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Effects of Increased Biofuels on the U.S. Economy in 2022

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Abstract

Achieving greater energy security by reducing dependence on foreign petroleum is a goal of U.S. energy policy. The Energy Independence and Security Act of 2007 (EISA) calls for a Renewable Fuel Standard (RFS-2), which mandates that the United States increase the volume of biofuel that is blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022. Long-term technological advances are needed to meet this mandate. This report examines how meeting the RFS-2 would affect various key components of the U.S. economy. If biofuel production advances with cost-reducing technology and petroleum prices continue to rise as projected, the RFS-2 could provide economywide benefits. However, the actual level of benefits (or costs) to the U.S. economy depends importantly on future oil prices and whether tax credits are retained in 2022. If oil prices stabilize or decline from current levels and tax credits are retained, then benefits to the economy would diminish.

Keywords: Bioenergy, economywide, ethanol, petroleum, trade, macroeconomic factors, RFS-2

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Contents

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Summary

Diversifying the Nation's energy supply is one of the primary means for providing long-term energy security. A diverse energy portfolio can also have far-reaching economic impacts by reducing dependence on foreign oil. The Energy Independence and Security Act of 2007 (EISA) mandates a Renewable Fuel Standard (RFS-2) under which the United States will annually produce 36 billion gallons of biofuel, primarily ethanol, by 2022. Transitioning away from nonrenewable fossil fuels (such as petroleum oil) without placing additional burden on the U.S. economy is a long-term challenge. Although experts and policymakers generally agree on the importance of energy security, how best to achieve this goal and at what cost is subject to debate.

What Is the Issue?

Reducing dependence on foreign energy by expanding domestic renewable fuels can have impacts for the overall U.S. economy because of energy's importance in consumption, production, and trade. In the past, increasing energy independence would generally be expected to place a greater burden on the U.S. economy because of the higher domestic costs of producing alternative energy to replace relatively inexpensive foreign petroleum. However, according to the U.S. Department of Energy, petroleum prices are more likely to continue rising in the long term relative to the cost of producing domestic biofuels. Although the exact timing is uncertain, cost-reducing technology in biofuel production is expected to be a key factor in expanding production and making biofuels competitive with petroleum. However, without policies that provide incentives to deploy renewable energy technology, biofuel producers likely will shy away from investing in new technology because of market uncertainty. The RFS-2 mandate is accompanied by incentives in the form of tax credits to ethanol blenders. Tax credits, however, could add to taxpayers' costs and place greater burden on the economy. This study examines the potential effects of the RFS-2 on the U.S. economy as measured by gross domestic product (GDP), household income and consumption, price and quantity of energy fuels, and agricultural production and trade. We compare the U.S. economy in 2022 with and without the RFS-2.

What Did the Study Find?

If biofuel production technology advances and petroleum prices continue to rise as projected, the RFS-2 could benefit the U.S. economy. U.S. household consumption would rise because of higher real wages, increased household income, and lower import prices. By substituting domestic biofuels for imported petroleum, the United States would pay less for imports overall and receive higher prices for exports, providing a gain for the economy from favorable terms of trade. Improved technology and increased investment would enhance the ability of the U.S. economy to expand.

Gross Domestic Product

Changes in GDP and the magnitude of benefits (or costs) are highly dependent upon assumptions about alternative biofuel support policies and the future price of oil. The greater the value of displaced petroleum for each dollar of biofuel produced and the lower the tax credits, the greater the benefit to the U.S. economy. Cost-reducing technology would not only reduce the costs of producing biofuels but also contribute to national GDP because production would rise as efficiency improves.

Household Welfare

Household consumption would increase regardless of whether or not tax credits were retained, with the gains primarily due to increased real income, favorable terms of trade with relatively lower import prices, and hence, greater purchasing power to the household. Consumption would increase by about $13-$28 billion, depending largely on oil prices. The RFS-2 would raise real wages and household disposable income as returns to labor and capital increase. Replacing imported oil with domestic biofuels would lower the cost of motor fuels. Thus, households would spend less on, but consume more, motor fuels. In addition, lower prices for imports and fuel would encourage greater consumption of other goods and services.

Energy and Trade

Expansion of domestic biofuel production would reduce petroleum demand, thereby reducing the quantity of imported crude petroleum. Crude oil, which is a major input for gasoline, would be displaced by ethanol. U.S. imports of crude oil would fall by 16-17 percent in 2022. The United States is the largest importer of crude oil, with imports accounting for about two-thirds of total U.S. supply. Reduced U.S. demand for petroleum would lower the price of crude oil. As a result of lower demand and a decline in the import price, the U.S. import bill for crude oil would decline by $61-$68 billion. With a smaller import bill, the U.S. dollar would appreciate. A stronger dollar would reduce the cost of importing other goods, including agricultural commodities, and reduce export volume because of increased prices in foreign markets for U.S. products. In addition, with greater demand for land to use for both energy crop production and all other agricultural activities, meeting the RFS-2 would reduce U.S. agricultural commodity exports and increase the demand for agricultural imports as crops must compete for limited land.

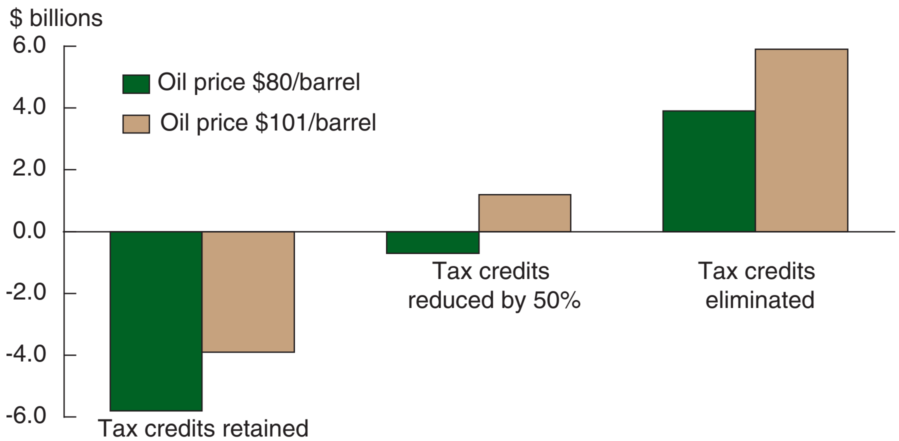
Caveats

This study does not predict the future but addresses the question of what would be the likely impacts on the U.S. economy should the RFS-2 mandate be met under different price/policy scenarios. The study acknowledges the uncertainty in meeting the mandate in 2022. The exact timing of the commercialization of new technologies to produce biofuels cannot be determined because of a myriad of uncertain factors. Future developments will also depend on new investments in infrastructure needed to support a transportation and distribution network for biofuels. Determining when such developments would take place is beyond the scope of this study. Long-term impacts on the U.S. economy from meeting the RFS-2 will depend partly on future petroleum prices. This study adopts a price projection from the U.S. Department of Energy that assumes that satisfying the growing world demand for petroleum will require accessing higher cost supplies of oil. Under these conditions, petroleum prices are likely to be higher in 2022 than current prices. Unlike previous decades, petroleum prices are likely to rise relative to the cost of producing biofuels.

How Was the Study Conducted?

The study used a detailed computable general equilibrium model for the United States—the U.S. Applied General Equilibrium (USAGE) model—comprising 534 industries. The model is a multipurpose framework for addressing a broad set of questions, including domestic and trade policy as well as macroeconomic links to trade. The model was modified to include additional sectors and industries involved in biofuel production, including conventional ethanol (corn-starch) produced from dry-milling and second-generation ethanol made from crop residues, dedicated energy crops, and other advanced biofuels. Other modifications include explicit treatment of U.S. agricultural land and regional land allocation for the production of biomass (organic material) and all other agricultural activities. A base, or reference, scenario without the RFS-2 was conducted for the year 2022 using the U.S. Department of Energy's projections. The effects of RFS-2 were determined as alternative scenarios using scenario analysis. Volumes of all types of ethanol were based on those established by EISA.

Impact of RFS-2 on U.S. gross domestic product



Note: In real prices.

Introduction

Diversifying the Nation's energy supply is the primary means for reducing long-term energy dependence on foreign sources. Although experts and policymakers generally agree on the importance of reducing dependence on imported petroleum, how best to achieve this goal is debatable. The Energy Independence and Security Act of 2007 (EISA) calls for a Renewable Fuel Standard (RFS-2), which mandates that the United States increase the volume of biofuel that is blended into transportation fuels from nearly 9 billion gallons in 2008 to 36 billion gallons by 2022. The RFS-2 mandate is accompanied by incentives in the form of tax credits, which are subject to change over time, to ethanol blenders. This study assesses the long-term effects of the RFS-2 by projecting into 2022 its impact on U.S. gross domestic product (GDP), trade, and household welfare.

Success in meeting the mandate depends on overcoming various challenges. One challenge is to diversify the sources of ethanol feedstocks beyond conventional corn, which involves greater reliance on cost-reducing technology, particularly if ethanol is to compete with petroleum in the future. A second challenge is to ensure sufficient demand for biofuels. Demand for transportation fuels in the United States is expected to continue to decrease as fuel efficiency standards for vehicles are raised. A third challenge is to find a solution to the "blend wall" constraint, in which increased ethanol production meets the 10-percent ethanol-to-gasoline blending limit. Regardless of the cost competitiveness of ethanol, the blend constraint could technically halt ethanol's growth unless domestic use is increased by altering automotive engine requirements to accommodate higher ethanol blends.

The effect on the U.S. economy in meeting the RFS-2 could depend on the incentives used to encourage investment. Without policies that provide incentives, underinvestment to advance renewable energy technology is likely due to risk aversion from market uncertainty (Rajagopal et al., 2009). Some argue that tax credits could be justified on the basis of achieving national energy security (Tyner, 2007). Others argue in favor of providing temporary protection to an infant industry, where learning by doing and adapting new technologies have future payoffs (Sheldon and Roberts, 2008). Although policies may be needed to correct market failures, sustaining incentives indefinitely may not be beneficial as industries mature. Economic incentives in the form of tax credits could add to taxpayers' costs and place greater burden on the economy. Some argue that industries with a mature technology, such as corn ethanol production, may no longer need tax credit incentives.[1] This report considers implications of tax credits on the U.S. economy in 2022.

[1]The U.S. Government Accountability Office (2009) suggests that the Volumetric Ethanol Excise Tax Credit (VEETC), a 45-cent-per-gallon Federal tax credit for ethanol, may not be needed to stimulate conventional corn ethanol production because production capacity is near the RFS limit of 15 billion gallons per year.

Another factor that can affect the impact of the RFS-2 on the U.S. economy is the competitiveness of biofuels. In the past, biofuels have not been competitive with petroleum oil. However, with cost-reducing technology, the prospects improve for biofuels to become competitive. In this case, biofuels might compete with imported petroleum oil in the future. Based on the U.S. Department of Energy's (DOE) (2009) long-term projections, ethanol prices in real terms are expected to fall, whereas petroleum-based gasoline prices would continually rise as crude oil prices rise with growing world demand. If DOE's projections hold, they may present an opportunity for the United

States to reduce its reliance on tax credits as ethanol becomes more competitive with petroleum. This study determines the impacts of the RFS-2 based on the DOE's price forecast.

The long-term gains to the economy from using cost-reducing technology in the production of ethanol, especially advanced biofuels, could offset costs associated with tax credits. The RFS-2 requires that ethanol be produced from a broad variety of organic material (biomass), with production of cellulosic ethanol (made from wood, grasses, algae, or nonedible parts of plants) increased from that of the previous mandate. Second-generation biofuels, such as cellulosic ethanol, have yet to exploit commercially existing technology advances. The farm and energy sectors are connected in many ways that can have important implications for meeting the RFS-2. The type of biomass used to satisfy the mandate can affect regional land allocation, farm production, and commodity trade.

In this study, we examine the interactions among energy and other sectors of the economy and estimate the long-term effects of the RFS-2 on the U.S. economy—that is, GDP, trade, and household welfare (income and consumption). Although there is much momentum for producing cellulosic ethanol, this study neither predicts when the technology for producing cellulosic ethanol will be adopted for commercial use nor determines the feasibility of meeting the timetable set by the 2007 EISA.

However, the study does present scenarios that take into account projected energy prices based on DOE long-term forecasts and tax credits for different types of ethanol. The study demonstrates that the RFS-2 mandate, when met under different conditions, involves tradeoffs for the U.S. economy.

Scenario Alternatives

To analyze the effects of the RFS-2, we compare the U.S. economy with and without the mandate in the year 2022. This comparison allows us to ascertain the impact of only the RFS-2, holding other factors constant. The projection of the U.S. economy in 2022 without RFS-2 is called the *reference* scenario (see appendix 1). Alternative scenarios of the U.S. economy with the RFS-2 assume full implementation of the mandate for the year 2022. However, it is unknown whether the RFS-2 will be met by retaining current tax credits for the duration of the mandate. Because the impact of the RFS-2 could depend on tax credits and petroleum oil prices, we present alternative scenarios with different tax credits and oil prices (see box, "Scenarios and Energy Price Projections"). We adopt the projected prices determined by DOE's long-term forecast.

The combination of different oil price assumptions, a low price (LP) of $80 dollars per barrel, a high price (HP) of $101 per barrel, and three tax credit assumptions provide six scenarios (S) to draw upon for the analysis:

(1) S1-LP: tax credits retained and low oil price.

(2) S2-LP: 50-percent reduction in tax credits and low oil price.

(3) S3-LP: no tax credits and low oil price.

(4) S1-HP: tax credits retained and high oil price.

(5) S2-HP: 50-percent reduction in tax credits and high oil price.

(6) S3-HP: no tax credits and high oil price.

Scenarios and Energy Price Projections

Long-term crude oil price projections depend on changing but highly unpredictable global petroleum supply and demand conditions. A number of factors may influence future prices of petroleum oil. For example, decisions made by the Organization of the Petroleum Exporting Countries (OPEC) can significantly affect global crude oil supply. DOE provides long-term forecasts of crude petroleum prices, supply, and use. We adopt DOE's forecast because projecting or forecasting petroleum prices is beyond of the scope of this report. According to DOE's reference forecast that assumes normal world growth, the price of crude oil is expected to gradually rise to $111 per barrel by the year 2030. The demand for petroleum oil would increase primarily from steady growth in developing countries (see appendix 2). Under normal growth conditions, the price of crude oil is projected to reach about $101 per barrel in 2022.

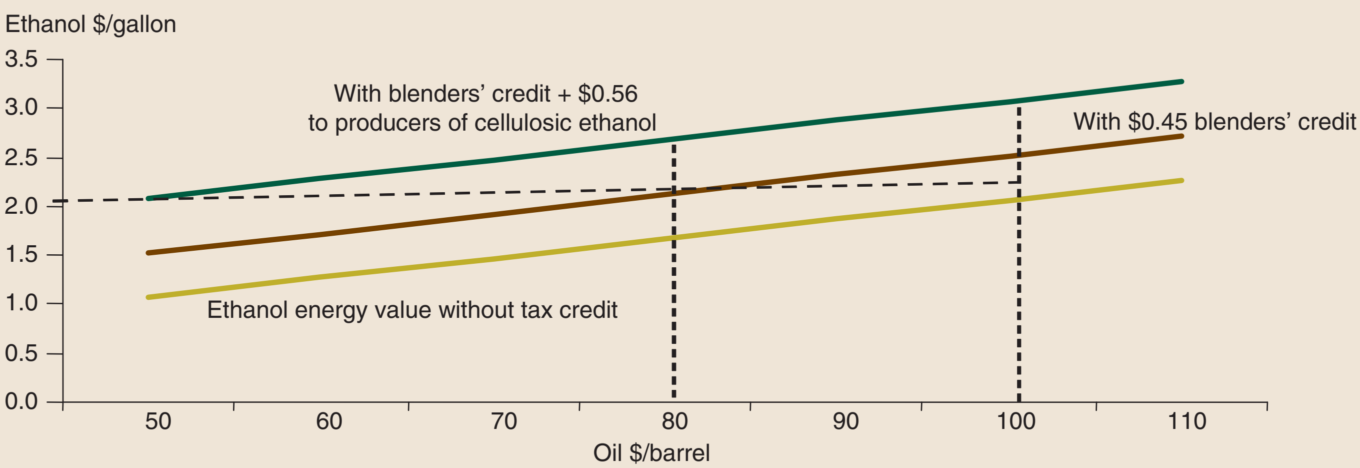
DOE projects the wholesale price of ethanol to remain near $2 per gallon through 2022. According to DOE, production costs are expected to fall in the long term, lowering the wholesale price of ethanol to below $2 per gallon through 2030. Improved efficiency in producing advanced ethanol, which would make ethanol more competitive with petroleum, is a key factor for the widening price gap between ethanol and gasoline over the next two decades. For this study, we adopt DOE's price for 2022 of $2.12 per gallon for ethanol in all scenarios, including scenarios that reduce or eliminate tax credits.

In our scenarios, we use DOE's projected oil price for 2022 of $101 as a high price and a corresponding energy-equivalent oil price using DOE's projected ethanol price of $2.12 per gallon. The figure below illustrates the correspondence between petroleum oil and ethanol prices on an energy-equivalent basis.[1] An oil price of $80 per barrel would correspond to DOE's projected ethanol price of $2.12 per gallon in 2022 on an energy-equivalent basis. For example, blenders could be willing to pay up to $2.12 per gallon for ethanol on an energy-equivalent basis when the price of crude oil is $80 per barrel and when the blender receives the 45-cent tax credit currently paid for corn ethanol. With oil prices above $80 per barrel, blenders could afford to pay more than $2.12 per gallon for ethanol. With the oil price of $101 per barrel and the tax credit retained at 45-cents per gallon, blenders could afford to pay $2.52 per gallon for ethanol. If ethanol suppliers were to receive $1.01 per gallon, blenders could offer up to $3.08 per gallon for cellulosic ethanol. Depending on future costs and technology advancement, this price could profitably compensate cellulosic producers.[2]

[1]This assumes ethanol contains two-thirds the energy of gasoline and a constant price relationship between petroleum oil and gasoline we adopt from Tyner and Taheripour (2007).

[2]The cost of producing cellulosic ethanol will depend on the size of the biorefinery, which could range from 20 to 100 million gallons per year. The production cost for producing cellulosic ethanol ranges from $1.60 to $2.00 per gallon, with yields ranging from 76 to 88 gallons per dry ton, depending on feedstock material. For further details, see National Academies Press (2009).

Energy price equivalent values



Source: Authors' calculations based on U.S. Department of Energy price projections.

Quantifying the Effects of the RFS-2 on the U.S. Economy

This section reports the results from the series of scenarios for the RFS-2. Results are simulated from an economywide modeling framework (see box, "The USAGE Model"). In doing so, the analysis identifies key links and interactions between energy, trade, and the farm sector from an economy-wide perspective.

Macroeconomic Impacts

Macroeconomic factors, such as GDP, household income and consumption, and international trade, are the broadest impact measures on the national economy. Meeting the RFS-2 results in multiple long-term effects on the U.S. economy. One effect is from the substitution of ethanol for gasoline in motor fuels. Replacing petroleum gasoline with less expensive ethanol would reduce domestic spending on motor fuels. This reduction would occur as long as ethanol is competitive with imported petroleum oil. The cost savings from reduced motor fuel expenditure are passed on to households. A second effect is from the reallocation of factors of production (production inputs). Industries with relatively high rates of technological progress generate increased returns to factors employed, thereby raising income to households. The overall economy benefits from resource allocation as returns to labor and capital increase. A third effect is from changes in trade and international prices for exports and imports. Household welfare increases when export prices rise relative to import prices (known as a "terms of trade effect").

This study measures gains or losses from changes in GDP and household welfare (in real terms).[2] The larger the value of displaced petroleum for each dollar of biomass produced, the greater the benefit to the U.S. economy. The higher the projected oil price, the greater the increase in GDP and household welfare. With oil at $80 per barrel and tax credits fully retained (S1-LP), GDP would decrease by $5.8 billion, partly because of the forgone revenue from tax credits. However, with oil at $101 per barrel and tax credits fully retained (S1-HP), GDP would fall a little less, by $3.9 billion (fig. 1).

[2]In this report, household consumption and household welfare are used interchangeably.

Cost-reducing technology plays an important role in meeting the RFS-2 not only by reducing ethanol's costs but also by contributing to national GDP. Assuming that reductions in tax credits are coupled with greater technological advances, lower tax credits would provide additional benefits to the economy. Reducing tax credits by 50 percent would increase GDP by $1.2 billion under the high oil price scenario. However, eliminating tax credits could raise U.S. output by nearly $6 billion under the high oil price scenario and by almost $4 billion under the low oil price scenario. Technological improvements in biofuel production could offset the negative effects associated with tax credits by improving efficiency and raising output in meeting the mandate. The contribution from technology would vary, depending on the price for oil (table 1). Under the assumption that technological progress permits ethanol of all types to become competitive with petroleum, the U.S. economy would benefit in meeting the RFS-2 as imported crude oil is reduced. The higher the U.S. import bill is for petroleum, the greater the potential for GDP to increase in meeting the RFS-2.

The USAGE Model

This study uses a model known as the United States Applied General Equilibrium model (USAGE). The model is an economywide framework of the U.S. economy and is designed for projections and policy analysis. USAGE is a multipurpose model developed by the Centre of Policy Studies at Monash University in collaboration with the U.S. International Trade Commission (USITC). The original theoretical basis for the model is based on Dixon and Rimmer (2002). The agricultural cost component is constructed from the Agricultural Resource Management Survey (ARMS) developed by USDA's Economic Research Service.

Several modifications were made for this application by adding additional industries, which provide explicit treatment for distinct types of biomass material for ethanol production and use (Winston, 2009). Modifications were necessary to represent implementation of the RFS-2, which specifies that ethanol be produced domestically from different sources, and to link agricultural production to regional land categories. One of the significant modifications to the USAGE model is the individual treatment of different types of ethanol using different feedstock materials.[1] This modification was necessary in order to implement the specified volumetric requirements of the RFS-2, which calls for different amounts of ethanol from three sources: corn ethanol, cellulosic ethanol, and other advanced biofuels.

Decisions for changes in land allocation are determined by producers' profit-maximizing behavior. The model includes biomass material—including cornstarch, cellulosic (crop residues and perennial energy crops), and other advanced (primarily from forestry residue)—for producing different types of ethanol. Differences in tax credits are also taken into account for individual types of ethanol. The model allows for flexibility in the substitution of multiple inputs for production of different types of ethanol (see appendix 3).

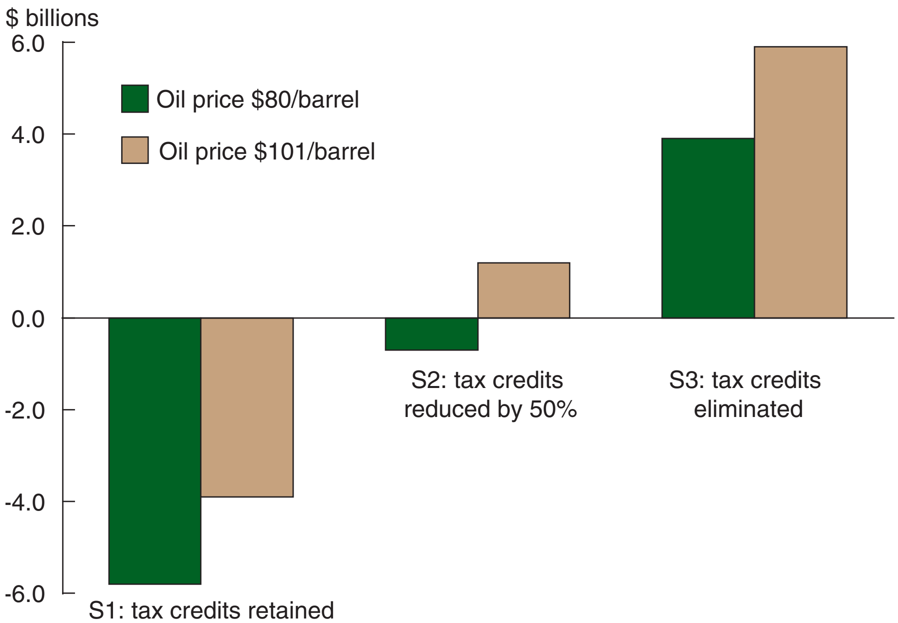
[1]Previous versions of the USAGE model did not distinguish different types of ethanol and biomass.

Household consumption would increase in all scenarios, and the consumption gains would be higher than GDP gains (fig. 2). Increases in consumption would depend on crude oil prices, tax credit reductions, and technology advances for meeting DOE's price projections. With oil at $80 per barrel and tax credits fully retained (S1-LP), consumption would increase by about $13 billion. With oil at $101 per barrel (S3-HP), consumption would increase by $28 billion from meeting the RFS-2. Consumption gains are primarily the result of increased real income, lower import prices, and higher export prices, all of which lead to greater purchasing power to the household.

Returns to factors of production in the form of wages and returns to capital would be enhanced by replacing more expensive imported petroleum (table 1). Real wages and real household disposable income would increase from meeting the RFS-2. With oil at $80 per barrel and tax credits fully retained (S1-LP), household disposable income would increase by 0.10 percent, but if tax credits were eliminated (S3-LP), income would increase by 0.15

percent (table 1). A higher oil price ($101 per barrel) with tax credits retained (S1-HP) would raise household disposable income by 0.14 percent. Similarly, real wages for consumers would increase with reduced tax credits and a higher oil price (S3-HP), while the dollar would appreciate in real terms.

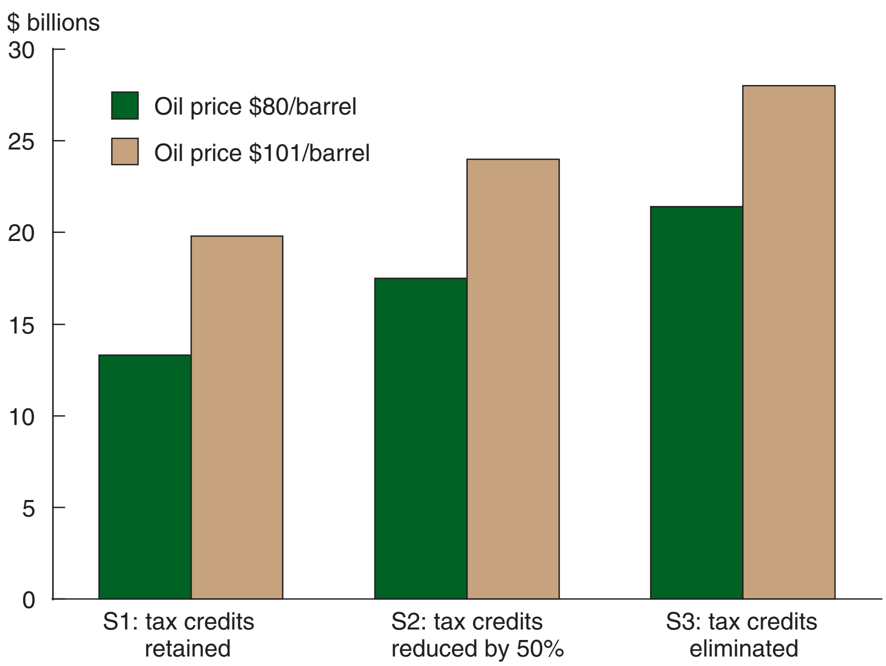
Figure 1
Impact of RFS-2 on U.S. gross domestic product



RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.

Figure 2
Impact of RFS-2 on U.S. household consumption



RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.

Table 1
Macroeconomic impact of RFS-2 in 2022[1]

Macroeconomic factors	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
	Percent change					
Household disposable income	0.10	0.12	0.15	0.14	0.17	0.20
Real wages for consumers	0.40	0.40	0.40	0.49	0.49	0.49
Real appreciation	0.91	0.94	0.96	1.16	1.19	1.21
Terms of trade	0.80	0.81	0.81	1.00	1.01	1.02
Export price	0.09	0.08	0.07	0.09	0.08	0.07
Import price	-0.70	-0.72	-0.73	-0.89	-0.91	-0.93
Import volume	-0.02	-0.04	-0.06	0.08	0.05	0.04
Export volume	-0.93	-0.96	-0.98	-1.05	-1.08	-1.10
Returns to factors of production	0.307	0.310	0.313	0.378	0.381	0.384
Technology contribution (to GDP growth)	0.244	0.261	0.274	0.240	0.262	0.271

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price. S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Replacing higher priced imported oil with domestic biofuels yields greater benefits as consumer spending on motor fuels is reduced. Among all consumer expenditures, those for motor fuels would fall the most, which in turn would encourage greater spending on other goods and services. The impact on expenditures for motor fuels would depend on the oil price. Expenditures for motor fuels would fall by about $9 billion with oil at $80 per barrel and by about $11 billion with oil at $101 per barrel. In addition, under the high oil price scenario, returns to factors of production would increase. Because household income is derived from wages and returns on capital, disposable income would also be greater. Higher incomes would also increase consumption of other goods and services.

Energy Fuel Impacts

The impacts on the U.S. economy in meeting the RFS-2 would come partly from lower priced imported petroleum oil and reductions in the price of domestic fuel. Table 2 presents the effects of the RFS-2 on price and quantity of energy fuels. The United States, as the largest single-country importer of crude oil, could potentially lower the world price of crude oil by reducing its imports. Reduced U.S. demand for petroleum would lower both the price and quantity of imported crude petroleum. The decrease in oil imports is significant because of the importance of petroleum in the total U.S. import bill.[3] The impact of meeting the RFS-2 on oil imports would affect the terms of trade for the United States as import prices would fall relative to export prices. The price of oil would fall about 4 percent. The reduction in the price of oil would also depend on future supply and demand conditions in the rest of the world.

Expansion of domestic biofuel production would reduce petroleum demand but increase the quantity demanded for motor fuels as the price of motor fuels falls (see box, “The RFS-2 and Implications for the Price and Quantity of Motor Fuels”).[4] The price of motor fuels is indirectly affected by the price

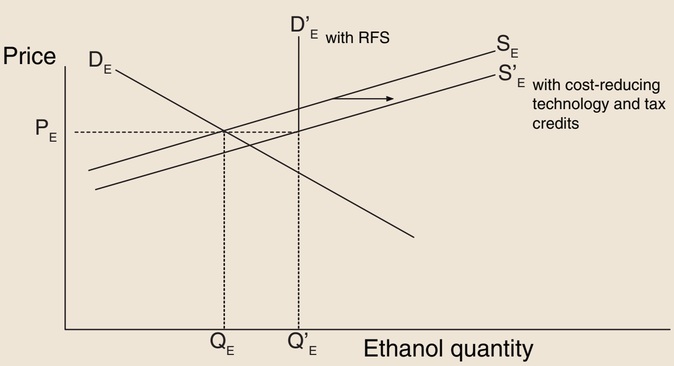
[3]U.S. imports of petroleum oil and petroleum-based products make up about 11 percent of total U.S. imports.

[4]Reformulated or blended fuel is produced by the “motor fuels” industry in the USAGE model.

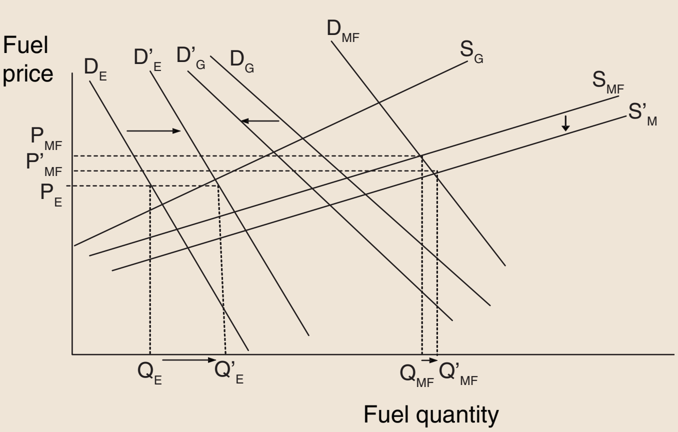
The RFS-2 and Implications for the Price and Quantity of Motor Fuels

The effect of the RFS-2 on motor fuels plays an important role in determining economywide impacts. The impacts of the RFS-2 depend partly on the price and quantity changes for blended motor fuels and petroleum-based gasoline. Meeting the RFS-2 could result in either an increase or a decrease in the price of motor fuels, depending on supply assumptions for gasoline and ethanol. Our price projections are based on the DOE's long-term price forecast for petroleum oil and ethanol. According to this projection, increased ethanol production over the long term could take place without the price of ethanol rising in real terms. To impose the DOE's price projection in our model, the ethanol industry's technological change is treated as endogenous. In other words, the model solves for technological change needed to satisfy the given quantity change according to the RFS-2 while imposing the longrun price projection. In this setting, meeting the RFS-2 is not binding as the supply increases to meet the DOE price forecast. In meeting the RFS-2 in 2022, the prices of gasoline and motor fuels are endogenous. The supply of gasoline is determined by the supply of crude petroleum oil, which depends on assumed supply and demand conditions in the rest of the world. Technological change is constant for gasoline and motor fuels production as prices for these fuels change.

RFS achieved with cost-reducing technology in ethanol production



Longrun impact on price of motor fuels with reduced demand for gasoline



The change in the equilibrium prices and quantities are depicted graphically in the accompanying diagrams. Meeting the requirement of the RFS-2 shifts the demand curve for ethanol from D_E to D'_E (top diagram). Cost-reducing technical change is denoted as a rightward shift in the supply of ethanol from S_E to S'_E . The quantity of ethanol increases from Q_E to Q'_E, while the price of ethanol P_E remains constant.

In this case the mandate is not binding and the market is able to satisfy the quantity demanded by RFS-2 without increasing the market price for ethanol. The price is determined from long-term reductions in the cost of producing ethanol, particularly for advanced ethanol.

Motor fuels, a mixture of gasoline and ethanol, get an increasing proportion of ethanol in meeting the RFS-2. The mixture of gasoline and ethanol depends on how much motor fuel quantity changes, which depends on the price of gasoline and ethanol. Ethanol displaces gasoline, thereby reducing gasoline demand, which is denoted as a shift from D_G to D'_G (bottom diagram). Given that the supply curve for gasoline (S_G) is upward sloping, the price of gasoline falls. The price of motor fuels falls as a result of substituting ethanol for gasoline and from using lower priced gasoline. The reduction in the price of gasoline allows the motor fuel industry to sell a greater quantity, shown as a rightward shift in the supply of motor fuels S_{MF}. Demand for motor fuels is depicted as a downward sloping curve D_{MF}. Consumers of motor fuels demand a higher quantity of motor fuels. The equilibrium quantity supplied and demanded for motor fuels increases from Q_{MF} to Q'_{MF}, as the price of motor fuels fall from P_{MF} to P'_{MF}. Total expenditures on motor fuels fall as a result of the drop in the price of motor fuels. The quantity demanded will depend on how responsive consumers are to a given change in the price of motor fuels.

[1]Previous versions of the USAGE model did not distinguish different types of ethanol and biomass.

of crude petroleum. Crude oil is a major input for petroleum-based gasoline, which affects the cost of gasoline. The price of motor fuels (a blended price) would fall as the price of petroleum-based gasoline decreases.

The price of gasoline would fall by about 9 percent under the low oil price scenario and by about 8 percent under the high oil price scenario (table 2). The 12-percent drop in the price of motor fuels is largely the result of substituting lower cost ethanol for gasoline. The ethanol price would remain at $2.12 per gallon according to the projection we adopt from DOE for the year 2022. As consumption of motor fuels (blended) increases, gasoline use increases. Thus, in meeting the RFS-2, U.S. gasoline consumption would not be reduced by the same amount of gasoline replaced by ethanol.[5]

[5]In this analysis, we assume that the consumer preference for higher blends of motor fuels would not change as a result of the RFS-2.

The value of imported crude oil would fall by $61 billion under the low oil price scenarios and by $68 billion under the high oil price scenarios (table 3). The total value of U.S. imports of all goods would fall under each scenario but would fall more with reduced tax credits and under the high price scenario for crude oil because the cost of importing goods would fall with an appreciating dollar. Non-oil imports would increase but would increase less with reductions in tax credits.

Table 2

Impact of RFS-2 on domestic fuel and imported crude oil in 2022[1]

Item	Unit	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
				Percent change			
Crude oil imports	Price	-4.11	-4.13	-4.15	-3.77	-3.79	-3.82
	Quantity	-17.46	-17.51	-17.55	-15.96	-16.00	-16.05
Gasoline	Price	-8.71	-8.72	-8.78	-7.82	-7.83	-7.83
	Quantity	-20.31	-20.31	-20.31	-18.13	-18.13	-18.13
Motor fuels (blended gasoline)	Price	-11.73	-11.74	-11.74	-12.02	-12.02	-12.02
	Quantity	2.47	2.47	2.47	2.53	2.53	2.54

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price. S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Table 3

Impact of RFS-2 on U.S. oil and non-oil imports in 2022[1]

Oil/non-oil imports	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Change in $ billions			
Crude oil imports	-61.23	-61.42	-61.59	-67.52	-67.75	-67.95
Non-oil imports	20.48	18.22	16.29	21.05	18.79	16.88
Total imports	-40.75	-43.20	-45.30	-46.47	-48.95	-51.07

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price. S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

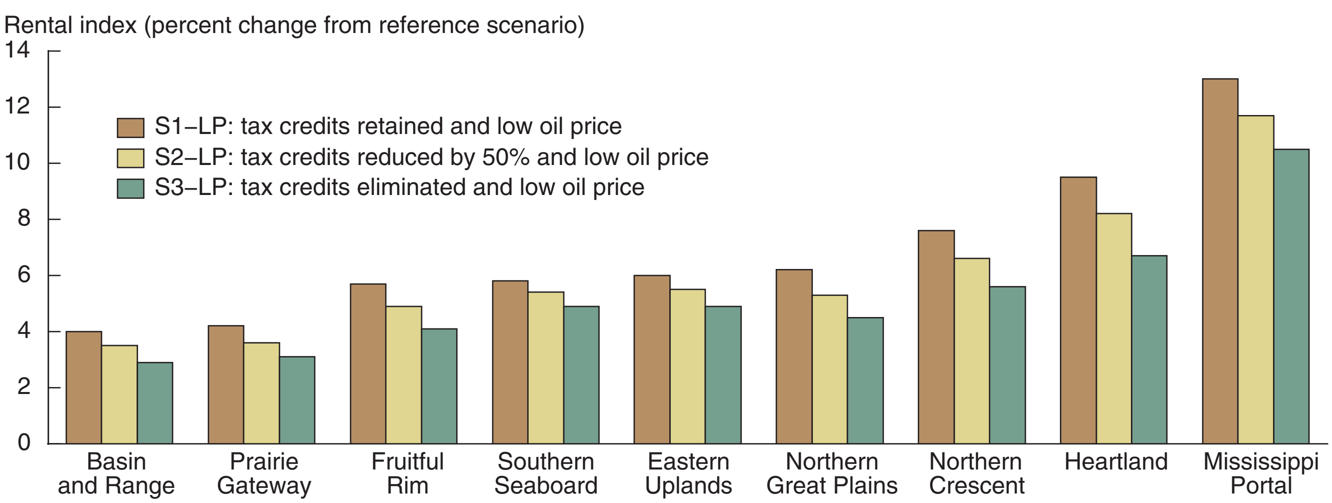
Farm Production and Trade Impacts

As previously discussed, meeting the RFS-2 mandate would reduce fuel prices and contribute to the dollar's appreciation. Both of these factors have the effect of lowering costs for the farm and food sector. However, competition for limited land could place upward pressure on land rents. This analysis considers the returns to land by location and production allocation to crop and livestock activities. Producers tend to allocate land to production activities that are expected to yield the largest benefit. The expected returns to land depend on the price of outputs and inputs, producers' preferences, and land quality (Lubowski et al., 2006). If meeting the mandate under the RFS-2 could be accompanied by cost-reducing technology for biomass and ethanol production, the land requirement to produce energy crops would be lower, which in turn, would mean less competition for land reallocation.

The analysis assumes that producers would not make alterations to enhance land capability, such as capital investment in irrigation, land reclamation, or conversions that might enable crops to grow on acreage previously classified as not suitable for growing crops. With fixed acreage, land rents would be a reflection solely of reallocating land to activities with higher returns. Demands on land differ because of the regional differences in acreage availability for growing energy crops and production characteristics of other crop and livestock activities. Producers alter acreage toward more profitable activities.

Increases in dedicated energy crop production would increase competition for all land types and consequently would raise rental rates. The effect of RFS-2 on land rents would depend on the proportion that energy crops would contribute to total cellulosic requirements. The magnitude of the increase in rental rates by region would capture differences in regional competition for land. Land types capable of supporting energy crops, including the Mississippi Portal, Heartland, and Eastern Uplands, are more likely to see higher rents (fig. 3). These areas would experience higher increases in land rents because of the land suitability for accommodating different crops,

Figure 3
Impact of RFS-2 on regional land returns, 2022



RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.

including energy crops. The land rents would also rise in the Fruitful Rim and Basin and Range, but the increase would be smaller.

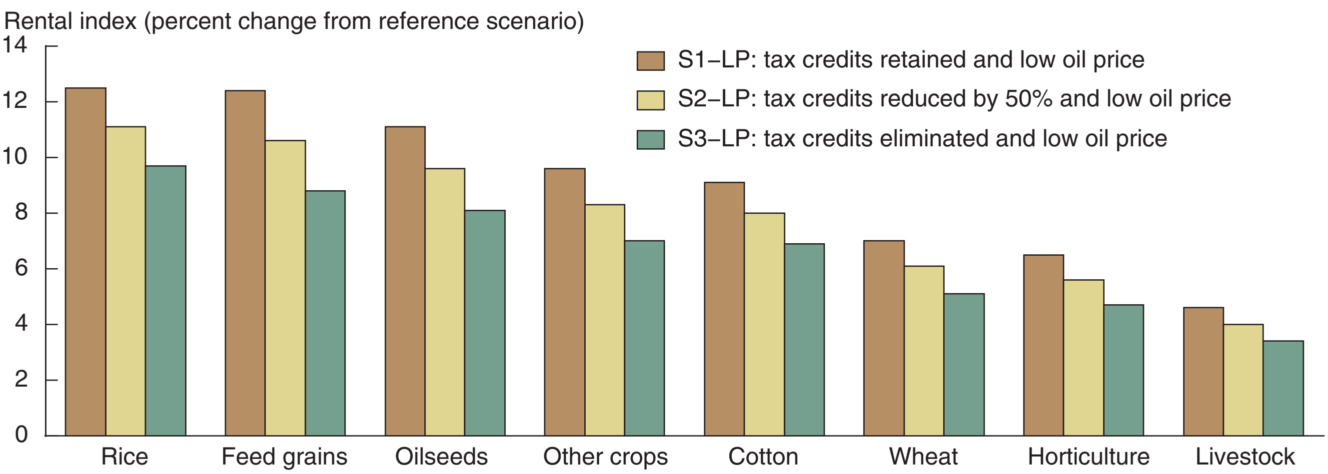
The abundance of farmland is not as important as its suitability for crop growing. For example, the Basin and Range region, with abundant and low-cost farmland, would be mostly unsuitable for growing energy crops due to inadequate rainfall and poor soil conditions. On the other hand, the Fruitful Rim region, with its suitable climate and soil conditions, would provide an ideal location for energy crops. However, energy crops would face greater competition with other traditional crops in this region. Land rents for rice would increase more than rents for other crops because of the indirect competition between rice and energy crop production (fig. 4). Because livestock and horticultural crops are produced in many places throughout the country, production of those commodities may face less intense competition from energy crops.

The RFS-2 would impact food prices considerably less than it would farm commodity prices in the long term (2022). For example, corn and rice prices would increase more than prices for downstream products, such as prepared feeds, for which prices increase by less than 0.5 percent (table 4). Farm commodity prices would rise partly because of increased competition for land, thereby raising production costs. Prices would increase less under alternative scenarios where tax credits are reduced.

The effects of the RFS-2 on crop production would vary, depending on the particular demand for each crop (table 5). Production of corn, used partly as an energy crop, would increase by 7-11 percent, whereas production of other crops not directly used for energy would likely fall. Improvements in cost-reducing technology, coupled with reduced tax credits, would reduce the effect of the RFS-2 on production under each scenario (S1-LP through S3-HP). Technological gains made for cellulosic energy crops could reduce the effects on production for all crop and livestock sectors.

Figure 4

Impact of RFS-2 on agricultural sector land rents, 2022



RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.

Table 4
Impact of RFS-2 on selected U.S. farm and food prices in 2022[1]

Commodity	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Percent change			
Corn	4.81	4.06	3.23	4.68	3.94	3.12
Rice	2.03	1.81	1.59	1.71	1.50	1.30
Fruits	0.71	0.62	0.52	0.63	0.54	0.45
Tree nuts	0.26	0.23	0.21	0.23	0.20	0.18
Meat	0.48	0.42	0.37	0.47	0.42	0.37
Fluid milk	0.52	0.46	0.40	0.53	0.48	0.42
Cheese	0.43	0.38	0.33	0.43	0.38	0.33
Flour	0.51	0.46	0.40	0.48	0.43	0.37
Prepared feeds	0.48	0.41	0.35	0.47	0.41	0.34
Bread	0.15	0.14	0.14	0.17	0.17	0.16

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price. S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Table 5
Impact of RFS-2 on U.S. farm output in 2022[1]

Commodity	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Percent change			
Corn	11.64	9.56	7.25	11.62	9.54	7.24
Rice	-1.43	-1.34	-1.25	-1.47	-1.37	-1.28
Cotton	-1.18	-1.17	-1.17	-1.15	-1.14	-1.12
Wheat	-0.65	-0.64	-0.64	-0.63	-0.63	-0.62
Other feed grains	-0.06	-0.10	-0.14	-0.05	-0.09	-0.14
Soybeans	-0.46	-0.55	-0.66	-0.47	-0.56	-0.66
Other oilseeds	-0.74	-0.77	-0.82	-0.72	-0.75	-0.79
Dairy	-0.39	-0.33	-0.27	-0.43	-0.37	-0.30
Beef	-0.53	-0.49	-0.45	-0.54	-0.50	-0.46
Other livestock	-1.01	-0.93	-0.84	-1.00	-0.92	-0.83
Tobacco	-1.25	-1.19	-1.13	-1.22	-1.16	-1.10
Fruits	-1.38	-1.25	-1.11	-1.45	-1.31	-1.17
Tree nuts	-1.71	-1.63	-1.55	-1.65	-1.56	-1.47
Vegetables	-1.66	-1.52	-1.37	-1.65	-1.50	-1.35
Other nonenergy crops	-0.41	-0.40	-0.40	-0.42	-0.41	-0.41

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price. S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Total land availability is constrained in this analysis. Thus, meeting the RFS-2 would reduce U.S. agricultural commodity exports and increase imports (tables 6 and 7) because domestic crops must compete with limited land. However, with gains from technological advances, the impacts on trade for all commodities would be reduced. Corn export and import flows would be affected more than those of other commodities by the RFS-2, with exports decreasing by 3-4 percent and imports rising 9-13 percent. For other commodities, reduced production would limit exports and increase imports. For example, with lower rice production, rice imports would rise by 3-4 percent, whereas exports would fall 1-2 percent. With imports further weakened by improved technology for cellulosic ethanol, most commodity imports would rise by less than 2 percent (table 7).

Increased biomass production would raise demand for farm inputs purchased from both domestic and foreign sources. This analysis assumes no capacity constraints in the United States or the rest of the world for farm input supplies. The responsiveness of farm input supply would moderate the impact of the RFS-2 on farm production and trade. Increased imports of farm inputs and lower energy prices would play an important role in determining domestic input supply response. Lower energy prices would reduce costs for domestic manufacturing of farm inputs. Both domestic fertilizer production and imported fertilizer would increase to meet increased demand (table 8).

Table 6

Impact of RFS-2 on U.S. farm exports in 2022[1]

Commodity	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Percent change			
Corn	-3.82	-3.36	-2.85	-3.81	-3.36	-2.86
Rice	-2.16	-2.03	-1.89	-2.10	-1.98	-1.85
Cotton	-1.30	-1.28	-1.26	-1.33	-1.31	-1.30
Wheat	-0.96	-0.95	-0.95	-0.99	-0.99	-1.00
Other feed grains	-0.54	-0.60	-0.67	-0.59	-0.65	-0.72
Soybeans	-0.79	-0.85	-0.93	-0.77	-0.84	-0.92
Other oilseeds	-1.15	-1.13	-1.12	-1.17	-1.15	-1.15
Dairy	-1.87	-1.74	-1.58	-1.97	-1.83	-1.68
Beef	-1.76	-1.65	-1.54	-1.84	-1.74	-1.63
Other livestock	-1.25	-1.18	-1.11	-1.30	-1.24	-1.17
Tobacco	-3.74	-3.44	-3.15	-3.47	-3.20	-2.92
Fruits	-2.71	-2.53	-2.35	-2.75	-2.58	-2.41
Tree nuts	-2.21	-2.07	-1.93	-2.31	-2.18	-2.04
Vegetables	-3.30	-3.09	-2.87	-3.46	-3.26	-3.05
Other crops	-1.77	-1.70	-1.62	-1.80	-1.73	-1.66

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price.
S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Table 7

Impact of RFS-2 on U.S. farm imports in 2022[1]

Commodity	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Percent change			
Corn	12.96	11.03	8.91	12.82	10.91	8.82
Rice	4.48	4.08	3.68	4.00	3.63	3.27
Cotton	1.61	1.57	1.54	1.46	1.43	1.41
Wheat	0.85	0.86	0.87	0.71	0.72	0.74
Other feed grains	0.84	0.96	1.10	0.86	0.98	1.13
Soybeans	0.80	0.79	0.80	0.72	0.71	0.73
Other oilseeds	1.46	1.31	1.16	1.44	1.29	1.13
Dairy	1.84	1.73	1.61	2.00	1.89	1.77
Beef	1.10	1.04	0.97	1.19	1.13	1.07
Other livestock	1.55	1.50	1.44	1.65	1.61	1.55
Fruits	0.80	0.78	0.75	0.87	0.85	0.82
Tree nuts	1.29	1.16	1.03	1.33	1.21	1.08
Vegetables	1.68	1.57	1.45	1.77	1.66	1.55
Other crops	1.25	1.14	1.02	1.21	1.11	1.00

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price.
S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Table 8

Impact of RFS-2 on U.S. fertilizer in 2022[1]

Item	S1-LP	S2-LP	S3-LP	S1-HP	S2-HP	S3-HP
			Percent change			
Output	6.27	5.70	5.18	6.26	5.70	5.18
Imports	10.31	9.43	8.61	10.31	9.43	8.61
Exports	4.34	3.93	3.56	4.29	3.88	3.50
Domestic price	0.01	-0.03	-0.07	-0.05	-0.09	-0.13

[1]2022 reference base year.
RFS-2 = Renewable Fuel Standard.

S1: tax credits retained; LP: Low oil price, HP: High oil price. S2: tax credits reduced by 50 percent; LP: Low oil price; HP: High oil price.
S3: tax credits eliminated; LP: Low oil price; HP: High oil price.

Source: USAGE model simulation.

Limitations and Further Considerations

Some limitations of this study are important in the analysis of the RFS-2. The modeling framework does not measure benefits from increased energy security or impacts associated with environmental change. Obtaining actual production data for second-generation energy crops and other advanced biofuels is still premature. How energy crops might affect regional allocation of land deserves more study. The underlying cost structure of energy crops and the differences in production costs by region could influence regional shifts in crop production. The report did not consider additional land that could potentially be used that is currently under the Conservation Reserve Program (CRP) or forest land. Furthermore, this study does not consider future developments in the rest of the world that could affect commodity supply and demand for the U.S. farm and food sector.

Another shortcoming of the analysis is in addressing public expenditures on research and development for the technological change, which would require the model to link technological change to expenditures explicitly. In addition, the study does not account for the long-term costs of infrastructure to support the biomass and biofuels industry. For example, such an accounting would involve including the costs of developing the infrastructure to support the transportation system for biomass and ethanol. Comprehensive infrastructure costs for meeting the RFS-2 are not yet known. In addition, the public costs associated with mitigating risks and financing of renewable energy investments were not taken into consideration. Capturing all future benefits and costs is beyond the scope of this study.

Conclusions

Increasing energy independence has been an aspiration for the United States since the early 1970s with the first major oil price spike. However, during much of the last 25 years, economic incentives for developing alternative energy has been limited because of low petroleum prices that made alternatives uncompetitive. Petroleum price increases were only temporary as oil supplies were restored within months. Low prices and policy incentives were not adequate to stimulate development of renewable fuels. The RFS-2 mandate could face similar challenges in the future.

Although global economic fluctuation creates uncertainty for near-term energy prices, technological advances play a key role in the success of a permanent and viable alternative energy industry. This analysis does not address the likelihood of meeting the RFS-2 timetable, but it attempts to provide estimates for whether and under what conditions the U.S. economy would benefit from meeting the mandate in 2022. Technological progress could enable biofuels to become competitive with petroleum, providing benefits to the U.S. economy. The larger the value of displaced petroleum for each dollar of biomass produced, the greater the benefit would accrue to the U.S. economy.

The challenge over the next decade is more likely to confront the uncertainty of short-term conditions that fall in the way of achieving long-term gains. Policies that provide incentives for producers may mitigate some risks associated with market uncertainties, whereas tax credits are more likely to reduce economic welfare. This study shows that, even with tax credits, technological progress could offset losses by raising welfare in meeting the RFS-2.

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Appendix 1: Developing the Reference Scenario

The base year of the U.S. Applied General Equilibrium (USAGE) model for this study is 2005. However, the reference scenario and analysis of the Renewable Fuel Standard (RFS-2) through 2022 require that projections be made for that year (2022). The modeling framework adopts projections for the U.S. economy to develop a reference scenario. Long-term macroeconomic and energy projections for the U.S. economy are used to simulate economic growth. In our reference scenario, variables are "targeted" to match projections determined by other projection models used by the U.S. Department of Energy (DOE) and the U.S. Department of Labor. The reference scenario, also known as a "forecast scenario" in the USAGE model is based upon projected variables, such as gross domestic product (GDP), consumption, investment, population, labor force, petroleum prices, exports, and imports. These variables are exogenous variables in the reference scenario because they are determined independently from the model. The scenario serves as a neutral growth scenario where the RFS-2 is not met and is consistent with the DOE's projections. In simulating the effects of the RFS-2, most macroeconomic variables are determined by the USAGE model and reported as deviations from the reference scenario.

Based on long-term projections, U.S. economic growth, trade, and consumption spending are expected to resume growth after the 2008-10 global economic downturn. Economic growth in the United States is assumed to take place as "business as usual" through 2022. GDP is expected to grow by 2.96 percent per year and by 64.2 percent between 2005 and 2022 (app. table 1). Private consumption in the United States is expected to grow at an annual rate of 2.86 percent. The dollar is expected to continue to weaken. The weaker dollar is expected to slow import growth to 4.25 percent per year and increase export growth to 5.5 percent per year. A weakening dollar would further reduce the U.S. trade deficit.

Appendix table 1

Reference scenario: Key U.S. macroeconomic variables, 2005-22

Item	Annual growth	Accumulative growth
	Percent change	
Private consumption	2.86	61.5
Labor supply	0.91	16.7
Capital stock	2.96	64.1
Real investment	3.20	70.9
Government consumption	1.85	36.5
GDP real	2.96	64.1
Population	0.85	15.6
Exports	5.50	148.5
Imports	4.25	102.9
Consumer price index	2.39	49.4

Source: U.S. Department of Energy and U.S. Department of Labor.

Projections for energy variables under the reference scenario are also determined outside the USAGE model for making projections for the year 2022 (app. table 2). As vehicle fuel efficiency standards are raised, it is expected that total motor fuel consumption will fall (4.6 percent) between 2005 and 2022. Domestic production of petroleum is expected to rise over the projection period, whereas fuel imports are expected to decrease. It is assumed that, without the RFS-2, corn-based ethanol would double between 2005 and 2022, reaching 8 billion gallons. The analysis assumes that 7 billion additional gallons of corn-based ethanol are produced due to the RFS-2 mandate.

In our reference scenario, we adopt two alternative crude oil prices. We use an oil price of $80 per barrel (*Low Price*) as a low bound corresponding to ethanol's energy value for replacing gasoline and $101 (*High Price*) per barrel as an upper bound, which is directly from DOE's reference case for imported crude petroleum. Appendix table 3 shows projections from imposing the macroeconomic and the energy component of DOE's 2022 *reference* scenario on the U.S. economy under the two alternative prices for crude oil—that is, $80 and $101 per barrel. The projections are expressed as percentage changes from the base year (2005). Under the reference scenario, we assume that 8 billion gallons of conventional corn-based ethanol are available without the RFS-2, which means that corn ethanol would need to expand by 94.3 percent from a base of 4.12 billion gallons in 2005 (app. table 3). The price of gasoline would rise by 73 percent from the base year in 2005. However, the price of *blended* motor fuels (gasoline with ethanol) would rise by a lesser amount under the projection that the real price of ethanol would be $2.12 per gallon in 2022. Imported petroleum oil would fall with the rise in the price of imported petroleum, starting from $40 per barrel in 2005.

Appendix table 2
Reference scenario: U.S. energy-related sectors, 2005-22

Item	Annual growth	Accumulative growth
	Percent change	
Natural gas consumption	0.76	13.67
Motor fuels consumption	-0.28	-4.60
Gasoline exports	0.84	15.24
Diesel exports	0.84	15.24
Crude oil exports	1.63	31.70
Gasoline imports	-2.21	-31.60
Diesel imports	-2.21	-31.60
Other petroleum imports	-2.21	-31.60
Natural gas imports	-0.69	-11.17
Electric services	1.61	31.22
Diesel production	1.45	27.70
Other petroleum fuels production	0.23	3.90
Crude petroleum production	1.13	21.10
Natural gas production	0.59	10.52
Corn ethanol production	4.16	100.00

Source: U.S. Department of Energy.

Appendix table 3

Reference scenario: Key U.S. macroeconomic variables, 2005-22

Item	Oil price $80/barrel		Oil price $101/barrel	
	Price	Quantity	Price	Quantity
	Percent change			
Gasoline	73.2	-0.2	109.0	-0.2
Motor fuels (blended gasoline)	69.3	0.1	103.5	0.1
Ethanol	0.0	94.3	0.0	94.3
Crude oil imports	100	-2.7	152.5	-2.7

[1]2005 base year.

Source: USAGE model simulation.

Appendix 2: Energy Price Projections

Future petroleum prices are likely to depend on the growth of the world economy and the underlying longrun costs for producing petroleum. The reasons for higher petroleum prices in the long run are discussed in this section.

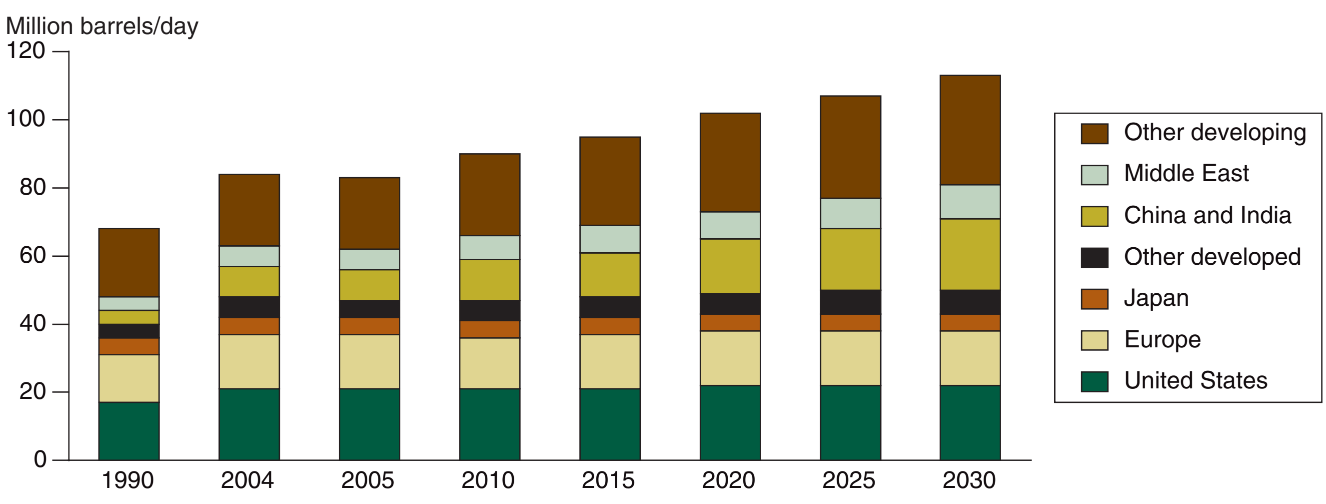
The last time the world economy experienced a major downturn that curbed global output, trade, and energy demand was more than a quarter of a century ago. For much of the last 25 years, low prices for petroleum limited development of alternative energy. Even as world growth resumed after the 1982 recession, energy prices did not recover. Between 1985 and 2004, the real price of gasoline in the United States remained flat, rarely rising above $2 per gallon. If those same conditions were to persist over the next decade, they would weaken incentives for developing biofuels. Although the recent recession is comparable to the downturn of 1982, a repeat of the 1980s, with suppressed and prolonged stagnation in petroleum prices, is not likely because, since then, a number of factors have altered world energy markets.

The supply of petroleum has always been subject to instability from geopolitical forces. Price surges in the past were mainly from supply disruptions. High prices were rarely sustainable for more than several months at a time. However, in the recent decade, petroleum prices were elevated over a multi-year period, even without a major supply disruption. Strong demand and sluggish supply contributed to higher prices.

World energy demand continues to grow, particularly in developing countries. Their share of world GDP is now much larger than it was in the 1980s, and their energy use per dollar of GDP (energy intensity) is higher than it is in developed countries. In 1990, China and India accounted for 5 percent of demand for global liquid fuels, but their share increased to 11 percent by 2005 (app. fig. 1). Economic growth was particularly strong for both of these countries between 2004 and 2008 and a key driver for raising petroleum

Appedix figure 1

Projected consumption of liquid fuels, 1990-2030



Source: U.S. Department of Energy, 2009.

prices during this time. By 2025, China and India are expected to account for 17 percent of global liquid fuel consumption, surpassing total consumption for all of Europe.

By 2015, other developing countries are expected to surpass the United States in liquid fuel consumption. Demand for liquid petroleum fuels is expected to remain nearly flat for Europe, Japan, and the United States between 2010 and 2025. The United States is expected to consume just 5 percent more in liquid fuels between 2007 and 2030, from 20.6 million barrels to 21.6 million barrels. Given this trend, and assuming improvement in fuel efficiency standards for vehicles, energy intensity is likely to fall in the United States. Developed countries would account for less than 50 percent of the world's liquid fuel consumption, whereas developing countries would drive nearly all of the world's increase in liquid fuel consumption. As consumers in developing countries switch to personal motorized transportation, per capita consumption of energy increases. Globally, transportation fuel use is expected to account for 74 percent of the increase in liquid fuel use. At the same time, industrial sectors are more likely to adopt efficient technologies that are lowering energy intensity.

The longrun cost of supplying petroleum fuels is more likely to rise for the following reasons. First, new investment would be needed for the world's oil producers to expand beyond current capacity. Second, the cost of extracting oil from proven oil reserves is more likely to rise. Third, oil exploration and development, which may require riskier investments that require higher rates of return, would also drive costs up.

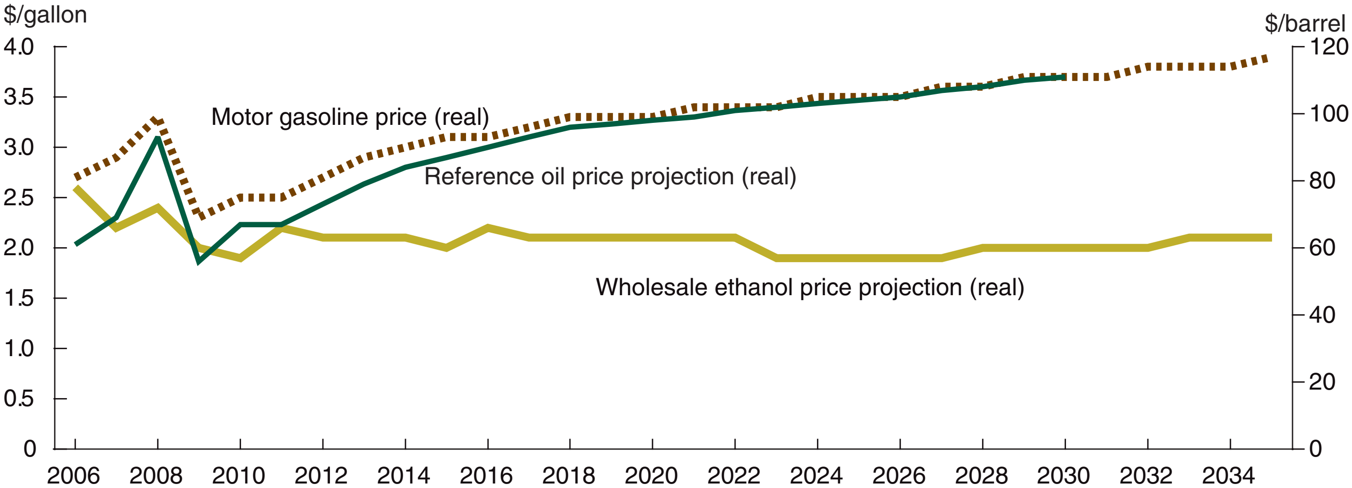
How much costs increase would depend on the source of supply because the cost structure of each petroleum source varies, depending on the geographic origin. Liquid fuels come from three basic sources: conventional petroleum from the Organization of the Petroleum Exporting Countries (OPEC), conventional petroleum from non-OPEC suppliers, and unconventional fuels, which could be supplied by both OPEC and non-OPEC sources.

Conventional petroleum supplied by OPEC is the lowest cost and most accessible liquid fuel. However, accessibility is a problem for conventional fuels supplied by non-OPEC countries. The lack of prospects for large conventional petroleum reserves in non-OPEC countries could constrain production. Development of small fields is a possibility but would come at high cost. Liquid fuels from unconventional sources are generally more expensive than those from conventional sources. Unconventional sources include oil sands (bitumen), coal-to-liquids (CTL), gas-to-liquids (GTL), and extra-heavy oil from Venezuela and Mexico.

In addition to rising costs of exploration and extraction of conventional and unconventional liquid fuels, OPEC's decision for maintaining its own market share in the world market adds to uncertainty. Even if OPEC maintains its current market share (about 40 percent) by increasing production to meet demand with other producers, the price of crude oil is more likely to continue its upward movement after 2010 (app. fig. 2). The price in 2022 would be $101 per barrel in real terms (U.S. Department of Energy, 2009). If OPEC could restrain supply, the price of crude oil would be higher. Limited supply from OPEC would raise the costs of producing crude oil as it encourages

Appedix figure 2

Fuel price projections, 2006-30



Source: Department of Energy, 2009.

production of higher cost liquid fuels by non-OPEC and unconventional sources.

In the long term, without advances in cost-reducing technology, the cost of imported crude oil will largely drive the wholesale price of gasoline (app. fig 2). Technological advances in producing alternative fuels would keep ethanol prices from rising. The longrun costs of producing alternatives fuels, like second-generation biofuels, are expected to decrease over the next decade. Although the exact timing is unknown, a growing share of ethanol is expected to be produced by second-generation biofuels as costs fall. Even as production of second-generation ethanol would expand over the decade, the real price of ethanol is not expected to increase over the long term. Improved efficiency in producing biomass and converting it to ethanol would be the key reasons for the widening price gap between ethanol and gasoline over the next two decades.

Appendix 3: Modifications for Modeling Energy Fuels

Production of cellulosic ethanol from dedicated energy crops does not yet exist on a commercial scale. This study does not attempt to make annual forecasts of production of dedicated energy crops. However, to fully implement the RFS-2 scenario, we need to make reasonable assumptions about future locations for growing dedicated energy crops. We assume that the potential for supplying dedicated energy crops varies by location because of the characteristics of the land (such as soil conditions), topography, climatic conditions, and competition with other crops.

To provide better treatment for farmland in the USAGE model, this study adopted a geographical categorizations scheme for the United States, known as Farm Resource Regions (FRR). The Farm Resource Regions were developed by USDA's Economic Research Service for depicting geographic specialization in production of U.S. farm commodities. It is used for addressing economic and resource issues in U.S. agriculture. The FRR designations consist of nine regions with boundaries defined by information on U.S. farm characteristics, county-level production, and land resource information. Regional boundaries are determined by the clustering of similar farm characteristics intersected with similar geographic climatic conditions. This type of regional grouping delineates geographical farm specialization more precisely than what would be possible using State-level groupings and aggregate farm production. For example, the Heartland region comprises three entire States but includes areas of five other States. The partial inclusion is because of the differences in farm characteristics and the underlying crop growing patterns. Each FRR has a distinct crop mix underpinning the uniqueness of each region's geography.

This study does not attempt to treat distinct types of perennial grasses in modeling cellulosic biomass. A perennial energy crop commodity, switchgrass is used to represent all related species of grasses used as dedicated energy crops in the USAGE model. Dedicated perennial energy crops may comprise multiple herbaceous species of which switchgrass is one. Although switchgrass has high potential for being grown in many regions, other species could be more suitable, depending on local conditions. Reliance on a single species, such as switchgrass, poses production risks for epidemic pest and disease outbreak. More than one species likely will be grown in any one location. Multiplicity of herbaceous species can also provide stability of yields over time. Among the promising species of perennial grasses are *Miscanthus*, reed canary grass, tall fescue, and Bermuda grass (Biomass Research and Development Board, 2008a). *Miscanthus* has higher yields than switchgrass and greater profit potential for a wide range of growing regions. The potential for dedicated energy crops varies by each FRR region (app. table 4). Regions with the highest potential are the Mississippi Portal, Eastern Uplands, the Heartland, and the Southern Seaboard. These regions would account for 80 percent of total production of dedicated energy crops. The "pre-simulated" shares reflect the potential for growing dedicated energy crops. The "post-simulated" shares reflect production based on economic returns. The USAGE model determines changes in the allocation of land for each crop based on profit maximization. Higher profits translate into higher returns to land. As

Appendix table 4
Estimates of the distribution of perennial energy crops for meeting the RFS-2 in 2022

Region	Pre-simulation	Post-simulation
	Percent	
Heartland	19.0	19.0
Northern Crescent	7.0	8.7
Northern Great Plains	6.0	7.4
Prairie Gateway	6.0	6.4
Eastern Uplands	20.0	19.6
Southern Seaboard	9.0	9.8
Fruitful Rim	2.0	2.4
Basin and Range	0.0	0.0
Mississippi Portal	32.0	26.6
Total	100.0	100.0

RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.

the relative returns to land with greatest potential increase from competition among competing crops, land is reallocated to the most productive uses. Production can be limited as profitability diminishes from increased competition for limited land in any one region.

The USAGE model uses multi-level nests of the CRESH (constant ratio of elasticities of substitution, homothetic) functional form, representing each industry's production structure. Each pair of inputs is governed by a common parameter for all pairs of inputs. This structure, however, can pose some limitations in allowing flexibility in the substitution of intermediate inputs for ethanol. For example, cellulosic ethanol made from dedicated energy crops is highly substitutable with ethanol made from crop residues. However, other intermediate inputs, such as chemicals and enzymes, would not be substitutable with other materials from biomass. The reason for a separate cellulosic material industry is to permit a high degree of substitution of crop residue material with energy crop material but not with other intermediates, such as chemicals and enzymes. In the USAGE model, a fictional cellulosic material industry produces a product that is a combination of switchgrass and crop residue purchased by the cellulosic ethanol industry (app. fig. 3). Unlike other conventional industries, the production of cellulosic material does not employ labor or capital (value-added).

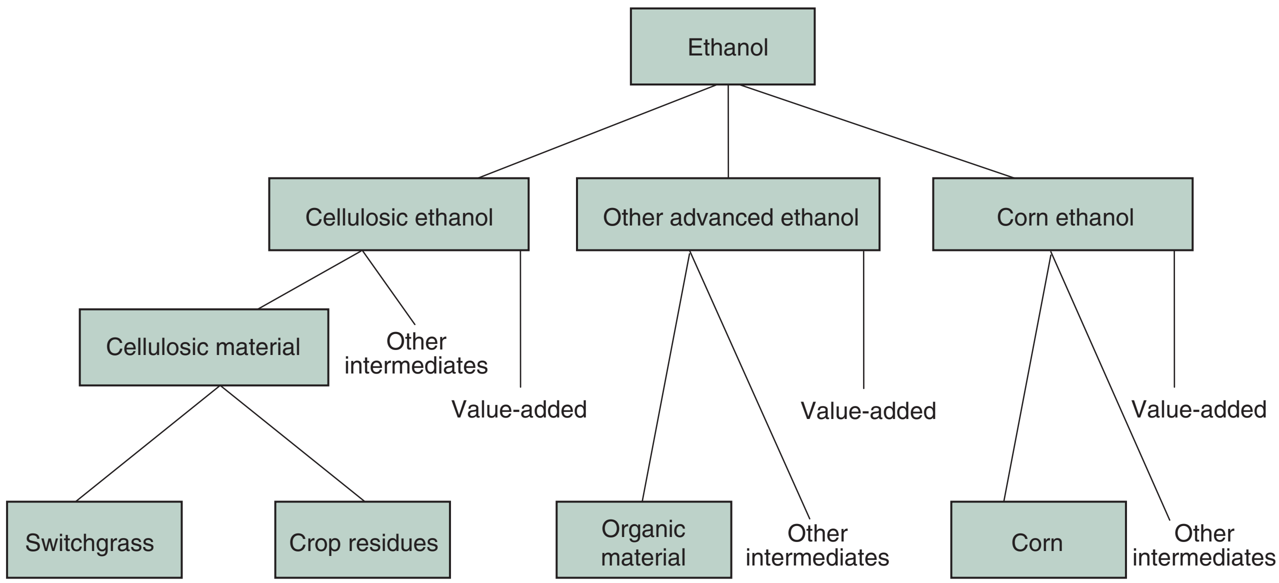
Crop residues for cellulosic ethanol production could potentially come from multiple crops, such as corn, wheat, sorghum, barley, and rice. Milbrandt (2005) estimated that approximately 157 million dry tons of biomass for producing cellulosic ethanol was available in 2005. Availability of crop residues is a function of several factors, including the crop-to-residue ratio, moisture content, and alternative uses, such as animal feed and compost.[6] In this study, the supply of crop residue comes from corn only. We assume that 1 ton of corn stover, on average, is produced for every ton of corn. USDA guidelines for soil erosion require that a minimum of 30 percent be left on the ground for anti-erosion coverage. The model uses a mixed complementarity

[6]See Biomass Research and Development Board (2008b) and De La Torre et al. (2003) for the potential supply of biomass in the United States.

approach to capture demand and supply relationships. Supply is governed by the feed grain industry facing a joint-profit maximizing decision for corn and corn stover.

Appedix figure 3

Ethanol production structure in USAGE model



Appendix 4: Sensitivity Analysis for Imported Crude Petroleum

The impact of meeting the RFS-2 on the U.S. economy will depend partly on the responsiveness of the supply of crude oil in the rest of the world. The reduction in U.S. demand for petroleum reduces both quantity supplied and the price for crude oil. The more responsive the supply is for crude petroleum, the smaller the decrease in the price of crude oil. Smaller declines in the price of oil translate into lower GDP and household welfare. The import supply elasticity captures the net effect of both the demand by non-oil-producing countries and the supply of oil-producing countries. Household welfare from the impact of the RFS-2 is positive over the entire range of import supply elasticities (10-0.5) (app. table 5). However, GDP becomes negative for elasticities greater than 1. This study adopts a midpoint import supply elasticity of 5. Although GDP and welfare are higher with the greater drop in petroleum, energy independence is reduced as imports of crude petroleum fall less and motor fuels output is greater.

Appendix table 5

Sensitivity analysis of the import supply elasticity for crude petroleum in meeting the RFS-2

Import supply elasticity	Crude oil imports	Crude oil price	Motor fuels output	Gasoline output	Welfare	GDP
			Percent change			
10	-18.0	-2.6	2.3	-20.0	0.084	-0.026
9	-17.9	-2.8	2.3	-20.0	0.087	-0.025
8	-17.7	-3.0	2.3	-19.9	0.090	-0.024
7	-17.5	-3.2	2.4	-19.9	0.093	-0.023
6	-17.3	-3.5	2.4	-19.8	0.098	-0.021
5	-17.0	-4.0	2.5	-19.7	0.105	-0.019
4	-16.0	-5.2	2.8	-19.4	0.123	-0.013
3	-15.4	-6.1	2.9	-19.2	0.136	-0.009
2	-14.2	-7.6	3.2	-18.9	0.159	-0.001
1	-11.1	-11.3	4.0	-18.0	0.216	0.016
0.5	-7.8	-15.1	4.8	-17.0	0.277	0.035

RFS-2 = Renewable Fuel Standard.

Source: USAGE model simulation.