellwinckel, C., Menard, J., Wilson, B., Roberts, R., and Walsh, M. “25% Renewable Energy for the

United States by 2025: Agricultural and Economic Impacts," The University of Tennessee, November 2006.

Fabiosa, J.F., Beghin, J.C., Dong, F., Elobeid, A., Tokgoz, S., and Yu, T. "Land Allocation Effects of the Global Ethanol Surge: Predictions from the International FAPRI Model," Center for Agricultural and Rural Development, Iowa State University, Working Paper 09-WP 488, March 2009.

Fales, S.L., Hess, J.R., and Wilhelm, W.W. "Convergence of Agriculture and Energy: II. Producing Cellulosic Biomass for Biofuels," Council for Agricultural Science and Technology (CAST) Commentary, QTA2007-2, November 2007.

Fargione, J., Hill, J., Tilman, D., Polasky, S., and Hawthorne, P. "Land Clearing and the Biofuel Carbon Debt," *Science*, vol. 319 (2008): 1235-1238.

Feng, H. and Babcock, B.A. "Impacts of Ethanol on Planted Acreage in Market Equilibrium," Center for Agricultural and Rural Development, Iowa State University, Working Paper 08-WP 472, June 2008.

Fronning, B.E., Thelen, K.D., and Min, D.H. "Use of Manure, Compost, and Cover Crops to Supplant Crop Residue Carbon in Corn Stover Removed Cropping Systems," *Agronomy Journal*, vol. 100, no. 6 (2008): 1703-1710.

Groom, M.J., Gray, E.M., and Townsend, P.A. "Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production," *Conservation Biology*, 22, no. 3 (2008): 602-609.

Hayes, D.J., Babcock, B.A., Fabiosa, J.F., Tokgoz, S., Elobeid, A., Yu, T., Dong, F., Hart, C.E., Chavez, E., Pan, S., Carriquiry, M., and DuMortier, J. "Biofuels: Potential Production Capacity, Effects on Grain and Livestock Sectors, and Implications for Food Prices and Consumers," Center for Agricultural and Rural Development, Iowa State University, Working Paper 09-WP 487, March 2009.

Heaton, E.A., Dohleman, F.G., and Long, S.P. "Meeting U.S. biofuel goals with less land: The potential of Miscanthus," *Global Change Biology*, 14 (2008): 1-15.

Hill, J., Nelson, E., Tilman, D., Polasky, S., and Tiffany, D. "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol

Biofuels," *Proceedings of the National Academy of Sciences*, vol. 103, no. 30 (2006): 11206-11210.

Hipple, P.C., Duffy, M.D. "Farmers' Motivations for Adoption of Switchgrass," in J. Janich and A. Whipkey (eds.),*Trends in New Crops and New Uses* (Alexandria, Va.: ASHA Press, 2002): 252-266.

Hochman, G., Sexton, S.E., and Zilberman, D. "The Economics of Biofuel Policy and Biotechnology," *Journal of Agricultural & Food Industrial Organization*, vol. 6, no. 8 (2008): 1-22.

Johnson, J.M.F, Coleman, M.D., Gesch, R., Jaradat, A., Mitchell, R., Reicosky, D., and Wilhelm, W.W. "Biomass-Bioenergy Crops in the United States: A Changing Paradigm," *The Americas Journal of Plant Science and Biotechnology*, 1, 1 (2007): 1-28.

Johnson, J.M.F, Reicosky, D., Allmaras, R., Archer, D., Wilhelm, W. "A Matter of Balance: Conservation and Renewable Energy," *Journal of Soil and Water Conservation*, Jul/Aug, 61, 4 (2006): 120A-125A.

Khanna, M. "Cellulosic Biofuels: Are They Economically Viable and Environmentally Sustainable?" *Choices*, vol. 23, no. 3 (2008): 16-21.

Kim, S. and Dale, B.E. "Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel," *Biomass and Bioenergy*, vol. 29 (2005): 426-439.

Lawrence, C.J. and Walbot, V. "Translational Genomics for Bioenergy Production from Fuelstock Grasses: Maize as the Model Species," *The Plant Cell*, 19 (2007): 2091-2094.

Lawrence, J.D., Mintert, J., Anderson, J.D., and Anderson, D.P. "Feed Grains and Livestock: Impacts on Meat Supplies and Prices," *Choices*, vol. 23, no. 2 (2008): 11-15.

Low, S.A. and Isserman, A.M. "Ethanol and the Local Economy: Industry Trends, Location Factors, Economic Impacts, and Risks," *Economic Development Quarterly*, vol. 23, no. 1 (2009): 71-88.

McDonald, S., Robinson, S., and Thierfelder, K. "Impact of Switching Production to Bioenergy Crops: The Switchgrass Example," *Energy Economics*, vol. 28 (2006): 243-265.

Mitchell, D. “A Note on Rising Food Prices,” The World Bank, Policy Research Working Paper, no. 4682, July 2008.

McPhail, L.L. and Babcock, B.A. “Short-Run Price and Welfare Impacts of Federal Ethanol Policies,” Center for Agricultural and Rural Development, Iowa State University, Working Paper 08-WP 468, June 2008.

Naylor, R.L., Liska, A.J., Burke, M.B., Falcon, W.P., Gaskell, J.C., Rozelle, S.D., and Cassman, K.G. “The Ripple Effect: Biofuels, Food, Security, and the Environment,” *Environment*, vol. 49, no. 9 (2007): 31-43.

Oak Ridge National Laboratory, prepared for DOE and USDA. “Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply,” April 2005.

OECD, *Economic Assessment of Biofuels Support Policies*, 2008.

Parcell, J.L. and Westhoff, P. “Economic Effects of Biofuel Production on States and Rural Communities,” *Journal of Agricultural and Applied Economics*, vol. 38, no. 2 (2006): 377-387.

Pimentel, D. and Patzek, T.W. “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower,” *Natural Resources Research*, vol. 14, no. 1 (2005): 65-76.

Rajagopal, D., Sexton, S.E., Roland-Holst, D., and Zilberman, D. “Challenge of Biofuel: Filling the Tank without Emptying the Stomach?” *Environmental Research Letters*, vol. 2 (2007): 1-9.

Rajagopal, D. and Zilberman, D. “Review of Environmental, Economic and Policy Aspects of Biofuels,” The World Bank, *Policy Research Working Paper*, no. 4341, September 2007.

Robertson, G.P., Dale, V.H., Doering, O.C., Hamburg, S.P., Melillo, J.M., Wander, M.M., et al. “Sustainable Biofuels Redux,” *Science*, vol. 322 (2008): 49-50.

Sarath, G., Mitchell, R.B., Sattler, S.E., Funnell, D., Pedersen, J.F., Graybosch, R.A., and Vogel, K.P. “Opportunities and roadblocks in utilizing forages and small grains for liquid fuels,” *Journal of Industrial Microbiology and Biotechnology*, vol. 35, no. 5 (2008): 343-354.

Schmer, M.R., Vogel, K.P., Mitchell, R.B., and Perrin, R.K. “Net Energy of Cellulosic Ethanol from Switchgrass,” *Proceedings of the National Academy of Sciences*, vol. 105, no. 2 (2008): 464-469.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabioso, J., et al. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change,” *Science*, vol. 319 (2008): 1238-1240.

Senauer, B. “Food Market Effects of a Global Resource Shift Toward Bioenergy,” *American Journal of Agricultural Economics*, vol. 90, issue 5 (2008): 1226-1232.

Tokgoz, S., Elobeid, A., Fabiosa, J., Hayes, D.J., Babcock, B.A., Yu, T.H., Dong, F., and Hart, C.E. “Bottlenecks, Drought, and Oil Price Spikes: Impact on U.S. Ethanol and Agricultural Sectors,” *Review of Agricultural Economics*, vol. 30, no. 4 (2008): 604-622.

Tyner, W., and Taheripour, F. “Biofuels, Policy Options, and Their Implications: Analyses Using Partial and General Equilibrium Approaches,” *Journal of Agricultural and Food Industrial Organization*, vol. 6, article 9 (2008).

Walsh, M.E., De La Torre Ugarte, D.G., Shapouri, H., and Slinsky, S.P. “Bioenergy Crop Production in the United States—Potential Quantities, Land Use Changes, and Economic Impacts on the Agricultural Sector,” *Environmental and Resource Economics*, vol. 24, no. 4, (2003): 313-333.

Westhoff, P., Thompson, W., and Meyer, S. “Biofuels: Impact of Selected Farm Bill Provisions and Other Biofuel Policy Options, Food and Agricultural Policy Research Institute at University of Missouri-Columbia, *FAPRI-MU Report* no. 06-08, 2008.

U.K. Renewable Fuels Agency. “The Gallagher Review of the Indirect Effects of Biofuels Production,” East Sussex, United Kingdom, July 2008.

USDA, Cooperative State Research, Education, and Extension Service, “The Human and Social Dimensions of a Bioeconomy: Implications for Rural People and Places,” Discussion Paper, March 2007.

USDA, Economic Research Service and Office of Chief Economist. “An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture,” May 2007.

USDA, Office of the Chief Economist, De La Torre Ugarte, D.G., Walsh, M.E., Shapouri, H., and Slinsky, S.P. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture," Agricultural Economic Report, no. 816, February 2003.

USDA, Economic Research Service. "Productivity Growth in U.S. Agriculture," Economic Brief Number 9, September 2007.

USDA, Economic Research Service. "Economic Measures of Soil Conservation Benefits," Technical Bulletin Number 1922, September 2008.

USDA, Economic Research Service. "Feed Grains Backgrounder," March 2007.

USDA, Economic Research Service. "Environmental Effects of Agricultural Land-Use Change: The Role of Economics and Policy," Economic Research Report Number 25, August 2006.

USDA, Economic Research Service. "Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices," July 2008 (revised).

USDA, Economic Research Service. "Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?" May 2007.

USDA, National Agricultural Statistics Service, 2007 Census of Agriculture, Vol. 1, Part 51, February 2009.

USDA, Office of the Chief Economist. "USDA Agricultural Projections to 2017," February 2008.

United Nations Food and Agriculture Organization. *The State of Food and Agriculture: Biofuels—Prospects, Risks, and Opportunities*, Rome, Italy, 2008.

Varvel, G.E., Vogel, K.P., Mitchell, R.B., Follett, R.F., and Kimble, J.M. "Comparison of Corn and Switchgrass on Marginal Soils for Bioenergy," *Biomass & Bioenergy*, vol. 32 (2008): 18-21.

Appendix II: Economic Studies Examining the Impacts of Increased Biofuel Production on U.S. Food and Agricultural Markets

We selected 12 key economic studies on the impacts of increased biofuel production on U.S. food and agricultural markets. The authors generally found, to varying degrees, that increased demand for biofuel production will affect many sectors throughout food and agriculture. We summarized the results of these studies for biofuel production, feedstock prices, feedstock production, food prices, other crop and livestock production and prices, land-use effects, changes in government program/welfare impacts, net farm income, and other impacts. The variation in impact found between these studies may be due, in part, to the different economic models, time periods, data and assumptions that they used. However, in general, the studies found that increased demand for corn ethanol had the following effects:

- Corn and soybean prices rose significantly, with the amount of the rise varying with the baseline, time period, and the scenario that the researchers used to make assumptions about economic conditions and ethanol demand.

- The production of other traditional crops declined with increases in biofuel demand while their prices increased.

- The increased prices of corn and other feed crops caused livestock production to decline, but the amount of this decline varied by animal, with the deepest declines in dairy, swine, and poultry.

- Increased production of dried distiller's grains (DDG)—a livestock feed and a co-product of ethanol production—mitigated the effects of increased feed prices somewhat in the short run.

- Land area devoted to corn increased and some other crops, such as barley and oats, used for livestock feed increased, while land planted to soybeans and other crops declined sharply.

- In six of the studies that looked at retail food prices, increased biofuel demand caused small increases in food prices.

Several of the studies also looked at the impacts on agricultural markets of increased biofuels from cellulosic feedstocks, and their outcomes varied, in part based on the baseline used, model, and assumptions they made about the land that was available and type of cellulosic feedstock assumed.

In table 8, we describe the basic methodology and modeling assumptions of the economic studies of the impacts of increased biofuel production. Specifically, we explain several aspects of the studies, including the main objective, type of model, data and time period, major assumptions, model scenarios, government policies examined, and other aspects examined. For most of them, the sources of biofuel feedstock examined was corn for ethanol, but corn stover, switchgrass, and other cellulosic feedstocks were also included, as well as soybeans for biodiesel. The studies assumed various analytical frameworks, including partial equilibrium and general equilibrium,[1] and employed a range of different modeling techniques, including econometric models, simulation models, optimization models, break-even analysis, and representative farm models.[2] For the most part, we selected studies that took a broader, more national approach. We also included studies that were quantitative or empirical in nature, in order to measure the impacts of increased biofuel production on various sectors of the food and agricultural market. To observe the impact of increased biofuels production on various market conditions, a majority of the studies included a variety of different scenarios, including higher crude oil prices, production shortfalls, higher productivity levels, various subsidy and biofuel mandate levels, and land-use policies. Also, three of the studies that we examined measured the impacts on various stakeholders, such as biofuel producers, crop and livestock producers, taxpayers, and consumers.

[1]Partial equilibrium models study a market for a commodity or industry in isolation, given the prices and production of all other commodities or industries in the economy are held constant. General equilibrium analysis looks at an economic system as a whole and observes the simultaneous determination of all prices and quantities of all goods and services.

[2]Although each model in the studies is adapted to the particular analysis at hand, a brief description of these general economic techniques is as follows: (1) Econometric analysis seeks to verify economic theory and measure economic relationships by statistical and mathematical methods, using such tools as regression analysis, for the purpose of forecasting future events and choosing desirable policies. (2) Simulation techniques are a form of forecasting that generates a range of alternative projections based on differing assumptions about future events, specifically to answer the question, “what would happen if” and is often used to assess the likely impacts of various economic policies. (3) Optimization models are a type of mathematical model that attempts to optimize (maximize or minimize) an objective function subject to certain resource constraints; they are also known as mathematical programming models. (4) Break-even analysis is an investigation of how changes in volume of production affect costs and profit, and is a valuable tool in setting price. The break-even point is the one which insures that all fixed and variable costs are covered, given a particular selling price. (5) Representative farm models are typically used to model or simulate the impact on reforms or policy changes on the individual farmer or household. This type of model relies on the identification of a typical or representative farm and production decisions made by the farm subject to resource constraints are generally modeled for the farm.

Table 8 presents some of the main results of these studies, including the impacts of increased biofuels production on feedstock production and prices, food prices, other crop and livestock prices, land-use impacts, government programs, and other effects. For most studies, we reported the results for all scenarios, but for a few we only reported on the major scenario due to space limitations.

Table 8: Major Economic Studies of Agricultural Market Impacts of Biofuels Production

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Economic Research Service and Office of Chief Economist, USDA, May 2007.				
Main purpose is to assess the effects on agriculture of alternative levels of biofuels production from corn (ethanol) and soybean oil (biodiesel). Also, to review the expansion of cellulosic ethanol production.	National Model: Food and Agricultural Policy Simulator (FAPSIM) using 2007 USDA baseline for years 2007-2016. Regional Model: Regional Environmental and Agricultural Programming Model (REAP) uses crop mix from 1992 National Resources Inventory.	-Increase in biofuel production was assumed to occur gradually over time, from 2007-2016. -Assumes only dried distiller's grain. -Conservation Reserve Program (CRP) acres remain constant in 2016.	**3 Scenarios:** 1) Corn ethanol increase to 15 billion gallons by 2016, biodiesel to 1 billion gallons. 2) Corn ethanol increase to 20 billion gallons by 2016, biodiesel to 1 billion gallons. 3) Effects of a production shortfall of 10% below baseline in 2012 for each scenario above.	-For scenarios 1 and 2, respectively: Corn production and price rise in both scenarios; 5.4 and 7.2 billion bushels and \$3.61 and \$3.95 per bushel in 2016. -Overall livestock production is reduced. -Soybean, wheat, cotton, and rice acreage declines over baseline. -Retail prices for pork, dairy, and broilers increase by 5.4, 4.8 and 4.4% (scenario 1) and 2, 1.4, and 1.9% (scenario 2) annually during 2007- 2016. -Net farm income increases by \$2.6 and \$7.1 billion, in scenarios 1 and 2, respectively.
De La Torre Ugarte, English, and Jensen, *American Journal of Agricultural Economics*, 2007.[a]				
Projects economic impacts of increasing ethanol beyond RFS: production to 10, 30, and 60 billion gallons by 2010, 2020, and 2030, and biodiesel production by 1 and 1.6 billion gallons by 2012 and 2030.	POLYSYS/ IMPLAN Integrator (PII) – a dynamic agricultural sector model incorporating an economic input-output model. 2006 USDA baseline. Facility output costs, feedstock and associated costs based on prior studies.	-Cellulose-to-ethanol assumed commercially available by 2012. -Switchgrass is proxy for energy crop with yields from 1.5 to 5%. -No-till increases from 20-55%. -307 million acres crops plus hay and 56.2 million for pasture. -DDGs in feed ration are 30% for beef, and 10% for dairy, hogs, and broilers.	**3 Scenarios:** 1) ETH60-attain targets assuming cellulose-to-ethanol by 2012; 2) ETH60CA- allows corn ethanol to adjust as cellulose-to-ethanol is available in 2012; 3) ETH60CACD-delays cellulose-to-ethanol until 2015, and corn ethanol adjusts.	ETH60 Scenario; -Corn, soybean, and wheat prices increase. Corn ethanol production until 2012. After 2012, switches to cellulose of wood residues and then dedicated energy crops. - Higher feed prices, but lower cattle inventories reduce demand for feed, offsetting feed prices. DDGS more heavily incorporated into cattle rations. -Savings in government payments of \$150 billion and increase in net farm income of \$210 billion in 2007-2030. -Economic impacts of \$368 billion per year and 2.4 million jobs.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Tokgoz, Elobeid, Fabiosa, Hayes, Babcock, Tun-Hsiang, Dong, and Hart, *Review of Agricultural Economics*, Vol. 30, No. 4, 2008.				
The study estimates how large the U.S. biofuels sector could become and assesses the likely impact of this sector on crop markets, trade, and on wholesale and retail livestock markets.	A multi-commodity, multi-country, partial equilibrium econometric model of the agriculture sector which incorporates a biofuels component. Feedstocks include ethanol from corn, corn stover, and switchgrass, although ethanol only one included in baseline and scenarios due to positive returns. Data for supply and use from F.O. Lichts, FAO, and USDA. Macro data from Global Insight and other various sources. Adjusted NYMEX crude oil prices. Baseline for U.S. and international commodity models based on 2006 data. Projections between 2007 through 2016.	-Assumes long-run equilibrium conditions baseline and for Scenarios 1 and 2. -Analysis of flex-fuel vehicles and "E-85 Bottleneck" issue. -Parameters estimated from the literature, or expert opinion. -Assumes 20 DDGs for pork and poultry; this does not affect quality. -Assumes domestic and border policies (duties, tariff-rate quotas, export subsidies) in all scenarios.	**2 Scenarios:** 1) Scenario with higher crude oil prices ($10 higher on $60/barrel oil) but with constrained demand from an E-85 "bottleneck." 2) Short-crop scenario that mimics the 1988 drought in 2012-13 marketing year (middle of projection period) with an ethanol mandate in place of 14.7 billion gallons. Results of the 2 scenarios are considered relative to the baseline projections.	*Scenario 1:* Ethanol production increases to 22.4 billion gallons or a 55% increase in 2016-17. Corn production increases by 11% and price increases by 20% from $3.15 to $3.75 per bushel. Wheat and soybean production decreases, and prices increase by 9%. Planted area for corn increases by 11% and other crops decrease 3 – 6 %. Overall food price increases small, about 1%. Retail meat, dairy, and egg prices would increase. *Scenario 2:* Ethanol production from corn falls 2.4% to 14.3 billion gallons. Corn price increases 44% and production decreases by 23%. Soybean production decreases by 21% and price increases by 22%. Planted area for corn increases by 2%, wheat stays the same, soybeans area declines. Livestock production decreases. *Overall:* Finds no ethanol price that justifies growing switchgrass.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Tyner and Taheripour, *Journal of Agricultural & Food Industrial Organization*, Vol. 6, Article 9, 2008.				
The study investigates the economic consequences of further ethanol expansion for key economic variables of the U.S. agriculture and energy markets under several policy options. They extend the analysis to look at global biofuels impacts.	Break-even analysis, partial equilibrium model simulating various policy scenarios, and computable general equilibrium built on GTAP. For the break-even analysis, use actual price observations of corn and ethanol from 2000 to 2008. For partial equilibrium, models calibrated for 2004-2006 data.	-All simulations done with a 5% fuel demand shock. -A 40% corn export demand shock for fall in value of dollar. -Infrastructure and blending wall does not restrict the market.	**4 Scenarios-partial equilibrium model:**[b] 1) A fixed subsidy of 45 cents per gallon, starting 2009. 2) No ethanol subsidy. 3) Variable subsidy beginning at $70 for crude oil, increasing $0.0175 for each dollar of crude that falls below $70. 4) A renewable fuel standard (RFS) of 15 billion gallons.	*Partial Equilibrium Analysis*; Under $40 oil prices and fixed subsidy, 10.25 billion bushels of corn production (less than 15 billion RFS). With oil at $100 or greater, the subsidy induces higher corn production. Above $120 oil, the RFS is not binding. Models show a tight linkage between oil and corn prices. Price increase from 2004-2008 due to ethanol subsidy ($1) and due to an increase in oil prices ($3). At $140 oil, see corn price of $6 under all scenarios except fixed subsidy. -RFS cost is paid by the consumer at the pump and is high at low prices and low at high oil prices. - Fixed and variable subsidy costs are financed through the budget. - Fixed subsidy rises linearly with oil prices. -Variable subsidy has low costs at higher oil prices, and manifests only at lower oil prices. -At oil prices greater than $80, the cost of RFS is always lower than the fixed subsidy.
Walsh, De La Torre Ugarte, Shapouri, and Slinsky, *Environmental and Resource Economics*, 24, 2003.				
The study seeks to identify what prices are needed for bioenergy crops to compete for agricultural land, and what would happen to traditional crop prices and farm income if a bioenergy market could be developed to use all of the biomass potentially available at a given price. Bioenergy crops include switchgrass, hybrid poplar, and willow.	POLYSYS, a simulation model of the U.S. agricultural sector. Uses 1999 USDA baseline for 8 major crops and 1999 FAPRI baseline for alfalfa and other hay. Baseline timeframe runs from 1999-2008. CRP baseline is 1998. Crop enterprise budgets using the APAC Budgeting System which estimates costs associated with traditional crops. BIOCOST estimates costs for bioenergy crops — hybrid poplar and willow.[c]	- A planning horizon of 40 years with a real discount rate of 6.5%. - On CRP acres, existing contracts can be renewed under same conditions or planted to bioenergy crops with 25% of rental rate forfeited. - Rational expectations is incorporated into farmers' decisions. - Prices of biofuel crops are exogenous to the model.	**2 Scenarios** 1) Prices of $30/dt, $31.74/dt, and $32.90/dt for switchgrass, willow, and hybrid poplar. Assumes wildlife management practices are employed on CRP acres and farmers receive 75% of rental rate for producing bioenergy crops. 2) Prices of $40/dt, $42.32/dt, and $43.87/dt for switchgrass, willow, and hybrid poplar. Assumes production management practices employed on CRP acres and 75% of rental rate.	-*Overall:* Authors conclude government policies needed to encourage use of bioenergy production. Switchgrass is more profitable than poplars or willows in nearly all regions, but under the wildlife scenario (1) acres are split between switchgrass and poplars. -*Scenario 1:* Supplies about 8.5 billion gallons of ethanol. For feedstock, total switchgrass production of 60.4 million dry tons annually. Poplar annualized to 35.5 million dry tons. Traditional crop prices increase by an estimated 4 to 9 percent. An estimated 19.4 million acres planted to bioenergy crops. -*Scenario 2:* Supplies 16.7 billion gallons of ethanol. All from Switchgrass (188 million dry tons). Traditional crop prices rise by 9 – 14 percent with 41.9 million acres planted to bioenergy crops.

Model Description				
Objective of the study	Model/Time/ Data	Major assumptions	Scenarios	Results
Anderson, Outlaw, Bryant, Richardson, Ernstes, Raulston, Welch, Knapek, Herbst, and Allison, Agricultural and Food Policy Center, Texas A&M, April, 2008.				
Objectives of this study that we focused on are to 1) examine the impacts of higher corn and energy prices on food price increases, 2) evaluate the impacts of higher crop prices on the livestock industry. and 3) analyze the effects of a reduction of the renewable fuel standard for 3 different ethanol policy scenarios.[d]	For the effect of feed prices on livestock markets, study uses representative farm models and costs studies. For food price section–time series vector autoregression econometric model. Uses DOE oil prices, BLS labor prices, and BLS and USDA retail food prices. No. 2, yellow corn prices Central Illinois, Primark Datastream. Feeder cattle prices from AMS/USDA, Fed price from Texas-Oklahoma average price. Use monthly data for 2006-2008. For RFS scenarios, authors use a hybrid stochastic simulation model.	For the retail food model: Assumes underlying structural model is recursive with— - Price of crude oil in one period is not affected by same period shocks in any other variables; -Labor price is affected by same period crude oil shocks; -Corn price could be affected by shocks in the same period for either oil or labor prices. -Retail food prices are determined last. For the RFS model: tax credits for ethanol and biodiesel blending are assumed to continue and biodiesel RFS continues at 1 B. gallon after 2012.	**For the RFS model 3 scenarios:** 1) First, the current RFS, and all other government programs, proceed as currently planned. 2) The conventional biofuel RFS is immediately and permanently reduced by one-quarter. 3) The conventional biofuel RFS is reduced by one-half.	For *livestock model:* For dairy, feed costs increased from 17 to 22 percent from 2006-2008. For cattle, breakeven feed prices went from $94 to $107 per cwt as feed costs increased and feeder steer prices fell from $110 to $98 per cwt over the same period. For broilers, feed costs increased from an index of 93.5 in 2006 to 144.3 in 2008. For *retail model:* High corn prices have small overall impact on retail food prices. On a product-by-product basis, they found a significant effect of corn price on eggs, bread, and milk prices. The livestock industry is in the middle of transition, and higher livestock prices have yet to be passed on to the retail level to reflect the higher costs of feed. For *RFS model:* Relaxing the RFS does not significantly reduce corn prices—they are fairly steady under all scenarios. However, they gradually diverge, with the one-quarter RFS waiver corn prices falling about $0.30 per bushel below the full RFS price, and the one-half RFS waiver corn price about $0.50 to $0.60 per bushel below the full RFS price.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
The Biomass Research and Development Board, 2008.[e]				
The goal of this report was to research and make recommendations to address the constraints surrounding the availability of biomass feedstocks. As part of this study, an economic assessment was developed that linked an analysis of environmental consequences of feedstock production from agriculture and forestry sources.	Two comprehensive models: REAP — Regional Environment and Agriculture Programming model, a mathematical optimization model which analyzes the feedstocks associated with producing first-generation biofuels. The baseline case uses the USDA baseline for 2007, which provides projections to 2016. POLYSYS, an agricultural policy simulation model, used to assess the impacts of cellulosic production of ethanol in 2022 on agricultural prices and production. To simulate 2022, the 2007 USDA baseline for all crop prices and production used extended to 2022 based on an extrapolation of trends in the last 3 years of the USDA baseline. Report uses the renewable fuel volumes in EISA as basis for scenarios.	Some key assumptions: REAP: - All demands are national except for regional livestock demands. -Crop rotations are allocated proportionately and yields fixed at average levels. -Total CRP land is fixed, but allowed to reallocate among regions. POLYSYS: - Constrained to remove no more than 34% of corn stover and 50% of wheat straw. - Cropland used as pasture will be converted to energy crops provided the net returns are greater than the rental rates, they are the most profitable, and hay production can offset lost forage production. - In cellulosic high productivity scenario, corn productivity doubles the rate over baseline in 2022 and energy crops increase at an annual rate of 1.5% starting in 2012.	*First generation scenarios:* 1) Reference case: for 2016 represents a total biofuel target of 16 billion gallons, 15 billion of corn-based ethanol and 1 billion biodiesel. 2) A high productivity scenario represents an increase in productivity by an additional 50% above baseline assumptions. 3) A high input cost scenario represents an increase in the cost of energy-intensive inputs of 50 percent over baseline. 4) A price of $25 is assumed for the positive carbon price scenario Cellulosic scenarios:[f] 1) Reference Scenarios: 36 BGY biofuel scenario - 15 BGY of corn-based ethanol, 1 BGY soybean diesel, and 20 BGY of cellulosic biofuels. This is broken down into 3 cases of various proportions of cropland, forestland, and imported biofuels. 2) Increased Productivity: Same as reference case scenarios only with high productivity assumption (see assumptions).	*Reference case:* A 3.6% increase in corn production is accompanied by a 4.6% increase in price over baseline. The price of soybeans is 3.2 percent higher, while the prices of other crops increase by less than 1 percent. Planted acreage in 2016 is 4.4 million acres over USDA baseline. Corn acreage expands by 3.7-million-acres with an additional 700,000 acres in other crops. Each region exhibits an increase of 3% -7% in corn acres, most new corn acres are in the Corn Belt, Northern Plains, and the Lake States. The Corn Belt absorbs about 1 million CRP acres, with CRP acres in the Mountain region increasing by 1 million acres. Net farm returns increase by 10.4% for corn and 3.5% for other crops. Returns for livestock producers decline by 0.8% due to increased feed costs *High Productivity Scenario:* In the high-productivity case, a 50% increase in yield growth led to a 6.3% decline in corn price with a 2.6% increase in production. Also, the price and production effects on other crops are mostly mitigated. Net returns for corn producers decline by 2.7% compared to the reference case and decline 1.8% for other crop producers. The lower price of corn lifts returns for livestock producers by 1.4%. Total acres planted is 1.6 million less; 3 million fewer corn acres are planted nationally than the reference case. *Cellulosic Scenarios:* For the reference cases: Cellulosic feedstock prices *coming entirely from cropland* reach over $60/dry ton in 2022. About 36 percent of this feedstock would come from perennial grasses, woody crops, and annual energy crops with the remainder from crop residues, mainly corn stover. For a cropland scenario of 15 BGY, prices needed to secure sufficient feedstock are about $15/dry ton less than under the previous scenario and are about $20/dry ton less under the 12 BGY scenario of advanced biofuels from cropland. Scenarios with less cropland bring in larger shares of energy crops relative to crop residues.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Rajagopal, Sexton, Roland-Holst, and Zilberman, *Environmental Research Letters*, No. 2, 2007.				
The objective of the study is to estimate the maximum amount of ethanol that could be produced from principal food crops today if they were diverted entirely to energy production. The authors also estimate the impacts of biofuels on food and fuel production and develop a framework for estimating the wealth transfers from biofuel production.	Conceptual model and welfare analysis - authors employ a conceptual model of supply and demand for a crop with multiple uses, like food and fuel. With this conceptual model, they develop estimates of short-run costs and benefits of the ethanol production tax credit for the year 2006.	Corn demand elasticity of -0.5 Corn supply elasticity of 0.2 Gasoline demand elasticity of -0.23 and supply elasticity of 0.25 Elasticities short-run (inelastic), whereas in the long-run both supply and demand are more elastic. Conceptual model does not include impacts of other crops, livestock, import tariffs, RFS, or deficiency payments.	N/A[g]	Corn market –U.S. corn production was 12.5 billion bushels with 1.8 billion allocated to ethanol. Average price of corn for marketing year 2006-07 was $3 per bushel. Increase in corn price due to additional ethanol demand was estimated to be 21% higher; price of corn in absence of ethanol demand $2.48 per bushel. Gasoline Market - The average price of gasoline was $2.53 per gallon and was estimated to be 3% higher or $2.61 per gallon in the absences of ethanol. Welfare estimates: Cost to taxpayers from ethanol production—$2.5 billion Increase in corn producer surplus—$6.4 billion Loss in U.S. consumer surplus to non-ethanol corn users—$4.4 billion Loss in consumer surplus (from corn) to rest of the world -$1.1 billion

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Fabiosa, Beghin, Dong, Elobeid, Tokgoz, and Yu, Working Paper 09-WP 488, Center for Agricultural and Rural Development, Iowa State University, March 2009.				
Authors investigate the trade-offs between food, feed, energy, and environment and where they occur in terms of geographic and market location. In particular, the authors examine the land allocation effects of ethanol expansion and its effects on land devoted to feedstock and competing crops.	Analysis uses FAPRI model, a multi-market, partial-equilibrium model of world agriculture. They compute average effects of ethanol shocks in deviations from 2007 FAPRI baseline and calculate proportional impact multipliers on key variables for 2007/08 to 2016/17. Data from F.O. Lichts, FAOSTAT, USDA, and the European Commission Directorate General for Energy and Transport, and UNICA. Macroeconomic data from IMF and Global Insight.	- Supply and demand elasticities for crop and livestock based on econometric and consensus estimates. - Supply and demand elasticities for ethanol estimated at the sample average of 2000 - 2004. - Profit margins do not signal entry and exit, except in ethanol capacity. - Baseline assumes continuity of policies in the coming decade. - Domestic and international policies include tariffs, tariff-rate quotas, export subsidies, intervention prices, set-aside programs, and other domestic support.	**2 Scenarios:** 1) A 10% exogenous increase in the U.S. demand for ethanol leading to a 3% increase in ethanol use. 2) An exogenous 5% increase in world demand for ethanol (specifically, in Brazil, China, the EU, and India) leading to an increase in aggregate demand in these countries of about 3%/.	*Scenario 1:* A 3% increase in ethanol use elicits a much smaller increase in total corn use. Derived demand for feedstock increases, as corn displaces other grains. Corn for feed use falls and seed use increases. Corn exports decrease and stocks fall substantially. Lower DDG prices result. There is a short-run departure in prices of DDGs and corn, going back to their strong correlation in the long-run. Land area devoted to corn increases. Land area planted to hay and barley increases. There is a sharp reduction in land devoted to soybeans. Food corn use falls slightly; most significant being HFCS; other food use falls by much less. Small reduction in aggregate meat production. Wholesale prices increase moderately while retail prices increase by less. *Scenario 2:* U.S. ethanol production and feedstock are barely affected because of the segmentation of the U.S. and world markets due to the ethanol import tariff and sugar trade protection. U.S. and world ethanol markets are segmented by the ethanol tariff. Authors believe that removing the ethanol tariff would remove the corn land area effect of the current U.S. ethanol expansion.

Model Description				
Objective of the study	Model/Time/ Data	Major assumptions	Scenarios	Results
McDonald, Robinson, and Thierfelder, *Energy Economics*, Vol. 28, 2006.				
To evaluate the effects of substituting a biomass product, in this case switchgrass, for crude oil in the production of petroleum in the U.S. In particular, the study focuses on the global general equilibrium implications using a multi-region general equilibrium model with detailed commodity markets.	Policy simulations using a global computable general equilibrium (CGE) model. The policy change simulated in the model is substitution of crude oil by switchgrass in the petroleum activity. The database used is a Social Accounting Matrix (SAM) representation of the Global Trade Analysis Project (GTAP). For this study, it was necessary to add a switchgrass commodity and activity accounts to the SAM for the U.S.	- Model incorporates the Armington approach—that domestically produced and consumed products are imperfect substitutes for both imports and exports. -Assumes that the private costs equal the social costs; does not consider negative externalities of crude oil consumption. -Assumed that if 6% of US land was changed to switchgrass production, there would be a 4% decline in use of crude oil activity. -Assumed equivalent variations for measure of welfare effects of policies.[h]	**4 Scenarios**: 1) "One-to-one" direct substitution—4% increase in switchgrass for 4% decrease in crude oil. 2) "Calibrated" simulation—6% of land is devoted to switchgrass. 3) With total factor productivity or "TFP"—estimates extent to which the efficiency in petroleum activity must increase to compensate for use of switchgrass. 4) "With land"—land restored to agricultural production (such as land restored to production from government "set aside" programs) is used to produce switchgrass.	1) "One-on-one"- translates into about a 3% increase in land to switchgrass. Production increases by 4.83% in the U.S. and draws land from other food commodity production. Production in the U.S. of cereals, other crops, and livestock decline by between 0.22% and 0.4%. . U.S. has small increase in welfare of $1.1 billion. While in U.S. there are inefficiencies due to switchgrass production, these costs are offset by lower crop subsidies for cereals. World welfare effects are slightly negative. 2) This scenario results in 6% of land area converted to switchgrass, but this increase makes production less efficient. Decreased production of cereals, other crops, and livestock by 0.40% to 0.69%. Increased prices for U.S. cereals between 1.5 and 2%. Welfare declines by $2.02 billion in U.S. due to loss of productivity. 3) 30% increase in total factor productivity of petroleum sector would offset productivity loss of using switchgrass. Increase of U.S. price of cereals between 1.5 and 2%. Same increase in land area as in scenario 2. Welfare increase to U.S. of $700 million. 4) Drawing land from "set-aside" program nullifies nearly all negative U.S. price impacts from earlier scenarios. Welfare change in U.S. of $190 million. Overall: Impacts same as partial equilibrium results — world price of cereals increases slightly. As the U.S. imports less crude oil, its exchange rate appreciates. Regions that depend upon U.S. imports are hurt because their imports become more expensive.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Congressional Budget Office, April 2009.				
The 2009 CBO study examines the period from April 2007 to April 2008, during the period in which rapidly increasing production of ethanol coincided with rising prices for corn, food, and fuel. CBO estimated how much of the rise in food prices during that time was due to an increase in the consumption of ethanol and how much the rise in food prices would have boosted federal expenditures on food assistance programs. In addition, they examine how increased use of ethanol may lower emissions of greenhouse gases.	Time period of April 2007 to April 2008. For corn price increases attributed only to ethanol, CBO used estimates of supply elasticities, along with the actual price increases from USDA. CBO used a range of corn supply elasticity estimates of 0.3 to 0.5 gathered from the agricultural economics literature. To estimate the impact of changing corn prices on the CPI for food, CBO used the proportion of corn used in total food expenditures and average price increase of corn. For the federal food programs, CBO estimated the changes in the CPI-U categories for food consumed at home and food away from home attributable to increased production of ethanol.	- Assumed rising demand allowed producers to pass along the increase in costs to consumers for corn, animal feed prices, and other crops. - Assumed all food costs were passed along in the same period. Study notes that the computation used a “snapshot” from 2007 of the consumption and use of corn in the United States. - CBO did not consider how the amount of biodiesel produced in 2007 and 2008 affected prices for corn and soybeans. - For the food programs, calculations incorporated the assumption that 66 percent of calories were consumed at home and 34 percent of calories were consumed away from home. Also assumed program participation remained somewhat constant.	N/A	-CBO estimates that corn prices increased by between 50 and 80 cents per bushel between April 2007 and April 2008. This was a range equivalent to between 28 percent and 47 percent of the increase in the price of corn, which rose from $3.39 per bushel to $5.14 per bushel during the same period. -Overall, CBO estimates that from April 2007 to April 2008, the total rise in food prices resulting from expanded production of ethanol contributed between 0.5 and 0.8 percentage points (10 – 15% of the increase) of the 5.1 percent increase in food prices as measured by the consumer price index (CPI) -To break this down, CBO estimated the higher prices of corn resulting from the production of ethanol increased consumers’ expenditures on food by an additional 0.2 percent to 0.4 percent. Similarly, an increase in soybean prices raised expenditures on food by between 0.2 percent and 0.3 percent. -CBO projected for 2009 that increased production of ethanol and higher prices for food most likely would account for an estimated $600 million to $900 million, or roughly 10 percent to 15 percent of the change in federal spending for food and child nutrition programs as a result of higher food prices.[i] -The impact of higher prices for food will probably be greater in other countries because the percentage of households’ income spent on food is larger and the value of commodities makes up a bigger share of the cost of food.

Model Description				
Objective of the study	**Model/Time/ Data**	**Major assumptions**	**Scenarios**	**Results**
Hayes, Babcock, Fabiosa, Tokgoz, Elobeid, Yu, Dong, Hart, Chavez, Pan, Carriquiry, and Dumortier, Center for Agriculture and Rural Development, March 2009.				
In an earlier paper, Tokgoz (2007) analyzed the likely impact of the growing biofuel sector on the grain and livestock sectors and on consumer prices. This report updates that earlier paper, specifically, to allow for recent economic changes and policy changes introduced by the provisions of the EISA, endogenizes gasoline and ethanol prices, adjusts for the new blenders' credits, and increases international farm-level production costs when energy prices rise.	The model is similar to that used in the earlier paper by Tokgoz et al. (2007, 2008). It utilizes the FAPRI model, a broad partial equilibrium model of the world agricultural economy that is used to develop a baseline calibrated on data from January, 2008. The projection period is extended to the year 2022. Crude oil price projections were taken from NYMEX and extended to 2022 using a simple linear trend. The price of unleaded gasoline is calculated through a price transmission mechanism.	- The model was revised to allow for the impact of ethanol production on gasoline prices. Wholesale price of gasoline responsive to the changes in ethanol supply at the rate of $0.03 per billion gallons - Revisions in model are made to explore long-run equilibrium effects. - Ethanol capacity is fixed at 2008/09 and 2009/10 based on construction reports, beyond that, model solves for it. - International rice and cotton models were run. - Higher crude oil prices in the U.S. increase the costs of production for all crops. -Assumes that the livestock producer passes along costs in full. Also, that the retailer passes along these extra production costs on a dollar-for-dollar basis.	**Scenarios:** Baseline: Used the provisions of the EISA and the energy provisions of the farm bill of 2008, coupled with a crude oil price of $75 per barrel. 1) "High Energy Price" scenario crude oil prices are increased by 40%, to $105, and increased natural gas prices 19%. 2) "High Energy Price —Removal of Biofuel Tax Credits" high energy price scenario without biofuel tax credits. 3) "Removal of Biofuel Support" includes the baseline $75 crude oil price with the elimination of tax credits, the RFS, and import tariffs and duties. 4) The "no bottleneck" scenario where the energy price is high and there are no bottlenecks in the delivery mechanism for ethanol. Assumed that market can absorb all ethanol mandated by RFS plus that by market forces.	*Baseline:* Ethanol production from corn 16.9 billion gallons and uses 5.9 billion bushels of corn with total ethanol production at 32.9 billion gallons. The ethanol price is at $1.55/gallon. The price of corn reaches $3.73/bushel and corn area planted is 101.2 million acres. Soybean area planted is 73.6 million acres with a price of $9.79/bushel. H*igh Energy Price:* With a crude oil price of $105/barrel, total ethanol production from corn increases by 50% and price increases by 18%. The price of corn increases by about 20%, and corn net exports decline by 23%. Soybean planted area decreases by 7%, and price increases by 9%. *High Energy Price with Removal of Biofuel Tax Credits:* Total ethanol production from corn declines by 35% relative to the case of a high petroleum price and a continuation of biofuel support policies. The ethanol price declines by 11% and corn price falls by 16%. Less area planted to corn leads to more land available for other crops. *Removal of Biofuel Support:* Ethanol production from corn declines by 72%. The ethanol price increases by 13%, and ethanol use declines by 68%. Corn price decreases by 18%, planted area decreases by 9%, and corn exports rise by 24%. Corn used for exports and for feed increases. Less area going into corn means more area is available for other crops. *High Energy Price - No Bottleneck:* Corn-based ethanol production reaches 39.8 billion gallons, and ethanol use is approximately 40% of gasoline use. The ethanol sector uses more than 13 billion bushels of corn, and price is $5.63. Food Prices: CPI food component would increase by 0.8% for $1 increase in corn. Price impacts greatest for grain-intensive products such as eggs and poultry and impacts of value-added products much smaller.

Source: GAO analysis.

[a]We report only the results of the ETH60 scenario due to space limitations. The authors also depict two other scenarios, including ETH60CA, which allows corn-to-ethanol to adjust as cellulose-to-ethanol becomes available in 2012, and ETH60CACD, which delays the cellulose-to-ethanol technology until 2015, and the corn ethanol industry is allowed to adjust.

[b]We excluded the results for the two scenarios in this article that include the CGE modeling: (1) the effects of country biofuel mandates in land-use changes and (2) one incorporating biofuels by-products.

[c]BIOCOST is a budget generator model developed by the Oak Ridge National Laboratory to estimate the cost of producing bioenergy crops.

[d]We report on only certain questions or objectives posed by the Texas A&M study that are pertinent to our analysis.

[e]We report on only a limited number of scenarios for the Biomass Research and Development Board study regarding both the first and second generation biofuels analyses.

[f]Billion gallons per year.

[g]Not applicable.

[h]Equivalent variations is the amount of money that, paid to a person, group, or whole economy, would make them as well off as a specified change in the economy. It provides a monetary measure of the welfare effect of that change that is similar to, but not in general the same as, compensating variation (Deardorff's Online Glossary of International Economics).

[i]These programs included the Supplemental Nutrition Assistance Program, formerly known as the Food Stamp program and Child Nutrition Programs such as the National School Lunch Program, the School Breakfast Program, and other, smaller programs.

Appendix III: Scientific Studies on the Environmental Impacts of Biofuels

Alexander, R.B. R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. “Differences in Phosphorous and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin,” *Environmental Science and Technology*, vol. 42, no. 3 (2008): 822-830.

Barney, J.N. and J.M. DiTomaso. “Nonnative Species and Bioenergy: Are We Cultivating the Next Invader?” *Bioscience*, vol. 58, no. 1 (2008): 64-70.

Bechtold, R., J. Thomas, S. Huff, J. Szybist, T. Theiss, B. West, M. Goodman, and T. Timbario. *Technical Issues Associated with the Use of Intermediate Ethanol Blends (>E10) in the U.S. Legacy Fleet: Assessment of Prior Studies*, Oak Ridge National Laboratory, Department of Energy, Oak Ridge, Tennessee, August 2007.

Berndes, G. “Bioenergy and water- the implication of large-scale bioenergy production for water use and supply,” *Global Environmental Change*, vol. 12 (2002): 253-271.

Biomass Research and Development Board. *Increasing Feedstock Production for Biofuels, Economic Drivers, Environmental Implications, and the Role of Research*, Washington, D.C., March 2009.

Biomass Research and Development Board. *The Economics of Biomass Feedstocks in the United States, A Review of the Literature*. Occasional Paper No. 1, Washington, D.C., October 2008.

Börjesson, P. and G. Berndes. “The prospects for willow plantations for wastewater treatment in Sweden,” *Biomass and Bioen*ergy, vol. 30 (2006): 428-438.

Chesapeake Bay Commission. Biofuels and the Bay: *Getting It Right to Benefit Farms, Forests and the Chesapeake*, September 2007.

Delucchi, M. Emissions of Criteria Pollutants, Toxic Air Pollutants, and Greenhouse Gases, From the Use of Alternative Transportation Modes and Fuels, UCD-ITS-RR-96-12. Institute of Transportation Studies, University of California. Davis, California, 2002.

Dominguez-Faus, R., S.E. Powers, J.G. Burken, and P.J. Alvarez. “The Water Footprint of Biofuels: A Drink or Drive Issue?” *Environmental Science and Technology*, vol. 43 (2009): 3005-3010.

Department of Energy. *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, Washington, D.C., December 2006.

Diaz, R.J. and R. Rosenberg. "Spreading Dead Zones and Consequences for Marine Ecosystems," *Science*, vol. 321 (2008): pp. 926-929.

Donner, S.D. and C.J. Kucharik. "Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River," *Proceedings of the National Academy of Sciences*, vol. 105, no. 11(2008):4513–4518.

Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare, and D.M. Kammen. "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, vol. 311, no. 5760 (2006): 506-508.

Gerbens-Leenes, P.W., A.Y. Hoekstra, and Th. Van der Meer. "The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply," *Ecological Economics*, (2008): Web-published.

Gilliom, Richard and others. *The Quality of Our Nation's Waters: Pesticides in the Nation's Streams and Ground Water, 1992-2001*: *U.S. Geological Survey Circular 1291*, 2006, 172 p.

Gilliom, R. J. "Pesticides in U.S. Streams and Groundwater," *Environmental Science and Technology*, (2007): 3409-3414.

Graham, R.L., R.G. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. "Current and Potential U.S. Corn Stover Supplies," *Agronomy Journal*, vol. 99, no. 1 (2007): 1-11.

Granda, C.B., L. Zhu, and M.T. Holtzapple. "Sustainable Liquid Biofuels and Their Environmental Impact," *Environmental Progress*, vol. 26, no. 3 (2007): 233-250.

Groom, M.J., E.M. Gray, and P.A. Townsend. "Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production," *Conservation Biology*, vol. 22, no.3 (2008): 602-609.

Heaton, E.A., F.G. Dohleman, and S.P. Long. "Meeting US biofuel goals with less land: the potential of Miscanthus," *Global Change Biology*, vol. 14 (2008): 2000-2014.

Hill, J. "Environmental costs and benefits of transportation biofuel production from food and lignocellulose-based energy corps. A review." *Agronomy for Sustainable Development*, vol. 27 (2007): 1-12.

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels." *Proceedings of the National Academy of Sciences*, vol. 103, no. 30 (2006): 11206-11210.

Hill, J., S. Polasky, E. Nelson, D. Tilman, H. Huo, L. Ludwig, J. Neumann, H. Zheng, and D. Bonta. "Climate change and health costs of air emissions from biofuels and gasoline," *Proceedings of the National Academy of Sciences*, vol. 106, no. 6 (2009): 2077-2082.

Intarapapong, W., D. Hite, and L. Reinschmeid. "Water Quality Impacts of Conservation Agricultural Practices in the Mississippi Delta," *Journal of the American Water Resources Association*, vol. 38, no. 2 (2002): 507-515.

Jacobson, M.Z. "Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States," *Environmental Science & Technology*, vol. 41, no.11 (2007): 4150-4157.

Jacobson, M.Z. "Review of Solutions to Global Warming, Air Pollution, and Energy Security," *Energy and Environmental Science*, December 2008, published online.

Johnson, J.M., M. Coleman, R. Gesch, A. Jaradat, R. Mitchell, D. Reicosky, W. Wilhelm. "Biomass-Bioenergy Crops in the United States: A Changing Paradigm," *The Americas Journal of Plant Science and Biotechnology*, vol. 1, no. 1 (2007): 1-28.

King, C.W. and M.E. Webber, "Water Intensity of Transportation," *Environmental Science and Technology*, vol. 42, no. 21 (2008): 7866-7872.

Landis, D.A., M.M. Gardiner, W. van der Werf, and S.M. Swinton. "Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes." *Proceedings of the National Academy of Sciences*, vol. 105, no. 51 (2008): 20552-20557.

Lavigne, A. and S.E. Powers. "Evaluating fuel ethanol feedstocks from energy policy perspectives: A comparative energy assessment of corn and corn stover," *Energy Policy*, vol. 35 (2007): 5918-5930.

Lubowski, R.N., S. Bucholtz, R. Claassen, M.J. Roberts, J.C. Cooper, A. Gueorguieva, and R. Johansson. *Environmental Effects of Agricultural Land-Use Change, The Role of Economics and Policy*. USDA Economic Research Service, Economic Research Report No. 25 (August 2006).

Mackay, D.M., N.R. de Sieyes, M.D. Einarson, K.P. Feris, A.A. Pappas, I.A. Wood, L. Jacobson, L.G. Justice, M.N. Noske, K.M. Scow, and J.T. Wilson. "Impact of Ethanol on the Natural Attenuation of Benzene, Toluene, and o-Xylene in a Normally Sulfate-Reducing Aquifer," *Environmental Science and Technology*, vol. 40, no. 19 (2006): 6123-6130.

Malcom, S. and M. Aillery. "Growing Crops for Biofuels Has Spillover Effects." *Amber Waves*, vol. 7, issue 1, USDA Economic Research Service (March 2009): 10-15.

Mann, L., V. Tolbert, and J. Cushman. "Potential environmental effects of corn (*Zea mays* L.) stover removal with emphasis on soil organic matter and erosion." *Agriculture, Ecosystems and Environment*, vol. 89 (2002): 149-166.

McMahon, P.B., Böhlke, J.K., and Carney, C.P. Vertical Gradients in Water Chemistry and Age in the Northern High Plains Aquifer, Nebraska, 2003: U.S. Geological Survey Scientific Investigations Report 2006–5294, (2007): 58 p.

Mitchell, R., K.P. Vogel, and G. Sarath. "Managing and enhancing switchgrass as a bioenergy feedstock." Biofuels, Bioproducts and Biorefining, vol. 2 (2008): 530-539.

Morris, R.E., A.K. Pollack, G.E. Mansell, C. Lindhjem, Y. Jia, and G. Wilson. Impact of Biodiesel Fuels on Air Quality and Human Health: Summary Report September 16, 1999-January 31, 2003. National Renewable Energy Laboratory, Golden, CO, May 2003.

Mubako, S. and C. Lant. "Water resource requirements of corn-based ethanol," *Water Resource Research*, vol. 44 (2008).

Nassauer, J.I., R.C. Corry, and R.M. Cruse. "The landscape in 2025: Alternative future landscape scenarios: A means to consider agricultural policy." *Journal of Soil and Water Conservation*, vol. 57, no. 2 (2002): 44A-53A.

National Research Council. *Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities*. The National Academies Press, Washington, D.C., 2008.

National Research Council. *Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico*. The National Academies Press, Washington, D.C., 2008.

National Research Council. *Transitioning to Sustainability Through Research and Development on Ecosystem Services and Biofuels: Workshop Summary*. P. Koshel and K. McAllister, Rapporteurs, The National Academies Press, Washington, D.C., 2008.

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

Nolan, B.T. and K.J. Hitt. "Vulnerability of Shallow Groundwater and Drinking-Water Wells to Nitrate in the United States." *Environmental Science and Technology*, vol. 40 (2006): 7834-7840.

Orbital Engineering Company, *Market Barriers to the Uptake of Biofuels Study: A Testing Based Assessment to Determine Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Passenger Vehicle Fleet*, Report to Environment Australia, March 2003.

Orbital Engineering Company, *Market Barriers to the Uptake of Biofuels Study: Testing Gasoline Containing 20% Ethanol (E20)*, Phase 2B-Final Report, Report to Department of the Environment and Heritage of Australia, May 2004.

Powers, S.E. *Quantifying Cradle-to-Farm Gate Life-Cycle Impacts Associated with Fertilizer Used for Corn, Soybean, and Stover Production*. National Renewable Energy Laboratory, Technical Report, NREL/TP-510-37500, Golden, CO, May 2005.

Powers, S.E. "Nutrient Loads to Surface Water from Row Crop Production." *International Journal of Life Cycle Analysis* (2007): 1-9.

Rabalais, N.N., R.E. Turner, B.K. Sen Gupta, E. Platon, and M.L. Parsons. "Sediments Tell the History of Eutrophication and Hypoxia in the Northern Gulf of Mexico," *Ecological Applications*, vol. 17, no. 5 (2007): S129–S143.

Robertson, G.P, V.H. Dale, O.C. Doering, S.P. Hamburg, J.M. Melillo, M.M. Wander, W.J. Parton, P.R. Adler, J.N. Barney, R.M. Cruse, C.S. Duke, P.M. Fearnside, R.F. Follett, H.K. Gibbs, J. Goldemberg, D.J. Mladenoff, D. Ojima, M.W. Palmer, A. Sharpley, L. Wallace, K.C. Weathers, J.A. Wiens, W.W. Wilhelm. "Sustainable Biofuel Redux," *Science*, vol. 322 (2008): 49-50.

Ruiz-Aguilar, G.M.L., K. O'Reilly, and P.J.J. Alvarez, "A Comparison of Benzene and Toluene Plume Lengths for Sites Contaminated with Regular vs. Ethanol-Amended Gasoline," *Ground Water Monitoring & Remediation*, vol. 23, no. 1 (2003): 48-53.

Secchi, S., P.W. Gassman, M. Jha, L. Kurkalova, H.H. Feng, T. Campell, and C.L. Kling. "The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale," *Journal of Soil and Water Conservation*, vol. 62, no.1 (2007): 10-21.

Secchi, S., J. Tyndall, L.A. Schulte, and Heidi Asbjornsen. "High crop prices and conservation: Raising the Stakes," *Journal of Soil and Water Conservation*, vol. 63, no. 3 (2008): 68A-73A.

Simpson, T.W., A.N. Sharpley, R.W. Howarth, H.W. Paerl, and K.R. Mankin. "The New Gold Rush: Fueling Ethanol Production while Protecting Water Quality," *Journal of Environmental Quality*, vol. 37(2008): 318-324.

Tillman, D., J. Hill, and C. Lehman. "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science*, vol. 314, no. 5805 (2006): 1598-1600.

Turner, R.E., N.N. Rabalais, and D. Justic. "Gulf of Mexico Hypoxia: Alternate States and a Legacy," *Environmental Science and Technology*, vol. 42, no. 7 (2008): 2323–2327.

West, B., K. Knoll, W. Clark, R. Graves, J. Orban, S. Przesmitzki, and T. Theiss. *Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines*, *Report 1*. Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, October 2008.

Winebrake, J.J., M.Q. Wang, and D. He. "Toxic Emissions from Mobile Sources: A Total Fuel-Cycle Analysis for Conventional and Alternative Fuel Vehicles," *Journal of the Air & Waste Management Association*, vol. 51 (2001): 1073-1086.

Wu, M. *Analysis of the Efficiency of the U.S. Ethanol Industry 2007.* Analysis by Center for Transportation Research, Argonne National Laboratory, Delivered to Renewable Fuels Association on March 27, 2008.

Wu, M., M. Mintz, M. Wang, and S. Arora. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline.* Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, January 2009.

Wu, M., Y. Wu, and M. Wang. "Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment," *Biotechnology Progress*, vol. 22 (2006): 1012-1024.

Appendix IV: Key Studies on the Lifecycle Greenhouse Gas Effects of Biofuels

Dale B. “Thinking Clearly About Biofuels: Ending The Irrelevant ‘Net Energy’ Debate And Developing Better Performance Metrics For Alternative Fuels,” *Biofuels, Bioproducts, and Bioreferences*, vol. 1 (2007): 14-17.

Del Grosso S.J., Ogle S.M., Parton W.J., and Adler P.R. “Impacts of Land Conversion for Biofuel Cropping on Soil Organic Matter and Greenhouse Gas Emissions,” p. 58-67. In: M. Khanna (Ed.) Transition to a BioEconomy: Environmental and Rural Development Impacts, Proceedings of the October 15 and 16, 2008 Conference, St. Louis, Missouri, Farm Foundation Oak Brook, IL.

Del Grosso S.J., Mosier A.R., Parton, W.J., Ojima, D.S. “DAYCENT model analysis of past and contemporary soil N2O and net greenhouse gas flux for major crops in the USA,” *Soil and Tillage Research*, vol. 83 (2005): 9-24.

Delucchi M.A. “Conceptual and Methodological Issues in Life Cycle Analysis of Transportation Fuels,” U.S. Environmental Protection Agency Office of Transportation and Air Quality, 2004.

Kammen D.M., Farrell, A.E., Plevin R.J., Jones, A.D., Nemet G.F., and Delucchi M.A. “Energy and Greenhouse Gas Impacts of Biofuels: A Framework for Analysis,” UCD-ITS-RR-0804, Institute of Transportation Studies, University of California, Davis, 2008.

Fargione J., Hill J., Tilman D., Polasky S., and Hawthorne P. “Land Clearing and the Biofuel Carbon Debt,” *Science*, vol. 319, issue 5867 (2008): 1235-1238.

Fargione J., Hill J., Tilman D., Polasky S., and Hawthorne P. “Supporting Online Material for Land Clearing and the Biofuel Carbon Debt,” *Science Express*, 2008.

Farrell A.E., Plevin R.J., Turner, B.T., Jones, A.D., O’Hare, M., and Kammen, D.M. “Ethanol Can Contribute to Energy and Environmental Goals,” *Science*, vol. 311, issue 5760 (2006): 506-508.

Food and Agriculture Organization of the United Nations. “The State of Food and Agriculture: Biofuels - Prospects, Risks, and Opportunities.” Rome, Italy, 2008.

Gallagher E. "The Gallagher Review of the Indirect Effects of Biofuels Production," U.K. Renewable Fuels Agency. United Kingdom: 2008.

Gibbs H.K., Johnston M., Foley J.A., Holloway T., Monfreda, C., Ramankutty, N., and Zaks, D. “Carbon Payback Times for Crop-Based Biofuel Expansion in the Tropics: The Effects of Changing Yield and Technology,” *Environmental Research Letters*, vol. 3 (2008): 1-10.

Gibbs, H.K., Johnston, M., Foley, J., Holloway, T., Monfreda, C., Ramankutty N., and Zaks, D. Supporting online material for “Carbon Payback Times for Crop-Based Biofuel Expansion in the Tropics: The Effects of Changing Yield and Technology,” Environmental Research Letters, 3 (2008): 034001.

Hill J., Polasky S., Nelson E., Tilman D., Huo H., Ludwig L., Neumann J., Zheng H., and Bonta D. “Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline,” *Proceedings of the National Academies of Sciences*, vol. 106, no. 6 (2009): 2077-2082.

Hill J., Polasky S., Nelson E., Tilman D., Huo H., Ludwig L., Neumann J., Zheng H., and Bonta D. Supporting information for “Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline,” *Proceedings of the National Academies of Sciences*, vol. 106, no. 6 (2009): 2077-2082.

Hill J., Nelson E., Tilman D., Polasky S., and Tiffany, D. “Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels,” *Proceedings of the National Academy of Sciences*, vol. 103, no. 30 (2006): 11206-11210.

Khanna, M. “Cellulosic Biofuels: Are the Economically Viable and Environmentally Sustainable?” *Choices – A Publication of the Agricultural and Applied Economics Association*, vol. 23, no. 3 (2008): 16-21

Kim H., Kim S., Dale B.E. “Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables.” *Environmental Science and Technology*, Accepted November 2008 (pre-publication).

Kim M.K., and McCarl B.A. "Carbon Sequestration and Its Trading in U.S.” Invited paper prepared for presentation at the Symposium on Measures to Climatic Change in the Agricultural Sector, Rural Development Administration (RD), (Korea) National Institute of Agriculture Science and Technology (NIAST), Seoul, Korea, September 7-11, 2008.

Kim S. and Dale B.E. “Allocation Procedure in Ethanol Production System from Corn Grain,” *International Journal of Life Cycle Assessment*, vol. 7, no. 4 (2002): 237-243.

Kim S. and Dale B.E. “Effects of Nitrogen Fertilizer Application on Greenhouse Gas Emissions and Economics of Corn Production,” *Environmental Science and Technology*, vol. 42, no. 16 (2008): 6028-6033.

Kim S. and Dale B.E. “Ethanol Fuels: E10 or E85 - Life Cycle Perspectives,” *International Journal of Life Cycle Assessment*, OnlineFirst (2005): 1-5.

Kim S. and Dale B.E. “Life cycle assessment of fuel ethanol derived from corn grain via dry milling,” *Bioresource Technology*, vol. 99, no. 12 (2008): 5250-5260.

Kim S. and Dale B.E. “Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel,” *Biomass and Bioenergy*, vol. 29 (2005): 426-439.

Liebig M.A., Schmer M.R., Vogel K.P., Mitchell R.B. “Soil Carbon Storage by Switchgrass Grown for Bioenergy,” *Bioenergy Research* (2008): 215-222.

Liska A.J., Yang H.S., Bremer V.R., Klopfenstein T.J., Walters D.T., Erickson G.E., and Cassman K.G. “Improvements in Life-Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol,” Submitted to the *Journal of Industrial Ecology*, Nov. 10, 2008 (prepublication).

Liska A.J. and Cassman K.G. “Towards Standardization of Life-Cycle Metrics for Biofuels: Greenhouse Gas Emissions Mitigation and Net Energy Yield,” *Journal of Biobased Materials and Bioenergy*, vol. 2 (2008): 187-203.

McCarl B., Gillig D., Lee H.C., Qin X., Cornforth G. “Potential for Biofuel-Based Greenhouse Gas Emission Mitigation: Rationale and Potential.” Presentation for *Agriculture as a Producer and Consumer of Energy Conference*, Farm Foundation, Washington D.C., June 2004

McCarl, B.A. “Lifecycle Carbon Footprint, Biofuels and Leakage: Empirical Investigations.” Presented at USDA, FARM Foundation Conference on The Lifecycle Carbon Footprint of Biofuels: January 29, 2008, in Miami.

McCarl, B.A. “Bioenergy in a greenhouse mitigating world,” *Choices—A Publication of the Agricultural and Applied Economics Association*, vol. 23, no.1 (2008): 31-33.

McCarl, B.A., Maung T., and Szulczyk K.T. “Could Bioenergy be Used to Harvest the Greenhouse: An Economic Investigation of Bioenergy and Climate Change?” Chapter in *Handbook of Bioenergy Economics and Policy*, edited by Madhu Khanna, Jurgen Scheffran, and David Zilberman, forthcoming, spring 2009

Patzek T.W. “A First-Law Thermodynamic Analysis of the Corn-Ethanol Cycle,” *Natural Resources Research*, vol. 15, no. 4 (2006): 255-270.

Patzek, T.W. “A Statistical Analysis of the Theoretical Yield of Ethanol from Corn Starch,” *Natural Resources Research*, vol. 15, no. 3 (2006): 205-212.

Patzek, T.W. “Thermodynamics of Agricultural Sustainability: The Case of U.S. Maize Agriculture,” *Critical Reviews in Plant Sciences*, vol. 27, no. 4 (2008): 272-293.

Pimentel D. and Patzek T. “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower,” *Natural Resources Research*, vol. 14, no. 1 (2005): 65-76.

Schmer M.R., Vogel K.P, Mitchell R.B., and Perrin R.K. “Net Energy of Cellulosic Ethanol from Switchgrass,” *Proceedings of the National Academy of Sciences*, vol. 105, no. 2 (2008): 464-469.

Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J., Tokgoz S., Hayes D., and Yu T. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change,” *Science*, vol. 319 (2008): 1238-1240.

Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J., Tokgoz S., Hayes D. and Yu T. “Supporting Online Material to ‘Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change.’” Published 7 February 2008 on *Science* Express.

Shapouri H. Duffield J., and McAloon A.J. "The 2001 Net Energy Balance of Corn Ethanol." *Proceedings on the Conference on Agriculture as a Producer and Consumer of Energy*, Arlington, VA, June 24-25, 2004.

Sheehan, J., Aden, A., Paustian, K., Killian, K., Brenner, J., Walsh, M., and Nelson, R. “Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol,” *Journal of Industrial Ecology*, vol. 7, no. 3-4 (2004): 117-146.

Sylvester-Bradley, R. “Critique of Searchinger (2008) and Related Papers Assessing Indirect Effects of Biofuels on Land-Use Change.” ADAS UK Ltd. Prepared for the U.K. Renewable Fuels Agency. United Kingdom: 2008.

Tillman D., Hill J., and Lehman, C. “Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass,” *Science*, vol. 314, no. 5805 (2006): 1598-1600.

Wang M. and Huo H. “Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States.” Sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Argonne National Laboratory Center for Transportation Research, 2006.

Wang M., Huo H., Hong H., and Arora S. "Methods of Dealing with Co-Products of Biofuels in Life-Cycle Analysis and Consequent Results within the U.S. Context," Forthcoming in *Energy Policy Journal*. Submitted November 2008; Revised in June 2009

Wang M.Q. “Wells-to-Wheels Energy and Greenhouse Gas Emission Results and Issues of Fuel Ethanol.” Chapter from *Biofuels*, *Food and Feed Tradeoffs*. 2008 (prepublication).

Wu M., Wang M., Liu J., and Huo H. “Life-Cycle Assessment of Corn-Based Butanol as a Potential Transportation Fuel,” Sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Argonne National Laboratory Center for Transportation Research, 2007.

Wu M., Wu Y., and Wang M. “Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment,” *Biotechnology Progress*, vol.22 (2006): 1012-1024.

Appendix V: Recent Studies on Federal Supports for Biofuels

Bruce A. Babcock, Center for Agricultural and Rural Development, Iowa State University, Statement before the U.S. Senate Committee on Homeland Security and Governmental Affairs, Hearing on Fuel Subsidies and Impact on Food Prices (May 7, 2008).

Congressional Budget Office, *The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions* (Washington, D.C.: April 2009).

Council on Foreign Relations, Independent Task Force Report No. 61, *Confronting Climate Change: A Strategy for U.S. Foreign Policy*, (New York, N.Y.: June 2008).

Harry de Gorter and David R. Just, "The Economics of a Blend Mandate for Biofuels" forthcoming *American Journal of Agricultural Economics*, vol. 91: in press (2009).

Harry de Gorter and David. R. Just, "The Law of Unintended Consequences: How the U.S. Biofuel Tax Credit with a Mandate Subsidizes Oil Consumption and Has No Impact on Ethanol Consumption," Department of Applied Economics and Management Working Paper No. 2007-20, Cornell University (Oct. 23, 2007). http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1024525

Harry de Gorter and David R. Just, "The Welfare Economics of the U.S. Ethanol Consumption Mandate and Tax Credit." Department of Applied Economics and Management Working Paper unpublished, Cornell University (Nov. 4, 2008).

Bruce Gardner, "Fuel Ethanol Subsidies and Farm Price Support," *Journal of Agricultural & Food Industrial Organization*, vol. 5, iss. 2 (Dec. 2007)

Farzad Taheripour and Wallace E. Tyner, "Ethanol Subsidies, Who Gets the Benefits?" Purdue University, paper presented at Biofuels, Food and Feed Tradeoffs Conference, St. Louis, MO (April 12-13, 2007).

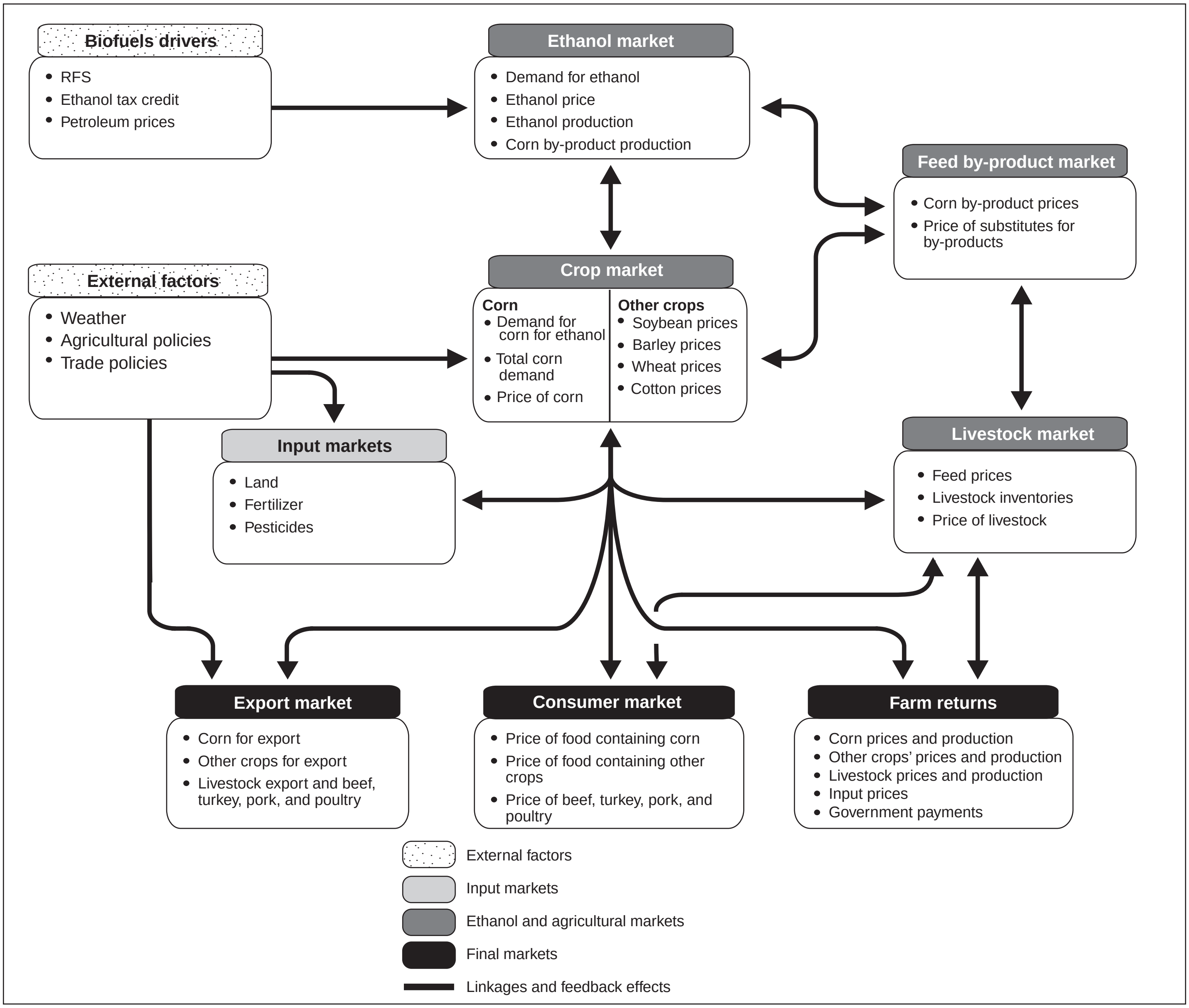
Wallace E. Tyner and Farzad Taheripour, "Future Biofuels Policy Alternatives," Department of Agricultural Economics, Purdue University, paper presented at Biofuels, Food, and Feed Tradeoffs Conference, St. Louis, MO (April 12-13, 2007).

Pat Westhoff, Wyatt Thompson, and Seth Meyer, "Impact of Selected US Ethanol Policy Options," Food and Agricultural Policy Research Institute, Report No. 04-09, University of Missouri (Columbia, MO: May 2009).

Appendix VI: Economic Linkages of the Corn Ethanol Industry to Food and Agricultural Markets

Figure 8 depicts some of the complex economic linkages of the ethanol industry to food and agricultural markets. Each of the markets is shown as a box and is related by supply and demand factors to other markets. Additional boxes, such as the one called “Biofuel Drivers,” depict external energy factors that drive these markets. In the figure, the boxes are connected by arrows, signifying that a change in a driver or a market leads to a change in another market. For instance, drivers of the biofuels market, such as the Renewable Fuel Standard (RFS), increase the demand for ethanol in the ethanol market, and thus the demand for corn for ethanol in the corn market. Within the boxes are a series of bullets indicating either the drivers of change or factors changing within a market. For example, within the ethanol market, an increase in demand for ethanol causes an increase in the price of ethanol, which causes an increase in production of both ethanol and ethanol by-products.

Figure 8: Economic Linkages of Ethanol Production to Food and Agricultural Markets



Source: GAO.

In the upper left-hand corner of figure 8, petroleum prices (*in particular, gasoline prices* for which ethanol is a substitute), the ethanol tax credit, and the Renewable Fuel Standards are all primary "biofuels drivers," leading to increases in the price and production of ethanol. As the ethanol price rises, so does the derived demand for corn for ethanol and thus corn prices in the crop market. Assuming overall production of corn remains constant during the period in question, corn used for ethanol would increase and corn used for feed is reduced. The increased corn price ripples down into the livestock market, increasing feed costs, and the price of livestock. At the same time, with greater ethanol production, there are larger supplies of the ethanol by-product, dried distiller's grains (DDG), an animal feed by-product, reducing its price in the feed market. To a certain extent, the lower-priced DDGs counterbalance the rise in corn prices in the livestock market. Also, instead of corn for feed, livestock producers may be able to substitute other crops in livestock rations, such as barley or hay. However, the effects of higher corn prices would very likely dominate for livestock such as poultry, swine, and dairy cows, since in general corn is a more important feed source than DDGs and there are limits on substituting by-products for corn. In the short-run, some producers may be able to mitigate the effect of higher corn prices by decreasing livestock inventories. Nevertheless, these cost increases lead to an overall decrease in livestock production and an increase in livestock prices.

In the longer-term, the higher demand for ethanol and higher corn prices affect farmers' future expectations, providing incentives for different crop, land allocation, and input decisions. For instance, with higher corn prices, farmers may switch from a corn-soybean rotation to a corn-corn rotation. With reduced supplies of other crops, such as soybeans and barley, their prices also increase. The higher demand for and price of corn and other crops would also affect the demand for and prices of agricultural inputs associated with crop production. For instance, the higher demand for corn for ethanol may provide economic incentives for farmers to take land out of pasture or rangeland and devote this land to crop cultivation. Prices or rental rates for cropland would then be bid up. The increased land devoted to crop cultivation also increases the demand for and prices of other inputs such as fertilizer and pesticides. Furthermore, these increased prices in the input market would have feedback effects on the corn and other crop and livestock markets.

For the farmer, the impact of the increase in corn prices as well as other crop prices would be an increase in net farm income. This may be tempered somewhat by the increasing costs of inputs. In the near term, for the livestock producer, increased feed costs may lead to lower overall returns to livestock production and lower net farm income. The main short-term adjustment option to higher costs for livestock producers is liquidation which would increase revenue temporarily to the individual producer. However, this could depress meat prices in the market and ultimately prevent livestock producers from covering higher feed costs. Also, in the absence of wide-spread herd liquidation, any short-term increase in meat prices could trigger an increase in imports from lower cost producers overseas, which in turn may lower prices. Many analysts see the livestock sector shrinking as ethanol expansion could ultimately lead to a smaller U.S. sector and more production shifting overseas. As far as government payments to farmers, increased ethanol demand would lead to lower counter-cyclical payments and marketing loan benefits because crop prices would be supported above the levels triggering these program benefits.

For consumers, higher prices for corn and other crops and livestock are eventually passed on in the form of higher food prices, although the share of the farm value and the amount of pass-through of price increases may be small. These food products for which consumer prices are expected to rise are meat or other processed food products that contain corn (such as high-fructose corn syrup) or other crops.

In the export market, increases in the price of corn and other crops, all else being equal, would generally cause U.S. corn exports to decrease compared to competing exporters. However, depending on other factors, such as world demand, exchange rates, stock levels, and world weather patterns, higher corn and other crop prices may not cause exports to contract and receipts from these exports may even increase.

Conversely, if the biofuel drivers were to decrease, all else being equal, the impacts would go in the opposite direction. For instance, if gasoline prices decrease, reducing the demand for ethanol, ethanol prices and production would also decrease. This could trickle down to other agricultural markets, contributing to lower crop prices, including the price of corn and other crops, livestock prices, the prices of inputs, and eventually the prices of food. Outside factors, such as weather, agricultural policies, and trade policies can either lessen or increase the impact of ethanol on crop and livestock markets. For instance, a production decline caused by a drought could amplify the price impacts of a large RFS target on the corn market.

Appendix VII: Summary of Researchers' Assumptions and Conclusions about Lifecycle Greenhouse Gas Emissions of Biofuels Production

This appendix describes the key assumptions and conclusions of 17 researchers we interviewed who have published work in the past 4 years on the lifecycle greenhouse gas effects of biofuels production. See appendix IV for a bibliography of the 46 research articles we reviewed.

Researchers	Assumptions and conclusions influencing greenhouse gas emission results
Timothy Searchinger (Princeton University)	• Food crops for biofuels will trigger higher crop prices and induce farmers worldwide to clear more forest and grassland • Carbon sequestered will always be higher if the land reverts to its native form than if it is used for biofuel feedstocks • Cellulosic feedstocks will be grown on productive, not marginal land • No energy is allocated to co-products for cellulosic feedstocks
Ralph Heimlich (Agricultural Conservation Economics)	• No new land will be available for biofuel feedstock production—these crops will come from existing croplands or “natural” lands. • Yields will continue to increase at the same rate as they have historically, but yields will not respond to price increases • General equilibrium models do not adequately estimate costs of production on marginal land • No energy is allocated to co-products for cellulosic feedstocks
Tad Patzek (University of Texas)	• Includes cumulative free energy consumed in farming and production as opposed to limiting inputs to fossil fuels • Includes as energy inputs both the photosynthetic energy value of corn grain as well as the energy used to restore biodiversity damage created by biofuel feedstocks • Processing co-products should be returned to the field
David Pimentel (Cornell University)	• Using lignin as fuel for cellulosic conversion might not save energy • Uses fossil fuels as utility energy inputs for both corn ethanol and cellulosic ethanol • Corn stover or other agricultural residue would intensify soil erosion and further degrade ecosystems by removing nutrients and other species and should not be used for ethanol • Includes energy inputs from farm labor, farm machinery, hybrid corn, and irrigation
Holly Gibbs (University of Wisconsin)	• Industrialized nations with biofuel mandates are unlikely to have the land needed to meet the demand for agricultural biofuels • Expansion of biofuels into productive tropical ecoystems will always lead to net carbon emissions for decades to centuries • Expanding into degraded or already cultivated land will provide almost immediate carbon savings • Increased demand for crop-based biofuels will likely require expanding agricultural production at the expense of tropical ecosystems • Crop yield improvements could increase biofuel production and in turn improve the carbon payback time • No energy is allocated to co-products

Researchers	Assumptions and conclusions influencing greenhouse gas emission results
Joseph Fargione (The Nature Conservancy)	• Agricultural land diverted to biofuel production from food crops causes land in undisturbed ecosystems to be converted to biofuel crop production, resulting in large carbon debts • Some cellulosic feedstocks may also accelerate land clearing by adding to the agricultural land base needed for biofuels • No-till farming might not result in soil carbon savings • Crops grown on abandoned agricultural land or from waste biomass may not accelerate land clearing • Energy is allocated to co-products using market-based method
Jason Hill (University of Minnesota)	• Carbon saved might not be higher if the land reverts to its native form if the biofuel feedstocks sequester more carbon than the original land • Used abandoned land as test sites for high-diversity grassland instead of land that could still be used for farming • No-till farming might not affect the amount of carbon lost • Recent advances in crop yields and in system machinery reduce biofuel energy impacts
Erik Nelson (University of Minnesota)	• The primary information gap in lifecycle analyses is how land-use change is linked to biofuels, since researchers cannot always differentiate between existing baseline changes and changes due to biofuels • Energy allocated to co-products using mass balance – the weight of the co-product versus the weight of ethanol • The method used to allocate energy to the co-product can change the final energy impacts
Michael Wang (Argonne National Laboratory, DOE)	• Including land-use changes is correct, but current models cannot project the extent to which land-use changes might affect biofuel energy impacts • Cellulosic feedstocks may not cause indirect land-use change impacts • Increased yields and conversion productivity will reduce greenhouse gas impacts • Agricultural practices and utility process fuels can reduce impacts • Energy is allocated to co-products using economic displacement
Mark Delucchi (University of California at Davis)	• Methods used to measure land-use change have significant uncertainties and omissions, including market-mediated effects, land-use change, climate impacts of emissions, and uncertain and highly variable data • There is not one single model and no well-accepted method that all researchers agree is the right one for calculating the magnitude of land-use change effects • Changes in carbon stocks related to deforestation might be the most important factor associated with land-use conversion • The environmental performance of ethanol varies greatly depending on production processes
Ken Vogel and Marty Schmer (Agricultural Research Service, USDA)	• There is no proof regarding indirect land-use change—high commodity prices from feedstocks may not lead to land change • Lignin from cellulosic feedstocks can be used to power biorefineries • No-till farming technique will lead to a zero-loss of soil carbon • Switchgrass will be grown on marginal land, not productive land

Researchers	Assumptions and conclusions influencing greenhouse gas emission results
Bruce Dale (Michigan State University)	• Current economic and equilibrium models cannot project global land-use, including unused and marginal land • Productive use could made of cleared timber, farmers could use conservation tillage or cover crops instead of plow tillage • Cover crops grown in the fall could reduce nitrogen leaching from the soil and greenhouse gas emissions, as well as lead to negative land requirements if the crop is harvested as an animal feed • Marginal and unused land should be included in the modeling
Kenneth Cassman (University of Nebraska-Lincoln)	• Does not include indirect land-use changes in response to commodity price increases because such indirect effects are applied generally to all corn ethanol at a national or global level and are not specific to a particular corn-ethanol biorefinery • Updated energy efficiencies in new ethanol plants that have initiated production since 2005 can reduce greenhouse gas emissions • Advances in agronomic science, not in genomic or biotechnology breakthroughs, can result in increased corn yields and reduced environmental impacts • Includes updated energy efficiencies in new ethanol plants, including plants that are located in close proximity to cattle feeding operations to reduce co-product greenhouse gas emissions • Energy is allocated to co-products using displacement method
Madhu Khanna (University of Illinois)	• Research is not clear on increases and decreases in biofuel acreage in response to prices • The amount of existing carbon in soil and biomass is unknown • At least one feedstock could be grown and harvested on Conservation Reserve Program land that would not compete with food and feed cropland
Steve Del Grosso (Texas A&M University)	• Researchers have to make assumptions about the elasticity of the supply of feed that might affect measurement results for indirect land-use change impacts • Conversion to no-tillage at the national scale could mitigate about 20 percent of U.S. agricultural emissions
Bruce McCarl (Texas A&M University)	• Indirect land-use change does affect analysis results, but no data are available on how much land would be replaced • Used a model that does not include alternative sources for utilities, such as biomass, but currently uses the average for the region • Satellite data to find implied land-use changes are not accurate • Allocates energy to co-products based on both the displacement method and market price

Source: GAO's analysis of greenhouse gas literature and interviews conducted with key researchers.

Appendix VIII: Comments from the Department of Agriculture

USDA REE

United States Department of Agriculture

Research Education Economics

Office of the Under Secretary

Room 216W
Jamie L. Whitten Building
Washington, DC 20250-0110

JUL 30 2009

Ms. Patricia Dalton
Managing Director
U.S. Government Accountability Office
441 G. Street, NW., Rm. 2T23A
Washington, D.C. 20548

Dear Ms. Dalton:

On behalf of the Department of Agriculture (USDA), I am responding to your letter of June 17, 2009, to Secretary Vilsack, requesting USDA comments on your draft report: "Biofuels: Challenges and Potential Effects of Required Increases in Production" (GAO-09-446). We appreciate the time and effort you and your staff have invested in reviewing this important topic, the care that you have taken to ensure your report is constructive and accurate, and the opportunity to review.

Overall, USDA considers the draft report to be a comprehensive, well-written, and accurate representation of the Government Accountability Office (GAO) review process involving USDA officials and experts. Indeed, the GAO provides a broad view that would be difficult for any one agency to replicate, and the resulting report will be a useful review reference for many parties having interest in the production of feedstocks for biofuels, including lawmakers considering energy legislation in the coming months. The report appropriately highlights the complexity of the issues and the many uncertainties ahead. We agree with most of the findings and conclusions. In the interest of strengthening the report, we offer several substantive comments and statements on recommendations for executive action.

Substantive Comments

1. Although we do not dispute most findings and conclusions, we note that the report generally tends to emphasize negative aspects of increased biofuels production. Since the title of the report refers to "challenges" of required increases in production, the reader is prepared for emphasis on potential adverse effects, and we consider many of these to be priorities for research in USDA. However, some of the negative effects may be overstated, including the extent of feedstock production and its adverse impacts on the environment. We suggest that the impact of feedstock production might be assessed differently under alternative—and equally likely—scenarios. Moreover, we saw few positive outcomes from increased biofuels production discussed in the report. For example, in discussing the potential problems of using ethanol in small engines (e.g., lawn mowers), the report provides virtually no consideration of the major benefits to air quality arising from the Environmental Protection Agency (EPA) reformulated gasoline program that relies on ethanol as a clean air additive. In some cases where studies critical of biofuels are cited, the literature answering such criticisms is not offered as a balance.

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To be sure, we agree that increasing biofuels production will present challenges such as those cited in the report concerning water quality and quantity, soil erosion, fertilizer use and runoff, pests and pesticide use, air quality, and wildlife habitat. However, these are challenges facing agriculture and forestry in general, and USDA has vigorous research programs addressing such challenges in many production systems and contexts. We are more optimistic than the report's writers that current and future research and development will rise to those challenges.

2. The report is written as if the EPA study on the Renewable Fuels Standard is still in progress. This study has been released. The GAO report could be improved if the EPA study's findings and conclusions are discussed, along with dimensions of the debate on including indirect land use changes in projecting impacts of biofuel feedstock production.

3. The report notes several mechanisms and processes that facilitate coordination of research and development spread among several Departments and agencies, but the report does not recognize one type of obstacle to achieving the best possible biofuels research: restrictions on eligibility for some research funding programs. The Energy Policy Act of 2005, Section 989, "Merit Review of Proposals," subsection (b) precludes scientists at Government Owned-Government Operated research facilities, such as those operated by researchers employed by the USDA Agricultural Research Service or Forest Service, from applying for and receiving research funds from the Department of Energy (DOE) Bioenergy Research Centers program. Competitive research funding programs should be open to competition from all sources to ensure support of the best science in the public interest. The report's recognition of how restricted funding eligibility limits the participation of certain Federal scientists could stimulate changes that enhance the pool of research talent available to focus on important topics in bioenergy research and development.

4. The impact of linkages between the corn ethanol industry and the livestock industry (Appendix VI, page 172) needs clarification and correction. In particular, the conclusion that the livestock industry could achieve an increase in net farm income due to increasing ethanol demand is questionable. We believe it would be possible only under certain assumptions the report's authors seem to have accepted without adequately explaining or justifying them. The discussion in Appendix VI does not seem consistent with the main text where impacts on the livestock sector are discussed (pages 43-44). Although our more detailed response to this issue can be found in our technical comments, our doubts about the report's conclusion on this important issue are substantial.

Comments on Recommendations for Executive Action

(Page 98, bottom) *"...[D]evelop a coordinated approach to identifying and researching unknown variables and major uncertainties in the lifecycle greenhouse gas analysis of increased biofuels production..."*

Ms. Patricia Dalton
Page 3

We agree with the general premise implicit in this recommendation, namely, that life cycle analyses are complex, delineating the boundaries of a system for life cycle analysis can be controversial, and analytical outcomes depend on many assumptions and methodological choices. Although we agree that the scientific expertise residing in USDA, EPA, DOE, and elsewhere should engage in a discussion of the complex issues of life cycle analyses, we have concerns about a potential undesirable consequence of this specific recommendation for executive action. Methods of conducting life cycle analyses differ depending on the system involved, so we would want to ensure that the coordinated scientific discussions do not lead to "standard methods" that become codified in regulations, which then would inhibit the adoption and use of new information and improved or more appropriate methods as they become available. We recommend that, while the science is still in its infancy and is being widely debated, USDA, EPA, and DOE should develop forums to engage the community of experts in ongoing discussions of methods and come to agreement on standards *not* for the analytical methods themselves, but instead, standards for transparent documentation of assumptions, methods, boundaries, and uncertainties in the analyses, so that differences in the outcomes of analyses on which polices are based can be freely examined.

(Pg. 134, bottom) *"...[G]ive priority to R&D on process technologies that can be used by the existing petroleum-based distribution and storage infrastructure and current fleet of U.S. vehicles."*

We agree that this is an important goal and that USDA R&D should address it. However, given the numerous and diverse challenges raised in the GAO report, research in USDA must progress simultaneously on several fronts, not just giving priority to the development of process technologies. Research must focus also on the development of feedstocks with physical and chemical properties that make them effective for conversion, and the creation of productive methods that are environmentally-sound and economically advantageous for producing large quantities of feedstocks.

(Bottom of page 134 to top of 135) *"...[R]eview and propose to the appropriate congressional committees any legislative changes the [EPA] Administrator determines may be needed to clarify what biomass material – based on type of feedstock or land – can be counted toward the RFS.*

We agree with this recommendation, the finding that there are inconsistent definitions of renewable biomass, and the stated consequences of these inconsistencies on development of regulations. USDA believes that a definition of biomass that excludes materials from all Federal lands and from naturally regenerating forests toward meeting requirements of the Energy Independence and Security Act (EISA) is unacceptable and will limit the role of existing forests in meeting energy demand and in maintaining or improving environmental quality of natural resources. For example, if the definition does not include all forest lands, then it will be difficult to attain 16 billion gallons of cellulosic biofuels in 2022. Furthermore, USDA favors the Farm Bill definition of biomass and agrees with the recommendation that Departments within the Administration come to agreement on a definition, and then work with Congress to resolve inconsistencies.

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Technical and editorial comments and corrections recommended by several different USDA agencies' staff are contained in the document accompanying this letter. We urge you to consider each of these recommendations, particularly those specified to correct matters of fact or interpretations of facts. We also acknowledge that GAO solicited technical comments directly from several USDA scientific experts. Some comments submitted directly to you in response to those requests are not included herein, but we trust they may be useful to you.

In closing, I reiterate my compliments on the high quality of work done by GAO on a complex and very visible topic. I hope our comments will be constructive as you finalize the report. Should you have questions, please contact Dr. Steven Shafer, Deputy Administrator for Natural Resources and Sustainable Agricultural Systems of the USDA Agricultural Research Service (301-504-7987), or contact my office (202-720-1542) directly.

Sincerely,

for Rajiv J. Shah
Chief Scientist, USDA
Under Secretary

Enclosure

cc:
F. Woods, USDA-AMS
S. Shafer, USDA-ARS
G. Casamassa, USDA-FS
P. Riley, USDA-FSA
H. Baumes, USDA-OCE
J. Johnson, USDA-NASS
C. Zelek, USDA-NRCS
B. O'Loughlin, USDA-RD

Appendix IX: Comments from the Department of Energy

Department of Energy
Washington, DC 20585
July 20, 2009

Ms. Patricia Dalton
Managing Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G. St., NW
Washington, DC 20548

Dear Ms. Dalton:

Thank you for the opportunity to comment on the draft GAO Report titled: "*Biofuels: Challenges and Potential Effects of Required Increases in Production*" (GAO-09-446). The Department of Energy (DOE) appreciates the effort put forth by GAO with regard to this report and the **Recommendations for Executive Action** it includes. The recommendations pertain specifically to the administration of the Renewable Fuels Standard (RFS) under the Energy Independence and Security Act and a requested shift in research priorities to be more supportive of biofuels that can be used in the existing petroleum-based fuels distribution and storage infrastructure with the current fleet of U.S. vehicles.

The DOE has reviewed the Report and its comments are detailed below.

On page 15, based on reasonable assumptions regarding E85 infrastructure development, the Energy Information Administration's *Annual Energy Outlook 2009* projects that E85 could account for 30% of the total ethanol volume in 2020 and 50% in 2030, as long as E85 is slightly less expensive than E10 on an "energy equivalent" basis. Thus the blend wall is not necessarily insurmountable to achieving the RFS goals. Nevertheless, allowing for E15 in conventional vehicles may be seen by some parties as an economic "path of least resistance" in the short run (2011-2015) while the fleet for FFVs increases and E85 equipment at the retail level becomes more readily available.

On page 17, with regard to the recommendation for improved coordination with the Environmental Protection Agency (EPA) and the U.S. Department of Agriculture in determining greenhouse gas emissions and defining fuels eligibility under the RFS, it should be noted that EPA already consults with DOE on these matters, but that DOE would welcome the opportunity to become more engaged in this process if requested to do so by the EPA Administrator.

Also on page 17, with regard to increased support for petroleum-based fuels, sometimes referred to as hydrocarbon fuels, the Department has already expanded in this direction. Beginning in 2007, DOE started funding hydrocarbon fuels development through our gasification and pyrolysis research and development. The $480 million funding opportunity announcement for integrated biorefinery operations that closed on June 30, 2009, included green diesel and green gasoline under eligible fuels. A new solicitation to

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fund consortia to accelerate development of advanced biofuels under the Recovery Act also supports infrastructure-compatible fuels and algae-based fuels. In the future it is anticipated that hydrocarbon fuels will become a higher priority and contribute to RFS requirements for advanced biofuels.

On page 18, regarding eligibility of biomass material suitable for meeting the RFS mandate, the Department supports an expansion of biomass eligibility to include Federal lands that do not come from land classified as environmentally sensitive and can be grown and harvested in a sustainable manner. Again, if the EPA Administrator requests clarification on biomass definitional considerations, DOE would be responsive and welcome the opportunity to participate in these deliberations.

Footnote 20 found on page 26 refers to Cello Energy's production plans. Since Cello Energy recently lost a fraud lawsuit, it is recommended that the authors consider hedging the remarks associated with this reference.

GAO's concerns about piercing the blend wall are fleshed out on page 129-132 of the report. Their concerns might partly stem from the statement found on page 131, "DOE and ethanol industry experts are also concerned about the limited capacity of the freight rail system…" In fact, ethanol cargo currently represents a mere fraction of the total rail cargo. Also, given major capital expansions envisioned over the coming decades by the railway industry, even with the growth of ethanol production mandated, ethanol cargo will still be a very minor portion of total rail capacity, although, "beefing up" of rail terminal infrastructure will need to occur . However, no mention was made of barge movement of ethanol, which could face more significant problems as ethanol distribution is increased (see NCEP's recent "Biofuels Infrastructure Task Force" white paper).

Finally with regard to the ethanol pipeline discussion on page 131, it should be noted that Kinder-Morgan has performed extensive testing on transporting ethanol in existing petroleum product pipelines in Florida.

Thank you again for the opportunity to comment on the draft Report. We look forward to working with GAO as we continue our efforts to develop the potential of biofuels.

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

Sincerely,

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

Appendix X: Comments from the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUL 24 2009

OFFICE OF
AIR AND RADIATION

Patricia Dalton
Managing Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G. St., NW
Washington, DC 20548

Dear Ms. Dalton:

Thank you for the opportunity to comment on the draft final report, "Biofuels: Challenges and Potential Effects of Required Increases in Production," (GAO-09-446), dated July 2009. This draft was distributed across the key offices of the Environmental Protection Agency (EPA) to assure a full review. In general, our reviewers found the draft report to comprehensively identify the main issues that should be considered when assessing expanded biofuel production. Herein we identify our major comments. We have also provided in a separate document additional technical comments; consideration of these comments will also enhance the final product.

The Report makes three critical policy and legislative recommendations that require Administration review.

GAO recommendation 1: The Congress may wish to consider amending the Energy Independence and Security Act of 2007 (EISA) to require the Environmental Protection Agency (EPA) to develop a strategy to assess the effects of increased biofuels production on the environment at all stages of the lifecycle – cultivation, harvest, transport, conversion, storage, and use – and to use this assessment in determining which biofuels are eligible for consideration under the RFS.

Comment: This recommendation might best be addressed by the newly created Executive Biofuel Interagency Working Group co-chaired by the EPA, the Department of Agriculture (USDA), and the Department of Energy (DOE). This Working Group is tasked to address, among other things, "new policy options to promote the environmental sustainability of biofuel feedstock production, taking into consideration land use, habitat conservation, crop management practices, water efficiency and water quality, as well as life cycle assessment of greenhouse gases." The draft report also on numerous occasions points out that the EISA legislation mandating the RFS2 program does not specifically require assessment of air quality impacts, water quality impacts and similar environmental impacts. We point out, however, that EPA has clear authorities and

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responsibilities under other statues (including the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act, and other legislation) and, indeed, is considering a range of environmental impacts as part of the RFS2 rulemaking. Further, under EISA Section 204, EPA is required to evaluate the environmental impacts of biofuels and submit a report to Congress; we intend to fully comply with that responsibility. In fact, EPA has worked very closely with DOE and USDA in the development of the lifecycle assessment proposed for the RFS2 regulations and will continue to do so as we develop the final rules. Further, improving biofuel lifecycle assessment will be an ongoing emphasis in EPA and we expect to continue to work closely with our federal partners.

GAO Recommendation 2: The Administrator of EPA, in consultation with the Secretaries of Energy and Agriculture, develop a coordinated approach for identifying and researching unknown variables and major uncertainties in the lifecycle greenhouse gas analysis of increased biofuels production, including standardized parameters for using models and a standard set of assumptions and methods in assessing greenhouse gas emissions for the full biofuel lifecycle.

Comment: As required by EISA, EPA has undertaken development of a comprehensive lifecycle greenhouse gas impact assessment of biofuels. The Agency proposed rules in May that include our draft analysis of the greenhouse gas impact of biofuels. Throughout development of that proposal we worked closely with experts in both the Departments of Agriculture and Energy in developing the lifecycle assessment methodology and, importantly, incorporated their input on critical data and assumptions to be used. We fully expect to continue that cooperative working relationship as we develop final rules implementing the amendments to the Renewable Fuels Program. Additionally, there is extensive interagency coordination already in progress and extensive sharing of information between U.S., European Union (EU) and other international governmental organizations and scientists on modeling including the impact of indirect land use change.

GAO Recommendation 3 To address inconsistencies in existing statutory language, the Administrator of EPA, in consultation with the USDA and DOE, upon review, propose to the appropriate Congressional committees any legislative changes the Administrator determines may be needed to clarify what biomass material – based on type of feedstock or type of land – can be counted toward RFS.

Comment: EPA is working with USDA to identify discrepancies and interpret how biomass is treated under two pieces of legislation, EISA and the 2008 Farm Bill.

<u>Additional Comments</u>

In addition to addressing the specific draft recommendations affecting EPA, we also wish to make the following comments. EPA earlier this year provided extensive comment on a prior draft of this report. We note that a number of our comments and recommendations are reflected in this redraft. However, as indicated in our earlier comments, the analyses provided via EPA's notice of proposed rulemaking for the Renewable Fuel Standard (RFS2) mandated under the Energy Independence and Security Act (EISA) represents the most up-to-date and comprehensive assessment of many of these issues. (74 FR 24904, May 26, 2009) While in a few cases the publically available work completed for that proposal is recognized in this draft, it is not clear that the Government Accountability Office (GAO) fully considered or acknowledged these analyses. We ask that the report more clearly reference this EPA product.

The report emphasizes the inconsistencies in biofuel assessments in reported literature and interprets these as suggesting a lack of agreement amongst researchers as to the impacts of biofuels. Literature on lifecycle assessment of biofuels has grown considerably in the last few years as more researchers evaluate different aspects of lifecycle assessment and continually refine the tools, methodologies and data used in these analyses. While it is clear lifecycle assessment is an area of evolving research and analysis, we are concerned that the portrayal of a wide range of analytical results in the literature is being interpreted as the range of uncertainty in biofuel lifecycle assessment. We believe that in many of the examples cited, the differences in analytical results can in large part be explained by either differences in what is being modeled or in some cases the use of more precise or up-to-date data and assumptions. We recommend the GAO acknowledge in the report that the results found in the evolving lifecycle literature reflect, in fact, improvements in lifecycle assessment.

Once again, thank you for the opportunity to review this draft report.

Sincerely,

Gina McCarthy
Assistant Administrator

Appendix XI: GAO Contacts and Staff Acknowledgments

GAO Contacts

Mark E. Gaffigan, (202) 512-3841 or gaffiganm@gao.gov for energy issues

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Staff Acknowledgments

In addition to the individuals named above, Richard Cheston, Assistant Director; Elizabeth Erdmann, Assistant Director; James Jones, Assistant Director; Sarah Lynch; Micah McMillan; Tim Minelli; Kevin Bray; Erin Carson; Jay Cherlow; Julie Corwin; Barbara El Osta; Cindy Gilbert; Rachel Girshick; Marietta Mayfield; Charles K. Orthman; Tim Persons; Jeanette Soares; MaryLynn Sergent; Ben Shouse; Anne Stevens; Barbara Timmerman; Swati Thomas; Lisa Vojta; and Rebecca Wilson made key contributions to this report.

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