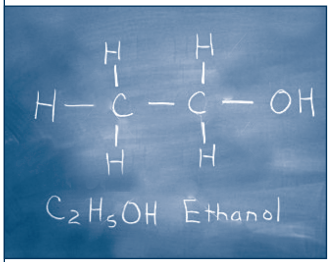
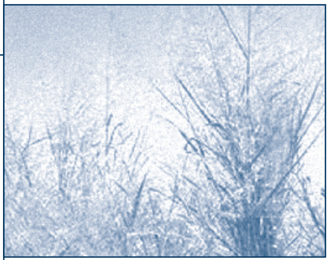
U.S. Department of Commerce
Internati l Trade Adm

Energy in 2020: Assessing the Economic Effects of Commercialization of Cellulosic Ethanol





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Manufacturing and Services Competitiveness Report

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Executive Summary

U.S. dependence on imports of crude oil has steadily increased for three decades. One way to reduce this dependence is to increase domestic production of renewable fuels such as ethanol. This report examines the effect on the U.S. economy in 2020 if advances in technology allow cellulosic ethanol to become commercially viable and if cellulosic ethanol production becomes adequate to allow total ethanol production to reach 30 billion gallons (including 10.5 billion gallons of corn-based ethanol). In this report, "oil" and "crude oil" are used interchangeably, unless otherwise noted. Our findings, based on production of 19.5 billion gallons of cellulosic ethanol in 2020, indicate the following:

- Compared with current projections for 2020, U.S. crude oil imports would be 4.1 percent lower than projected, amounting to a difference of about 460,000 barrels per day. Furthermore, the worldwide price of oil and the domestic U.S. fuel price would be 1.2 percent and 2.0 percent, respectively, lower than projected.
- The annual benefits to U.S. consumers of increased cellulosic ethanol production would be $12.6 billion in 2020. Expressed in terms of today's economy, that amount is equivalent to about 40 percent of the gains in real income that would accrue to the United States from eliminating all restraints on imports.
- The primary beneficiaries of commercially viable cellulosic ethanol production would be crop-producing U.S. industries and their suppliers. The increase in output over baseline projections from these sectors would range from 2.4 percent to 4.3 percent in 2020. U.S. agriculture could gain 20,350 jobs at the expense of other sectors.
- Conversely, lower prices for crude oil would hurt U.S. oil producers, although the motor fuel producing industry would benefit from lower input prices.

Two critical factors that influence our impact assessments are our assumptions on (a) the cost-competitiveness of cellulosic ethanol and (b) the volume of production of cellulosic ethanol in 2020. Sensitivity analysis indicates that the U.S. economy would benefit even if we assume that cellulosic ethanol is only cost-competitive when world oil prices are $60 per barrel, rather than the $50-per-barrel assumption used in the base scenario. Our findings further suggest that the benefits are roughly proportional to the volume of cellulosic ethanol produced domestically. In a best-case scenario where enough cellulosic feedstock is available to produce 49.5 billion gallons of cellulosic ethanol in 2020 and the world price of crude oil is $50 per barrel, U.S. crude oil imports in 2020 would be lowered by 1.2 million barrels per day over baseline projections and U.S. agriculture would gain 54,000 jobs compared with current baseline projections.

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Our analysis does not take into account all factors determining the costs associated with additional cellulosic ethanol use, such as the transitional investments necessary to replace crude oil with ethanol in the U.S. fuel supply. Similarly, this report does not address all the economic benefits associated with expanded cellulosic ethanol use, such as reduced greenhouse gas (GHG) emissions resulting from decreased petroleum consumption. Given that transition costs are likely to be incurred only once, whereas the benefits would accrue each year, the value of the stream of benefits from cellulosic ethanol production likely exceeds the one-time transition costs.

This report assesses the impact of cellulosic ethanol production from a U.S. economy-wide perspective. The report uses a computable general equilibrium model that tracks 500 industry sectors.

Introduction

The United States is importing an increasing share of the petroleum that it consumes each year and world petroleum prices are projected to remain high over the next few decades. Without alternative sources of transportation fuel, the U.S. economy could face adverse economic and political consequences.

Few viable alternatives exist for the crude oil used in transportation fuels. Although ethanol manufactured from corn can be used to replace gasoline, corn-based ethanol can replace only a limited amount of U.S. crude oil consumption. However, much more ethanol could be manufactured from the cellulosic materials in biomass, such as crop and forestry residues, energy crops, and wood wastes.

Because cellulosic ethanol is not yet commercially viable, the benefits of cellulosic ethanol production can be realized only if its production costs are reduced. The magnitude of benefits gained will depend on the degree of cost reduction and the volume of cellulosic ethanol produced domestically. The DOE has set a target for reducing cellulosic ethanol's production costs to $1.07 per gallon by 2012. Available literature indicates that annual ethanol production (both corn-based and cellulosic) could range from 30 billion gallons to 60 billion gallons in 2020.[1] Annual production of corn-based ethanol would be about 10.5 billion gallons in both cases, with the remaining ethanol production coming from cellulosic feedstock.[2,3] This report assesses the projected benefits to the U.S. economy and industries if price and volume targets are met.

To assess the economic impacts of meeting those targets, we constructed a simplified facsimile of the U.S. economy in 2020. This facsimile is consistent with forecasts of macroeconomic variables and energy prices released by the Energy Information Administration (EIA) *Annual Energy Outlook 2006* (AEO). The facsimile provides a snapshot of how the U.S. economy would look in 2020 without commercially viable cellulosic ethanol. We then assumed that 19.5 billion gallons of cellulosic ethanol could be produced at the Department of Energy (DOE) target cost of $1.07 per gallon, so that total ethanol production (corn-based and cellulosic combined) would replace 10 percent of the crude oil inputs used in gasoline and distillates. The findings are presented by comparing the alternate picture of the 2020 economy with the EIA's original or base projection. The report also examines a best-case outlook, in which 49.5 billion gallons of cellulosic ethanol could be produced in 2020, and an alternate scenario where the $1.07 per gallon cost target is not met.[4]

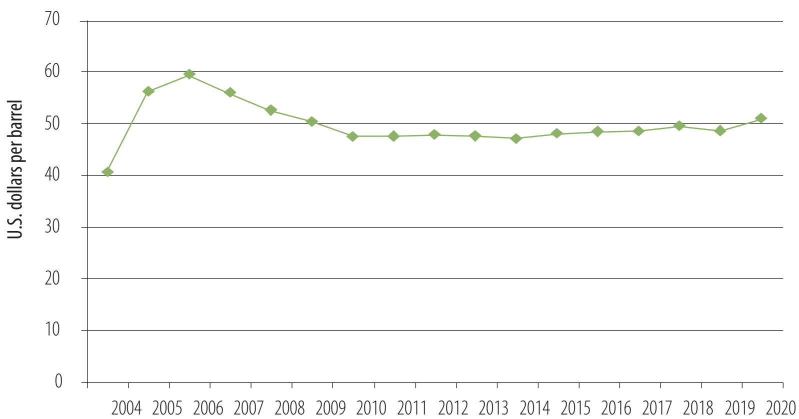
An understanding of the changes likely to occur in the petroleum and agricultural markets is essential to gauge the benefits to the U.S. economy associated with increased production and use of cellulosic ethanol. The study begins, therefore, with a description of the state of the world market for crude oil, including trends that are leading to higher world prices in the long run. The study then explains the different methods for reducing U.S. demand for petroleum, with ethanol as the primary option for directly replacing the petroleum used in vehicle fuel. The current market for corn-based ethanol and the potential for cellulosic ethanol production are explained next. The report concludes by describing the projected benefits to the U.S. economy if 19.5 billion gallons of cellulosic ethanol can be used to replace the petroleum used for vehicle fuel. Effects on specific U.S. industries are also highlighted.

Long-Term Demand Rising; Prices for Crude Oil Worldwide Will Remain High

The need to consider alternative fuels like cellulosic ethanol is driven largely by high crude oil prices and energy security. Not only are crude oil prices relatively high at present, but the EIA forecasts that crude oil prices will continue to be high, reaching $50 a barrel (in 2004 prices) in 2020. The increases in crude oil price will follow a decline between 2007 and 2014, when world crude oil prices are forecast to fall to $46.90 per barrel as new crude oil supplies enter the market (see Figure 1).

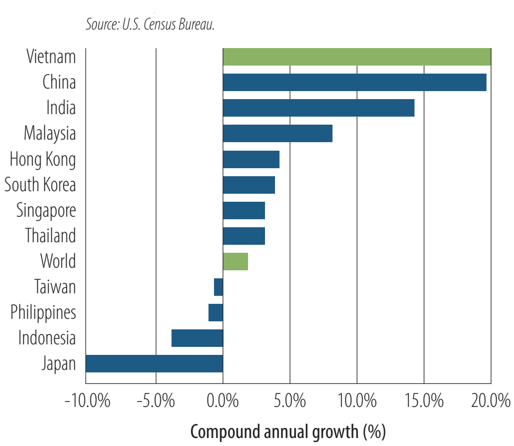
World oil supplies have become tight in recent years primarily because of strong demand from the United States and from developing countries in Asia, including China and India. The United States consumes about one-quarter of the world's petroleum production. Developing countries in Asia, including China and India, have enjoyed strong recent economic growth and have also become important users of petroleum. According to EIA forecasts, daily petroleum consumption by 2030 will rise by 5.4 million barrels over current levels in the United States and by 13.6 million barrels in developing Asian economies. Daily petroleum consumption will grow by 9.7 million barrels per day in the rest of the world by 2030 (see Figure 2).

Figure 1. Crude Oil Price Forcast in 2004 Dollars, 2004–20



Source: Energy Information Administration, Annual Energy Outlook 2006 (Washington, D.C.: U.S. Department of Energy, 2006), available at www.eia.doe.gov/oiaf/archive/aeo06/pdf/aeotab_12.xls.

Figure 2. World Oil Consumption Forcasts, 2010–30



Source: Energy Information Administration, International Energy Outlook 2006 (Washington, D.C.: U.S. Department of Energy, 2006), available at www.eia.doe.gov/oiaf/ieo/excel/ieoreftab_5.xls.

Ethanol Is the Only Current Substitute for Crude Oil in Transportation Fuels

Because the United States is the world's largest importer of crude oil, reducing U.S. demand for crude oil imports would significantly affect world demand and would likely cause world oil prices to fall, which could lead to significant economic benefits for the United States. One way to reduce U.S. demand for crude oil is to develop alternative fuels like cellulosic ethanol, although the size of the effect will largely depend on how much ethanol can be produced in the United States.

Currently, the only commercially viable substitute for crude oil in transportation fuels is corn-based ethanol.[5] Annual U.S. ethanol production in 2006 was slightly less than 5 billion gallons. Because ethanol holds about two-thirds of the energy content of gasoline, 5 billion gallons of ethanol can replace about 1.7 percent of U.S. gasoline and distillates. Currently, the United States consumes annually about 200 billion gallons of gasoline and distillates (including diesel fuel).

If cellulosic ethanol becomes commercially viable, the available literature suggests that between 19.5 billion and 49.5 billion gallons of cellulosic ethanol could be produced annually by 2020, while corn-based ethanol production would rise to about 10.5 billion gallons. Thirty billion gallons of ethanol would replace about 20 billion gallons of gasoline, or 10 percent of U.S. gasoline and distillate fuel consumption.

Market Forces Rather Than Regulations Are Becoming Increasingly Important for Ethanol

Until recently, environmental regulations drove the U.S. ethanol market. The Clean Air Act, as amended in 1992, requires that oxygenates be added to reformulated gasoline to lower automobile tailpipe emissions. Oxygenates are fuel additives (alcohols and ethers) that contain oxygen, which can boost gasoline's octane quality, enhance combustion, and reduce exhaust emissions. Methyl tertiary-butyl ether (MTBE) and ethanol are the two main oxygenates used to satisfy the Clean Air Act requirements. Until 2003, MTBE was the main oxygenate used, and ethanol demand (and production) was relatively low. MTBE was preferred because it is a byproduct of refinery operations, making it easier to handle and less expensive than ethanol when crude oil prices are low, as they were throughout the 1990s.

However, in 2004, a number of states (including California, Pennsylvania, and New York) banned MTBE because it tended to leak into and contaminate groundwater supplies. Ethanol then became the main oxygenate additive in those states. Ethanol demand rose significantly at that time and was largely driven by state-level environmental regulations mandating oxygenate use (see Figure 3).

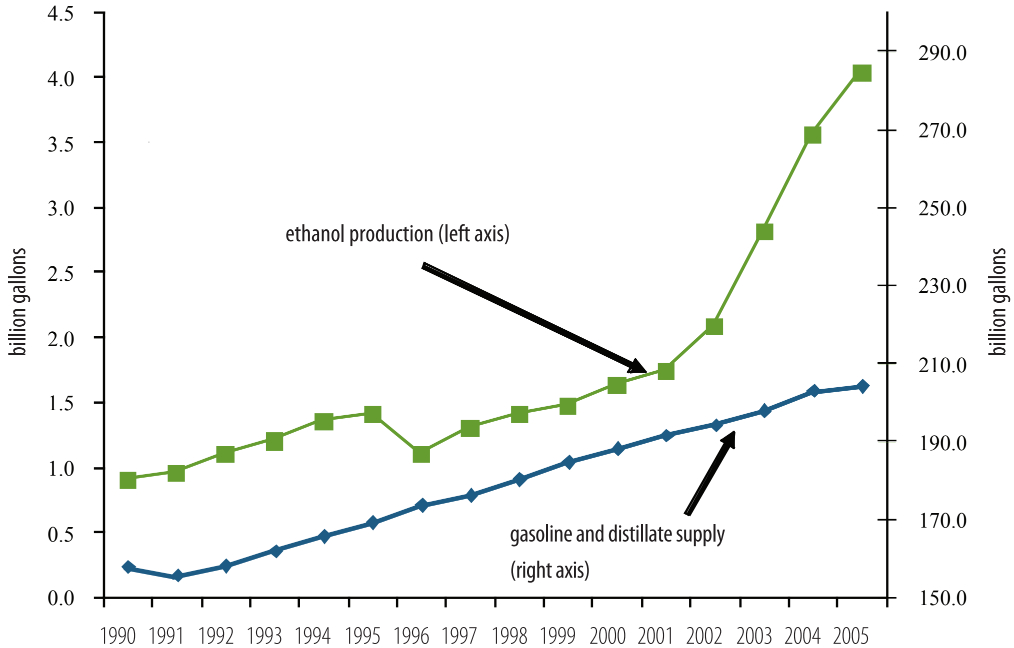
Since 2005, market forces have driven ethanol demand more than environmental regulations for two main reasons: (a) the 2005 Energy Policy Act (EPACT) eliminated the requirement to use oxygenates in reformulated gasoline, and (b) the price of oil rose, making corn-based ethanol more cost-competitive than MTBE.

The EPACT replaced the oxygenate requirement with the Renewable Fuels Standard (RFS), which mandates the use of renewable fuel. Currently the only commercially viable renewable fuel is ethanol. The RFS requires refineries and fuel importers to purchase enough ethanol to meet a nationwide target, rising from 4 billion gallons in 2006 to 7.5 billion gallons in 2012. On an energy-equivalent basis, the mandated consumption amount of 7.5 billion gallons would replace about 2.5 percent of current U.S. gasoline and distillate fuel consumption. However, because of continued high gasoline prices, market demand for corn-based ethanol has already led to production levels exceeding the RFS mandate. The AEO forecasts that corn-based ethanol production in 2012 will continue to exceed the mandate.[6]

The Potential to Displace Gasoline Consumption Is Greater for Cellulosic Ethanol than for Corn-based Ethanol

Most ethanol currently produced in the United States is produced from corn, but there is a limit to corn's ethanol production capacity. Given the stable demand for U.S. corn supplies from domestic and international livestock producers, it is unlikely that the entire U.S. corn crop would be used to produce ethanol. A report sponsored

Figure 3. U.S. Ethanol Production, 1990–2005



Source: Ethanol Production before 2001: Renewable Fuels Association, "Industry Statistics," www.ethanolrfa.org/industry/statistics/#A. All other production and supply statistics are from the 2004 to 2007 editions of the Energy Information Administration's Annual Energy Outlook (Washington, D.C.: U.S. Department of Energy)..

jointly by the U.S. Department of Agriculture and the DOE, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*[7] (henceforth the *Billion-Ton Biomass* report), predicts that corn used to manufacture ethanol could grow to a maximum of about 50 million to 97 million tons, depending on yield growth assumptions. A total of 97 million tons of corn would produce about 11 billion gallons of ethanol, which on an energy-equivalent basis would replace only 3.7 percent of current U.S. gasoline and distillate consumption. In its 2006 AEO, the EIA projected that ethanol production would reach 10.75 billion gallons in 2020 (10.5 billion gallons of corn-based ethanol plus 250 million gallons of cellulosic ethanol production, as mandated in the 2005 EPACT).

Although its production technology is not yet commercially viable, cellulosic ethanol offers a much greater potential to displace gasoline consumption than does corn-based ethanol. According to estimates from the DOE's Office of Energy Efficiency and Renewable Energy, as the price of cellulosic feedstock increases from approximately $29 to $33 per dry ton[8], cellulosic feedstock availability will increase from approximately 100 million to 220 million dry tons per year.[9] Combining the resulting cellulosic ethanol production with existing corn-based ethanol production would be enough to produce a total of 30 billion gallons of ethanol in 2020. The DOE's "biofuels roadmap" policy states that 60 billion gallons of ethanol could be produced annually by 2030, mostly from cellulosic feedstock, although in a best-case scenario the annual target of 60 billion gallons could be met earlier, between 2020 and 2025.[10] If the DOE's technological targets are met, 60 billion gallons of ethanol could be manufactured from 667 million tons of biomass. The "moderate crop yield growth with land-use change" scenario (from the *Billion-Ton Biomass* report) was meant to determine the maximum theoretical availability of biomass; under that scenario, as much as 710 million tons of biomass could be available between 2020 and 2025.

Cellulosic Ethanol Will Be Competitive With Corn-Based Ethanol If Cellulosic Costs Are Reduced to $1.07 per Gallon

Cellulosic ethanol currently costs about $2.65 per gallon to produce, down from more than $5 per gallon in 2001, while corn-based ethanol costs between $0.90 and $1.65 per gallon to produce, depending on the price of corn.[11] The DOE has set targets for technological advances that would reduce the cost of producing cellulosic ethanol to $1.07 per gallon by 2012, which would make cellulosic ethanol competitive with corn-based ethanol (in 2004 corn and crude oil prices).

Crucial differences exist between the technologies used to produce ethanol from corn and cellulose. In both technologies, feedstock sugars or starches are extracted and fermented to make ethanol, but extracting sugars from cellulose requires expensive chemical processes that are not necessary to extract sugars from corn.

According to a 2000 report by the National Renewable Energy Laboratory, it costs $30 million to construct a typical corn-based ethanol plant that can produce 25 million gallons per year.[12] Adding the pretreatment equipment needed for cellulose would increase the cost of constructing a plant with the same capacity to $136 million.

In addition to the higher capital costs, the pretreatment process must use enzymes to break cellulose down. Today, those enzymes cost about$0.40 per gallon of ethanol produced, down from more than $3.00 per gallon in 2001.

Currently, the cost of cellulosic feedstock per gallon of ethanol produced is approximately equal to the cost of corn grain used in traditional ethanol-producing facilities. One bushel of corn yields about 2.8 gallons of ethanol, so 0.36 bushels of corn are needed to manufacture one gallon of ethanol. At $3.00 per bushel, the cost of the corn feedstock in one gallon of ethanol is $1.07. The current estimated cost of cellulosic feedstock is about $60 per dry ton. With each ton of cellulosic feedstock yielding about 60 gallons of ethanol, the cost of cellulosic feedstock is $1 per gallon of ethanol.

Because of the expensive pretreatment process for cellulosic ethanol and its higher capital costs, the only way to make cellulosic ethanol cost-competitive with corn-based ethanol is to reduce the cost of the cellulosic feedstock. The DOE's $1.07 per gallon target can be reached by taking the following actions:

- Reducing the cost of enzymes to $0.05 per gallon.
- Reducing the cost of cellulosic feedstock to $30 per ton.
- Increasing ethanol yield from cellulosic feedstock to 90 gallons per ton.

Reaching the last two goals would lower the cost of cellulosic feedstock to $0.33 per gallon of ethanol, providing a cost advantage over corn feedstock that would be just large enough to offset the cost of enzymes and the higher capital costs. Our analysis assumes that the DOE's technological targets are feasible, and that the targets are met.

Ethanol Is Less Competitive Once Annual Production Exceeds 14 Billion Gallons

The demand for ethanol (both corn-based and cellulosic, which have essentially identical chemical properties) depends on whether ethanol is being used as an additive to gasoline or as a replacement for gasoline. When ethanol is used as an additive, its high octane and its other properties allow it to displace some of the more costly components of gasoline, and the market sets the price of ethanol about equal to the price of gasoline. The maximum percentage of ethanol allowed as a mixture into conventional gasoline is 10 percent. Current U.S. gasoline consumption is about 140 billion gallons, so the maximum amount of ethanol that can be used as an additive is 14 billion gallons. The 14-billion-gallon additive market is almost twice the 7.5-billion-gallon mandate for 2012 set in EPACT and is about 3.5 billion gallons higher than the projected level of corn-based ethanol production in 2020.[13]

Once total ethanol production capacity exceeds 14 billion gallons, most of the output of any additional capacity will be sold as E85, a fuel mixture consisting of 85 percent ethanol and 15 percent gasoline. Currently, E85 sales make up a small segment of the ethanol market, and the market price for ethanol is set by demand for ethanol as an additive. Once capacity significantly exceeds 14 billion gallons, the price for ethanol will be determined largely by the demand for E85.

Ethanol contains about 83,333 Btus (British thermal units) per gallon compared to 125,000 Btus per gallon for gasoline. Because of ethanol's lower energy content and the resulting decline in vehicle mileage per gallon, it may be difficult to sell ethanol without offering a 33 percent discount relative to gasoline.[14] Consequently, the market for ethanol may face a steep price decline when annual ethanol production exceeds 14 billion gallons. This property of the U.S. ethanol market has important implications for modeling the benefits of producing more than 14 billion gallons of ethanol.

Prices received by ethanol producers are comparable to gasoline prices at the refinery gate, which can be calculated by combining the value added by the refinery process with the cost of the crude oil used in gasoline. From 2000 to 2007, the value added by refineries to gasoline averaged about $0.30 per gallon. This amount can be considered as the long-run refinery margin required to keep refineries solvent. The price of gasoline leaving the refinery can then be characterized as follows:

$$P_{gasoline} = \$0.30 + \frac{P_{oil}}{42 * 0.93}$$

In this equation, $P_{gasoline}$ is the ex-refinery price of a gallon of gasoline, and P_{oil} is the price of a barrel of crude oil. The value 42 in the denominator converts barrels to gallons, and the value 0.93 recognizes that only about 93 percent of crude oil is usable (to make gasoline, diesel fuel, or other products).

If ethanol faces no discount relative to gasoline, meeting the DOE's cost target of $1.07 per gallon would make it cost-competitive when gasoline costs $1.07 per gallon leaving the refinery. However, if ethanol producers must offer a 33 percent discount relative to gasoline prices to account for ethanol's lower energy content, ethanol that costs $1.07 per gallon to produce would become competitive only when gasoline costs at least $1.60 per gallon. The findings in this study assume that meeting the DOE's cost target makes ethanol cost-competitive with gasoline only when the price of gasoline exceeds $1.60 per gallon (in 2004 dollars), which, according to the above formula, corresponds to crude oil prices of about $50 per barrel.[15]

Replacing 10 Percent of Gasoline and Distillates with Corn-Based and Cellulosic Ethanol in 2020 Would Reduce U.S. Dependence on Imported Oil and Improve U.S. Income

If the DOE's cost target is met, what would be the effect on the U.S. economy of producing enough cellulosic ethanol to reach total ethanol production of 30 billion gallons? In the 2006 AEO, the EIA forecast that corn-based ethanol production would reach 10.5 billion gallons in 2020, and cellulosic ethanol production would be 250 million gallons (as mandated in the 2005 EPACT). If corn-based ethanol production remains at the amount forecast by the EIA,[15] reaching the target of 30 billion gallons of ethanol production would require total production of 19.5 billion gallons of cellulosic ethanol production (including the 250 million gallons mandated by the EPACT). Because of ethanol's lower energy content, the additional 19.25 billion gallons of cellulosic ethanol production would replace 12.9 billion gallons of gasoline, or about 6.4 percent of total U.S. gasoline and distillate consumption.

To estimate the economic benefits of producing additional cellulosic ethanol, we used the U.S.A. General Equilibrium (USAGE) model to construct a simplified facsimile of the U.S. economy in 2020. This facsimile is consistent with forecasts of macroeconomic variables and energy prices released in the EIA's 2006 AEO. [17] The facsimile provides a baseline scenario of how the economy would look without commercially viable cellulosic ethanol. The baseline includes 10.75 billion gallons of corn-based and cellulosic ethanol production, which would replace about 3.6 percent of crude oil inputs used to manufacture gasoline and distillates in 2020. The construction was then altered to allow cellulosic feedstocks produced by the agricultural sector to replace another 6.4 percent of crude oil inputs, and this alternate picture of the 2020 economy was compared to the original.

Two main assumptions drive the differences between the two future snapshots:

Table 1. Macroeconomic Effects of Producing 19.5 Billion Gallons of Cellulosic Ethanol in 2020

	2004 prices ($ billion)	Percentage change, 2004–20		Effect of cellulosic ethanol production in 2020 economy[b] ($ billion)
		Base scenario	Alternate scenario[a]	
Public and private consumption	9,914	51.677	51.804	12.6
Investment	1,968	82.047	82.348	5.9
Exports	1,166	237.147	235.707	–16.8
Imports	1,849	112.234	112.073	–3.0
Gross domestic product[c]	11,199	65.811	65.853	4.7

	Index	Percentage change, 2004–20		Effect of cellulosic ethanol production in 2020 economy[b] (%)
		Base scenario	Alternate scenario[a]	
Real post-tax wage rate	1.000	31.868	32.003	0.102
Terms of trade	1.000	0.018	0.361	0.343

Source: USAGE Model Simulation

a. This scenario assumes additional cellulosic ethanol production.
b. Dollar values for 2020 are calculated by multiplying the 2004 value data by the percentage changes for base and alternate scenarios and subtracting.
c. Gross domestic product is the sum of consumption (public and private), investment, and net exports.

- From 2004 to 2020, the price of crude oil rises, while the cost of cellulosic feedstocks falls with the cost of agricultural production.
- Increased production of a domestically produced fuel lowers U.S. demand for domestically produced and imported crude oil. As a result of the decline in crude oil imports, both the world price of crude oil and the U.S. import bill subsequently decline.

In the original facsimile, the U.S. motor fuel sector uses domestically produced crude oil, imported crude oil, and a small amount of agricultural inputs to manufacture vehicle fuels and industrial chemicals. The alternate facsimile allows domestically produced agricultural inputs (specifically, from the feed-grains sector) to replace 6.4 percent of the crude oil inputs used to manufacture vehicle fuels. The amount of agricultural inputs that must be used is determined by the cost-competitiveness of cellulosic ethanol. The main findings result from assuming that cellulosic ethanol is competitive in 2004 prices when oil prices are at $50 per barrel. Table 1 summarizes the macroeconomic effects.

Furthermore, we assume that the costs of producing cellulosic ethanol will track the cost trends of feed-grains production in general, meaning that by 2020, cellulosic ethanol production costs would drop by an additional 12 percent. Ethanol production would then enjoy a cost advantage over crude oil. However, the additional demand for feed grains would cause the grains' price (and cellulosic ethanol production costs) to decline by less than the full 12 percent.[18] Because feed grains are an input into livestock production, animal-product prices also decline relatively less than their prices would have without the additional cellulosic ethanol production.[19]

Three other assumptions drive the results in the model:

1. Demand for imports and domestic crude oil production decline by the same amount when U.S. crude oil demand falls.
2. The value of global price elasticity of supply for crude oil is assumed to be equal to one.
3. The U.S. national savings rate is constant.

The United States is a high-cost producer of crude oil, but the United States also imports crude oil from many high-cost producers, such as Canada, Mexico, Nigeria, and Venezuela. Therefore, without definitive statistical evidence demonstrating the relative supply elasticities of imports versus domestic production, we assume that imports and domestic production are affected equally. If additional cellulosic ethanol production tends to replace more domestic production than imports, the benefits from cellulosic ethanol production would likely be smaller.

Similarly, given the lack of a reliable estimate of the global price elasticity of supply for crude oil, we assume a neutral parameter, or one. The more responsive the world crude oil market is to changes in U.S. demand, the higher the benefits are for the United States.

The assumption that the U.S. national savings rate remains constant implies that changes in domestic investment opportunities are met with changes in foreign investment flows.

Crude Oil Imports, World Crude Oil Prices, and Domestic Fuel Prices Would Be Lower

Our analysis indicates that if, as a result of meeting the DOE cost target, an additional 19.25 billion gallons of commercially viable cellulosic ethanol production were available in 2020, U.S. crude oil imports would be lower than baseline projections by 4.1 percent, or by about 460,000 barrels per day. Because the United States accounts for about a quarter of world consumption of crude oil, reducing the U.S. demand for oil imports through biofuels substitution would affect overall world demand. The world price for crude oil would, therefore, be 1.2 percent lower in 2020 than the world price would have been otherwise. Although strong demand from China and India will continue to drive the price of oil upward, the effect of increased crude oil demand from the United States in the baseline scenario would be lessened. The benefits of lower world oil prices would be shared by all net oil-importing countries, but the benefit to the United States from paying relatively lower prices for imported oil would be significant. At $50 per barrel, the yearly reduction in expenditures on U.S. oil imports in 2020 would be about $8.4 billion (in 2004 dollars).

U.S. domestic fuel prices would fall by 2.0 percent. Although cellulosic ethanol production enjoys a slight cost advantage over gasoline production, the primary effects on domestic fuel prices result from the decrease in crude oil imports, which causes the world price of crude oil to fall and the U.S. terms of trade to improve. The EIA projects that motor vehicle gasoline will cost an average of $2.08 per gallon in 2020. Lowering this price by 2 percent would save $0.04 per gallon.

Total Consumption Would Be Higher, and Annual Wage Incomes Would Rise

Our findings show that U.S. consumption expenditures in 2020 would be 0.08 percent higher (or $12.6 billion) with increased use of cellulosic ethanol. That figure measures the increase in the value of the goods and services consumed by U.S. citizens and the U.S. government. The U.S. economy would benefit from importing crude oil that costs less. Furthermore, the improvement in the U.S. terms of trade would attract foreign investment, which benefits gross domestic product (GDP). Improved terms of trade would also benefit U.S. consumers, who would pay less for imports.[20]

In 2006, the U.S. GDP was $13.2 trillion. Although an increase of 0.08 percent may look relatively small, the gains are still substantial when compared with benefits accruing from other microeconomic policy changes. For instance, the U.S. International Trade Commission's *2004 Import Barriers Report*, which also used the USAGE model, found that U.S. public and private consumption would rise by 0.20 percent if all U.S. import trade barriers were eliminated.[21] In terms of increased U.S. consumption, the benefits of cellulosic ethanol production account for about 40 percent of the size of the consumption benefits that would result from eliminating all U.S. trade barriers. In another study, the World Bank estimated that the benefit to the United States of global merchandise trade reform would be an increase in real income in 2015 of $16 billion.[22] Although not directly comparable to the results of this study, the orders of magnitude of effects between the two studies are similar.

Agricultural Employment Would Rise

Replacing transportation fuel with cellulosic ethanol would require a significant increase in activity in the U.S. agricultural sector, in both output and employment. From 1994 to 2004, U.S. employment in crop and livestock production declined by 75,000 jobs annually. The U. S. Department of Agriculture (USDA) now projects that the U.S. agricultural sector will grow in absolute terms over the near future and will have to attract new labor in order to do so. The increase of 20,350 U.S. agricultural jobs in 2020, as predicted by the simulation, would somewhat offset recent job losses and would contribute to further job growth in the U.S. agricultural sector.

Industries Connected to Agricultural Production Will Benefit the Most, While Domestic Oil Producers Will See Their Output Decline

When commercially viable cellulosic ethanol lowers U.S. fuel prices, the economic effects will be broad. U.S. consumers will spend less disposable income on fuel and will have more to spend on other consumption items. However, the competitiveness of some industries will be more directly affected than that of others (see Table 2). The two industries in the U.S. economy that will benefit the most in 2020 from commercially viable cellulosic ethanol are as follows:

- Agricultural industries producing feedstock for cellulosic ethanol production, together with industries supporting agricultural production, such as farm machinery and fertilizer producers. Output in those industries in 2020 would increase by between 2.4 percent and 4.3 percent over base projections.
- The motor fuel industry, which would benefit from lower input prices. In 2020, output in this industry would be 1.6 percent higher than base projections.

Table 2. Percentage Change in Output by Industry, 2020

Industry	Percentage change in output
Crop agriculture	4.27
Industries producing agricultural inputs	2.43
Motor fuels	1.57
Oil and gas field machinery	–0.76
Animal agriculture	–0.80
Meat packing plants	–1.00
Wet corn mills	–1.47
Crude oil and natural gas	–1.84
Pipelines, crude oil	–1.93
Petroleum and natural gas exploration	–2.12
Petroleum and natural gas drilling	–2.16
Average overall	0.04

Source: USAGE model simulations

Two broad categories of industries that would see their output fall are the following:

- Crude oil–producing industries in the United States. The output of these industries would decline by 1.8 percent from base projections as both demand and prices for crude oil fell.
- Industries using biomass commodities as inputs, such as livestock producers, meat packing plants, and wet corn mills. The output of these industries in 2020 would decline from base projections by between 0.8 percent and 1.5 percent as costs rose.

As is typical of models that rely on the "natural rate of employment" assumption, if aggregate employment is held constant, the increase in agricultural employment is offset by decreases in employment from other sectors of the economy. The most affected is the U.S. crude oil–producing industry, which would lose about 2,200 jobs.

Our findings suggest that one additional outcome of expanded cellulosic production is the appreciation of the U.S. dollar, which increases the price of U.S. exports and decreases the price of U.S. imports. Typically, an appreciating dollar would be expected to adversely affect the production of exporting industries and to benefit importing industries. Except for the petroleum refining industry, which is directly affected by changes in the world price of crude oil, the output effects for the top 10 importing and exporting industries are relatively small (see Table 3).[23] Net importers would see a small expansion in output, while net exporters would experience a contraction in output.

Results Are Robust to Changes in Assumptions

As with any simulation that is based on a simplified facsimile of an economy, the results in this study can be sensitive to assumptions. For example, the benefits would be larger if more cellulosic feedstock were available or smaller if cellulosic ethanol were not as competitive because research failed to reach the DOE's cost target. Alternative scenarios can reveal the extent to which the size of the benefits is sensitive to assumptions. Because the main results are driven by a number of sources of benefits that are effectively indepen-

Table 3. Top Net Exporting and Import-Using Industries, 2020

Industry	Net exports ($ billion)	Percentage change in output
Foreigners' holidays in the United States	125.6	−0.23
Industrial chemicals	23.7	−0.24
Banking	20.5	−0.01
Education of foreigners in the United States	19.2	−0.48
Motor vehicle parts and accessories	18.1	−0.27
Telephone and communications services	−18.9	0.07
Retail trade	−19.7	0.11
Federal government national defense expenditures	−22.3	0.09
Motor vehicles	−23.0	0.01
Petroleum refining	−116.0	1.68

Source: USAGE model simulations

Note: Net exports are defined as exports of output less imports of inputs.

dent of each other—lower costs of fuel production, lower international prices for oil, and exchange rate appreciation—the benefits are fairly robust to relaxing individual assumptions.

Benefits Are Substantial Even with More Conservative Assumptions on Cost-Competitiveness of Cellulosic Ethanol

Only a portion of the benefits to the U.S. economy from biofuels comes from the cost savings that would result from meeting the DOE's cost target for cellulosic ethanol production of $1.07 per gallon. Reducing the competitiveness of cellulosic ethanol could eliminate some of those cost savings, but the other sources of benefits would remain. For example, replacing oil imports with domestic ethanol production would reduce U.S. expenditures on imports, resulting in a stronger dollar and in increased prices for U.S. exports. Also, reducing U.S. demand for crude oil would lower world oil prices, thus reducing the cost of the oil that the United States still imports. Those benefits are independent of the cost-competitiveness of ethanol.

The primary findings in this report result from the assumption that, as a consequence of meeting the DOE cost target, cellulosic ethanol is competitive (without subsidies) if today's oil prices are about $50 per barrel. The DOE's cost target of $1.07 per gallon for cellulosic ethanol requires reducing costs for enzymes and feedstock, and it requires increasing yields from the current 60 gallons per ton to 90 gallons per ton. Failing to meet those targets would lower the competitiveness of cellulosic ethanol.

However, even if cellulosic ethanol is less cost-competitive than projected, the benefit of replacing petroleum imports with biofuels production could still be significant. In 2020, world crude oil prices are projected to be about $50 per barrel in 2004 prices. If cellulosic ethanol is cost-competitive today only when crude oil prices are higher than $60 per barrel, much of the cost savings advantages associated with using cellulosic ethanol are eliminated, but the price savings resulting from reduced U.S. crude oil demand remain. Consequently, the benefits from lower world crude oil prices and the appreciation of the dollar attributable to lower crude oil imports would result in a consumption increase of $10.1 billion in 2020, compared with $12.6 billion in the original simulation. However, U.S. GDP would rise by only $1.5 billion, compared with an increase of $4.7 billion in the original simulation.

Economic Benefits from Cellulosic Ethanol Are Greater If the 60-Billion-Gallon Target Is Met in 2020

The DOE's Biofuels Initiative, or "30 by 30" target, calls for annual production of 60 billion gallons of ethanol by 2030.[24] At 90 gallons per ton of cellulosic feedstock, the 60-billion-gallon target would require about 667 million tons of biomass. However, the "moderate crop yield increase with land-use change" scenario in the *Billion-Ton Biomass* report estimates that as much as 710 million tons of biomass could be available as early as 2020—about 130 million tons from forest residues and wastes and another 580 million tons from agriculture (corn, crop residues, and energy crops).

To demonstrate the effects on the results of different assumptions about cellulosic feedstock availability, we examined the benefits to the U.S. economy of a best-case scenario in 2020 in which we assume that 60 billion gallons of ethanol can be produced annually. Of those 60 billion gallons, 10.5 billion gallons would be corn-based, while the remaining 49.5 billion gallons would come from cellulosic feedstock. Increasing the amount of cellulosic ethanol production in 2020 to 49.5 billion gallons would provide almost triple the benefits, as follows:

- Annual U.S. consumption would increase by about $33.5 billion in 2020.
- Domestic U.S. fuel prices would fall by 5.2 percent.
- World oil prices would decline by 3.1 percent.
- U.S. oil imports in 2020 would decline by 10.7 percent, or by 1.2 million barrels per day.
- U.S. agriculture would gain 54,000 jobs in 2020.

The change in benefits is roughly proportional to the change in additional cellulosic ethanol production. Similar results would hold for any upward or downward adjustment of the amount of additional cellulosic ethanol produced.

Exporting Cellulosic Ethanol Technology Could Lead to Further Benefits

Our analysis considers a situation in which biofuels from cellulosic feedstock are commercially viable only in the United States. However, if the technology for making ethanol from cellulose were developed in the United States, it is possible that technology could be licensed to other countries. In addition to the revenue that U.S. producers would receive from licensing the technology, the United States would benefit significantly if all countries were able to substitute significant amounts of cellulosic feedstock for crude oil. The worldwide reduction in demand for crude oil would cause the price of U.S. crude oil imports to drop even further. However, the U.S. dollar may not strengthen as much as the currencies of other countries. Even so, the net effect in most cases would likely still be positive for the United States. Generally, replacing the demand for crude oil with cellulosic feedstock worldwide would benefit net importers of crude oil at the expense of oil-exporting countries.

Assessment of Benefits Will Improve as Information Becomes Available on Other Factors

This study does not address all the factors that could ultimately determine the costs and benefits associated with the use of cellulosic ethanol—partly because our goal is to assess a possible future situation without speculating on various transition scenarios. Moreover, the information necessary to provide a more complete picture is not available at this time. Three issues could particularly impinge on our overall findings and may require additional analysis to better gauge the benefits associated with increased cellulosic ethanol use:

- Assessment of transition costs.
- Availability of data on the (currently nonexistent) cellulosic feedstock market.
- Better understanding of emissions benefits (for example, the reduction of GHG emissions associated with substituting cellulosic ethanol for gasoline).

Furthermore, the estimates in this study are based on the assumption that crude oil prices will stabilize at $50 per barrel in 2020, as forecast by the EIA. If oil prices rise (for example, to the EIA's high-price scenario of $85 per barrel), the predicted benefits from cellulosic ethanol production would be even greater.

Analysis of Transition Costs

A complete economic analysis of any policy should contain a full accounting of both the costs and benefits associated with that policy. For cellulosic ethanol, a cost-benefit analysis would require an estimate of the costs of infrastructural investments required to handle the large volume of cellulosic ethanol production. For example, normal cars can use gasoline containing only up to 10 percent ethanol. Fuel mixtures with greater than 10 percent ethanol must be used only in flex-fuel cars, meaning that a significant portion of cars produced in the future would have to be flex-fuel cars, which cost approximately $100 more per vehicle.

Other transition costs include the costs of infrastructural changes to accommodate shipping large amounts of ethanol around the United States; a large increase in the number of E85 service stations; the costs of research and development to lower the cost of cellulosic ethanol production; and the adjustment costs that the U.S. economy must absorb when reduced demand for gasoline reduces the supply of refining byproducts, such as diesel fuel and industrial chemicals.

However, the findings in this study reflect the benefits to an economy that has already made the transitional investments necessary to replace a large amount of crude oil with cellulosic ethanol in the national fuel supply. The costs of making the transition occur only once. Therefore, it is likely that the present discounted value of the stream of benefits, starting at $12.6 billion per year in 2020, will exceed the one-time transition costs.

Detailed Description of the Market for Cellulosic Feedstock

A complete forecast of the future cellulosic ethanol market would ideally contain the effects of increased cellulosic ethanol production on the industries that provide cellulosic feedstock, like the agriculture and forest product industries. For example, one significant issue with cellulosic ethanol is related to concerns that energy crops would displace corn. Because one major feedstock for cellulosic ethanol would be corn stover—meaning that demand for cellulosic feedstock in the form of corn stover should add to corn demand—it would be helpful to model the demand for cellulosic feedstock explicitly and to show the extent to which demand for corn would change. The simplified facsimile of the U.S. economy used in this study is based on industry data published by the U.S. government. Because no cellulosic feedstock industry yet exists, no data exist on which to base an industry simulation. Other research programs are under way in the DOE and USDA to develop economic tools to analyze the cellulosic feedstock market.

Benefits of Reduced Emissions from Ethanol Consumption

Use of cellulosic ethanol could reduce green house gas (GHG) emissions. A gallon of gasoline emits about 25 pounds of carbon dioxide–equivalent GHG emissions. Cellulosic ethanol can achieve about an 85 percent reduction in GHG emissions relative to gasoline, resulting in a reduction of 21.25 pounds of carbon dioxide emissions per gallon of gasoline equivalent.[25] The current futures price associated with carbon dioxide emissions reductions in the European carbon dioxide trading market is $20 per ton of carbon dioxide equivalent. On the basis of this price, we calculate that the value of using cellulosic ethanol in terms of GHG reductions is about $0.193 per gallon.[26] Producing an additional 19.25 billion gallons of cellulosic ethanol would displace about 12.9 billion gallons of gasoline, which would reduce GHG emissions by about 123 million tons of carbon dioxide equivalent.[27] At $20 per ton of carbon dioxide equivalent, the economic value to the U.S. economy of reduced GHG emissions would be about $2.5 billion per year. This benefit is in addition to the other favorable findings, such as $12.6 billion in additional consumption.

The reduction in U.S. carbon dioxide emissions may not correspond to reductions in carbon dioxide emissions worldwide. Diversion of U.S. agricultural production to ethanol production (whether corn based or cellulosic) may lower the worldwide supply of agricultural products. If agricultural acreage in the rest of the world must increase to compensate, converting non-agricultural land (e.g., forests) to agriculture use could release carbon dioxide into the atmosphere.

Our analysis does not consider changes in emissions regulated by the U.S. Environmental Protection Agency or emissions requirements that would result from using 30 billion gallons of ethanol (10.5 billion gallons of corn-based ethanol and 19.5 billion gallons of cellulosic ethanol) in motor fuel. When mixed into conventional fuel, as in the most prevalent mixture of E10 (with 10 percent ethanol mixed), ethanol can have higher volatile organic compound emissions, which can contribute to formation of ground-level ozone (smog). Reformulated gasoline with ethanol added must be chemically altered—by removing highly volatile chemicals like butanes and, sometimes, pentanes—so that volatile organic compound emissions do not increase. However, any mixture with more than 20 percent ethanol, including E85, is less volatile then gasoline. If 30 billion gallons of ethanol are to be used in transportation fuel, it is likely that a good proportion of the fuel mixture will be sold as E85. The additive market for ethanol would be saturated at 10 percent of gasoline consumption, or about 14 billion gallons, so the other 16 billion gallons would have to be sold as E85. When vehicles are designed for E85 and meet Tier 2 exhaust and evaporative emission standards, the U.S. Environmental Protection Agency does not foresee the need to propose new exhaust or evaporative emission standards. By 2020, virtually 100 percent of the pre-Tier 2 in-use light-duty vehicle fleet (i.e. cars, pickup trucks, and SUVs) will have been replaced with vehicles that meet Tier 2 standards.

Conclusions

The benefits to the U.S. economy would be significant if the DOE's target to lower the cost of producing cellulosic ethanol to $1.07 per gallon were met. The additional consumption that U.S. consumers would enjoy is about 40 percent of the consumption benefits that would result from unilaterally eliminating all U.S. trade barriers, according to the U.S. International Trade Commission's 2004 import barriers report[28] and about half of the real income benefits that would result from worldwide merchandise trade liberalization, according to a World Bank study.[29] Producing 19.5 billion gallons of cellulosic ethanol would lower both the domestic cost of fuel and the worldwide price of oil and would lower U.S. crude oil imports by 4.1 percent over baseline projections, or 460,000 barrels per day, in 2020. Even if the $1.07 per gallon target is not fully met, the benefits to the U.S. economy would still be significant.

Although the benefits of lower gasoline prices would primarily help consumer demand, in turn boosting all industries in the U.S. economy, certain industries would be affected more than others. The U.S. crop-producing sector could see its output rise by about 4.3 percent over baseline projections. Industries using feed grains as an input, such as livestock producers and meat-packers, could see their costs rise and their output fall. As U.S. demand for crude oil falls, U.S. petroleum producers would see their output fall as prices decline, while producers of motor fuels would benefit from lower input costs.

Technical Appendix: Methodology

The simulation discussed in this report was undertaken using a computable general equilibrium model called USAGE that was developed at the Centre of Policy Studies, Monash University, in collaboration with the U.S. International Trade Commission. The theoretical structure of USAGE is similar to that of the MONASH model of Australia.[30] However, in its empirical detail (500 industries versus 100, with specifications capturing particular features of many industries), USAGE goes far beyond MONASH. The basic model describes the interaction of a detailed U.S. economy with a "rest of the world" region.[31]

The USAGE model uses input-output tables released by the Bureau of Economic Analysis to describe the physical requirements of industries at the six-digit Standard Industrial Classification level. The model also uses equations to describe supply and demand responses to price changes and investment opportunities. The model is based on data from the U.S. economy in 2004 and is updated to incorporate more recent data as it becomes available. However, the basic structure of the U.S. economy does not change much from year to year.

Alternate simulations can be carried out with the USAGE model by simulating a future economy using whatever data are available and by comparing this "base scenario" to a future economy with changes incorporated into it (the "alternate scenario"). Those changes can be policy related or technology related, or they may relate to any other exogenous parameter that creates a deviation from the base scenario. The difference between the two scenarios is interpreted as the effect of implementing the change. The different scenarios are both simulated as if the economy has reached long-run equilibrium, assuming a natural rate of employment.

In this study, the 2020 base scenario was simulated using macroeconomic forecasts in the Energy Information Administration's *Annual Energy Outlook 2006*. The alternate scenario changes the model to allow additional cellulosic feedstock to be used as an input into the motor fuel industry for no more than 19.25 billion gallons of cellulosic ethanol (replacing 12.9 billion gallons of gasoline) at prices that are competitive when crude oil costs $50 per barrel or more. The main results of the analysis are interpreted as differences between variables of interest (GDP, consumption, domestic fuel prices, world oil prices, and so forth) in the alternate and base scenarios.

The Base Scenario

At the macro level, the DOE reference case predicts the following:

- Very strong growth in U.S. exports (236 percent between 2004 and 2020, or 7.9 percent per year)
- Strong growth in U.S. imports (112 percent between 2004 and 2020, or 4.8 percent per year)
- Normal growth in real U.S. GDP (66 percent between 2004 and 2020, or 3.2 percent per year)
- Normal growth in U.S. employment (15 percent between 2004 and 2020, or 0.9 percent per year)
- Normal growth in U.S. investment (83 percent between 2004 and 2020, or 3.8 percent per year)
- Subdued growth in U.S. private consumption (57 percent between 2004 and 2020, or 2.9 percent per year)
- Very subdued growth in U.S. public consumption (27 percent between 2004 and 2020, or 1.5 percent a year)

Variables that are not provided by the 2006 AEO macroeconomic assumptions are generated from trends from a historical simulation of the USAGE model. The model is forced to track data from 1992 to 2004, generating trends for technology and consumer preferences as well as trends in the positions of world demand curves for U.S. exports and world supply curves for U.S. imports. Those trends are used in the 2020 base scenario. Importantly for this exercise, the simulation uses historical trends in U.S. agricultural prices, which have been declining fairly consistently for the past several decades.

With regard to energy, the most important aspects of the DOE reference case for our purposes are those concerned with the motor fuel industry. For this industry, the DOE sees strong growth in prices and slow growth in output. The price index for domestically produced motor fuels (including motor gasoline, jet fuel, distillate fuel, and residual fuel) increases by 57.3 percent between 2004 and 2020, whereas prices in general (measured by the price index for GDP) increase by only 47.8 percent. In other words, the price index for motor fuels increases by 6.4 percent [= 100 × (1.57/1.48 – 1)] relative to the GDP price index. The output of the motor fuel industry grows in the benchmark by only 1.6 percent a year. Hence, the output of the motor fuel industry declines as a share of GDP—from 2.6 percent in 2004 to 2.1 percent in 2020.

The dominant input to the motor fuel industry is crude oil. In 2004, inputs of crude oil accounted for 71.5 percent of the industry's costs, with domestically produced crude oil being 22.4 percent of costs and imported crude oil being 49.1 percent of costs. In dollar terms, domestically produced crude oil costs the motor fuel industry a total of $63.9 billion and imported crude oil costs the industry a total of $140.2 billion. In the DOE reference case, the price of crude oil increases by 24.4 percent between 2004 and 2020 relative to the increase in the price deflator for GDP.[32] Nevertheless, both domestic and imported crude oil decline slightly as shares in the costs of the motor fuel industry—from 22.4 percent and 49.1 percent, respectively, in 2004, falling to 19.2 percent and 47.9 percent, respectively, in 2020. The DOE sees quite slow growth in the demand for crude oil relative to the output of the motor fuel industry (0.5 percent annual growth in crude oil supplies compared with 1.5 percent annual growth in the output of the motor fuel industry). The DOE has built into its benchmark some fuel-saving technical changes in refining, increased imports of refined motor fuels, and some substitution of other inputs for inputs of crude oil, including 10.5 billion gallons of corn-based ethanol and 250 million gallons of cellulosic ethanol.

The Alternate Scenario

For our simulation, we assume that research and development leads to technologies in motor fuel production that will allow a considerable additional substitution of cellulosic feedstock for crude oil. Specifically, we assume that by 2020, crude oil input per unit of output from the motor fuel industry is reduced relative to the benchmark by about 6.4 percent. At the same time, cellulosic feedstock input per unit of output increases. We assume that the cost, in 2004 prices, of the extra cellulosic feedstock per unit of motor fuel output is 1.25 times greater than the cost in 2004 of crude oil used per unit of motor fuel output. Because the average price of oil in 2004 was $40 per barrel, the assumption is equivalent to assuming that research and development generates a 6.4 percent cellulosic feedstock replacement technology that would be competitive when oil prices are $50 per barrel.

In mathematical terms, the simulation is carried out by changing the technology of the motor fuel industry. In stylized form, the production function for the motor fuel industry is

$$Z^q(t) = F\left(\frac{X^q_{fg}(t)}{A^q_{fg}(t)}, \frac{X^q_c(t)}{A^q_c(t)}, \frac{X^q_{oth}(t)}{A^q_{oth}(t)}\right)$$

$$q = b \text{ and } p \qquad \text{(A1)}$$

where

- $Z^q(t)$ is the output of the motor fuel industry in year t in simulation q ($q = b$ for benchmark and $q = p$ for policy);
- the Xs are inputs of feed grain (fg), crude oil (c) and other (oth); and
- the As are technology coefficients.
- For the motor fuel industry, we assume that F takes the Leontief form. Thus $A^q(t)$ is input of fg, c, or oth per unit of output in simulation q in year t.

In our central policy simulation, we require

$$A^p_c(20) = 0.936 * A^b_c(20) \qquad \text{(A2)}$$

That is, we require inputs of crude oil per unit of output in 2020 to be 6.4 percent less in the policy simulation than in the benchmark. We also require

$$P^b_{fg}(04) * [A^p_{fg}(20) - A^b_{fg}(20)] = 1.25 * 0.064 * P^b_c(04) * A^b_c(04) \qquad \text{(A3)}$$

The left-hand side of (A3) is the value in 2020 at 2004 prices of extra feed grain per unit of output in the motor fuel industry caused by substitution of cellulosic feedstock for crude oil inputs. Under our cost-competitiveness assumptions, the cost of this extra feed grain is 1.25 times greater than the reduction in costs per unit of output that would be experienced in the motor fuel industry in 2004 if the industry were able to cut its crude oil inputs per unit of output by 6.4 percent. Thus the cost-competitiveness assumptions imply that cellulosic feedstock technology develops sufficiently such that if there were no change in prices and no benchmark change in crude oil inputs per unit of output, then $1 of crude oil used by the motor fuel industry could be replaced by $1.25 worth of agricultural output. However, there *are* changes in prices and in crude oil inputs per unit of output, and those changes affect the outcome of the simulation.[33]

The technology coefficients are changed to satisfy these requirements, essentially shifting the motor fuel industry's demand for crude oil downward and raising its demand for agricultural products.

In our simulation, we assume that the cellulosic feedstock used in the motor fuel industry comes from the feed-grains industry (mainly corn). However, the precise composition of the feedstock is not important for our results. What matter most are our assumptions about the extent of feedstock substitution and its competitiveness (that is, its cost, whatever its source, relative to the cost of the crude oil that it replaces).

Those technological assumptions contain two main implications: (a) the implied reduction in the cost of fuels made from cellulosic feedstock and (b) the implied availability of cellulosic feedstock.

The Implicit Cost Advantage of Cellulosic Ethanol

The EIA forecasts that oil prices will rise by 24 percent (in 2004 dollars) from 2004 to 2020, to about $50 per barrel. The price of feed grains is projected by the model to fall by 14 percent during the same period. The technology assumptions make cellulosic ethanol produced in 2004 cost-competitive when oil costs $50 per barrel. By 2020, however, the fall in agricultural prices implies that fuel produced from agricultural feedstock will enjoy about a 13 percent cost advantage over petroleum as an input into fuel production.

Cellulosic Feedstock Availability

If the DOE's goal of producing 90 gallons of ethanol per ton of cellulosic feedstock is met, the production of 19.5 billion gallons of cellulosic ethanol would require a total of about 211 million tons of cellulosic feedstock by 2020. That biomass would come from three main sources—from crop residues (such as corn stover), energy crops (such as switchgrass), and forest product revenues (such as wood chips).

The *Billion-Ton Biomass* report estimates that the maximum available amount of crop residues ("residues sustainably removable") and energy crops ("perennials") would be about 295 million tons and 147 million tons, respectively, in 2020 to 2025, rising to 455 million tons and 368 million tons, respectively, by the middle of the 21st century. Available forest product residues would be at least 130 million tons by 2020, rising to 368 million tons by the middle of the 21st century.

World Oil Demand Assumptions

A key result of this simulation is the effect of changes in U.S. petroleum demand on the world market. The numbers generated in this analysis were based on various assumptions about the world market for crude oil. Because the United States consumes a large proportion of the world's crude oil—25 percent—it is natural to assume that a large reduction in demand for crude oil imports by the United States would have a significant effect on world prices. Although there are no reliable estimates of the price elasticity of supply of the world crude oil market, a neutral assumption would be that it is unity. Consequently, reducing the U.S. demand for crude oil by 6.4 percent would reduce world crude oil demand by 1.6 percent, causing a 1.6 percent decline in world crude oil prices. Other interactions in the model will influence the final price change that results from the simulation. The actual price decline in world crude oil prices predicted by the model, after 6.4 percent of crude oil inputs in transportation fuel production were replaced by cellulosic ethanol, was 1.2 percent.

Changing assumptions about the world elasticity of supply for crude oil demonstrates how sensitive the results are to those assumptions. Additional simulations show that increasing the elasticity of world crude oil supply from 1 to 2 reduces the response of world prices to changes in U.S. crude oil demand and, therefore, causes the annual U.S. consumption benefits to decline by about $1 billion. Lowering the elasticity from 1 to 0.5 implies greater price response and causes U.S. benefits to increase by $1.5 billion.

Given the large current price volatility of the world crude oil market, it seems intuitive to conclude that the world oil supply is fairly inelastic, at least in the short run, suggesting we may have underestimated the response of world oil prices to the reduction in U.S. crude oil demand that would result from commercially viable production of cellulosic ethanol. Because a large proportion of the benefits of the simulation result from the changes in world oil prices, using too high an elasticity of supply may have caused us to underestimate the total benefits to the U.S. economy.

ENDNOTES

1 In his 2007 State of the Union Address, President George W. Bush proposed the "20 by 10" initiative, which would reduce gasoline usage by 20 percent in the next 10 years. Annual gasoline usage is 140 billion gallons, or 70 percent of total U.S. transportation fuel consumption. Part of the initiative would be a new mandated renewable fuels standard of 35 billion gallons by 2017, a more aggressive target than the scenario considered in this report of 30 billion gallons by 2020.

2 Corn-based ethanol availability is taken from the Energy Information Administration's *Annual Energy Outlook 2006* (Washington, D.C.: U.S. Department of Energy, 2006). The forecasts in this publication are the basis for this report and are available at *www.eia.doe.gov/oiaf/archive/aeo06/index.html*. Although the 2007 report has subsequently been released with updated forecasts, the amount of projected cellulosic ethanol production remains the same. The amount of corn-based ethanol production does not substantially change the results (while the base amount of corn-based ethanol production in 2020 rises to 11.9 billion gallons, the incremental effect examined in this paper remains the same).

3 *Annual Energy Outlook 2006* forecasts that cellulosic ethanol production in 2020 will be equal to the mandate in the 2005 Energy Policy Act, 250 million gallons, so the *additional* amounts of cellulosic ethanol production examined in this paper are 19.25 billion gallons in the base scenario and 49.25 billion gallons in the best-case scenario.

4 The scenario assuming 19.5 billion gallons and the scenario assuming 49.5 billion gallons are used in the study to illustrate the range of economic impacts from cellulosic ethanol production. Those endpoints should not be interpreted as production volumes that the Department of Commerce believes will be available in 2020.

5 Biodiesel is on the cusp of commercial viability (depending on prices of petroleum-based fuel) but supplies would not be large enough to significantly affect U.S. petroleum imports.

6 Excise taxes are lower on gasoline blends containing ethanol, creating a tax advantage equivalent to a subsidy of $0.51 per blended gallon of ethanol, which is part of the reason ethanol production is competitive at current crude oil prices. However, this study assumes no subsidy will be available for the additional cellulosic ethanol production.

7 Robert D. Perlack, Lynn L. Wright, Anthony F. Turhollow, Robin L. Graham, Bryce J. Stokes, and Donald C. Erbach, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge, Tenn.: Oak Ridge National Laboratory, April 2005), *www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.*

8 To meet the DOE's $1.07 per gallon cost target, the cost of feedstocks must be about $30 per ton.

9 "Cellulosic Biomass Supply Curve Update—2007," conducted for the Department of Energy by the University of Tennessee's Agricultural Policy Analysis Center, which used the POLYSYS (Policy Analysis System) model to generate revised supply curves for agricultural residues, forest residues, energy crops, urban wood wastes, and mill residues.

10 The best-case scenario would occur if (a) the DOE's $1.07 per gallon cost target were met and (b) the "moderate crop yield increase with land use change" scenario held (scenario 3 of the *Billion-Ton Biomass* report).

11 Keith Collins, Keynote Address at the **Energy Outlook, Modeling, and Data Conference, March 2007,** *http://www.eia.doe.gov/oiaf/aeo/conf/collins/collins.ppt***.**

12 Andrew McAloon, Frank Taylor, and Winnie Yee, "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks," Technical Report NREL/TP-580-28893, National Renewable Energy Laboratory, Golden, Colo., October 2000, *www.nrel.gov*.

13 Unless a car is specifically designed to use high-ethanol mixtures (as in a "flex-fuel vehicle"), the car's warranty is voided if fuel mixtures with an ethanol content higher than 10 percent are used.

14 According to a study carried out for the Office of Energy Efficiency and Renewable Energy, ethanol can be converted to energy more efficiently than gasoline because of ethanol's higher combustion efficiency, which could reduce the energy content gap by 5 percent. See David Andress and Jerry Hadder, *Factors Affecting the Demand for Ethanol as a Motor Fuel* (Kensington, Md.: David Andress & Associates, 1998)

15 Oil prices so far in 2007 have ranged between $55 and $95 per barrel. The EIA projects that 2020 oil prices will be about $50 per barrel (in 2004 dollars).

16 The main limiting factors in corn-based ethanol production are growth in corn yields and land availability, although additional corn supplies for corn-based ethanol production could be possible if high corn prices result in lower domestic feed use and lower feed exports (although demand for both is highly inelastic). As the cost of cellulosic ethanol production declines (currently about $2.65 per gallon), market forces will adjust corn prices so that corn-based ethanol supply is inframarginal, and the amount of corn-based ethanol production will tend to remain at the physical limits imposed by yield and land restraints. However, as the price of corn declines with lower cellulosic ethanol costs, corn-based ethanol production could decline as lower corn prices lead to higher domestic feed use and feed exports. A more careful analysis of the corn-based ethanol market is beyond the scope of this paper. The Economic Research Service of the U.S. Department of Agriculture is developing a modeling framework to address the corn-based ethanol market in more detail. The main results in this paper are driven by the assumed amount of additional cellulosic ethanol production; the exact amount of (inframarginal) corn-based ethanol production is largely irrelevant.

17 For a description of USAGE see the technical appendix. A paper reflecting an early stage of the research leading to the current report was presented at the 10th Annual Conference on Global Trade Analysis, Purdue University, June 2007 (see Peter Dixon, Stefan Osborne, and Maureen Rimmer, *"The Economy-Wide Effects in the United States of Replacing Crude Petroleum with Biomass,"* available at www.gtap.agecon.purdue.edu/resources/download/3358.pdf.) The central USAGE simulation in the Purdue paper shows much larger macroeconomic gains than the central simulation in this report. The larger gains occur for three reasons. First, the Purdue paper was concerned with a replacement of 25 percent of the crude oil used in motor fuels with biomass. In the present report, only 6.4 percent of crude oil is replaced. Second, the Purdue paper assumed that biomass in 2020 would be competitive (in 2004 prices) with crude oil costs at $40 per barrel. The present report assumes that biomass will be competitive only when crude oil costs $50 per barrel. Third, the Purdue paper allowed for a small increase in aggregate employment associated with delayed retirement of farmers. In the present report, aggregate employment in 2020 is unaffected by replacement of oil with biomass.

18 With an increase in demand for agricultural products, there would be an increase in the rental value of agricultural land. The version of the USAGE model used in this study does not identify agricultural land as a separate factor of production. We allowed for the increase in the rental value of agricultural land by introducing an increase in the rate of return on capital in the expanding agricultural sector. Because cellulosic ethanol would not rely on corn but rather on energy crops and on crop and forestry product residues, the effect on food prices from cellulosic ethanol production would be less than any effects from corn-based ethanol production.

19 Industries in the model are based on data collected by the U.S. government. No data are collected on the cellulosic feedstock industry, which does not yet exist. Therefore, the feed-grains industry was used as a proxy, which may tend to overstate the effect of cellulosic ethanol production on the feed-grain sector, particularly on feed prices.

20 For a complete technical description of the simulation results, see Peter B. Dixon, Stefan Osborne, and Maureen T. Rimmer, "The Economy-Wide Effects in the United States of Replacing Crude Petroleum with Biomass," *Energy and Environment* 18, no. 6 (2007): 709–22.

21 U.S. International Trade Commission, *The Economic Effects of Significant U.S. Import Restraints: Fourth Update 2004* (Washington, D.C.: U.S. International Trade Commission, June 2004).

22 Thomas W. Hertel and L. Allan Winters, *Poverty and the WTO: Impacts of the Doha Development Agenda* (Washington, D.C.: The World Bank, 2005).

23 A *net exporting industry* is one whose exports of output are greater, in dollar terms, than its imports of inputs.

24 See *www1.eere.energy.gov/biomass/biofuels_initiative.html*.

25 "Fuel Cycle Assessment of Selected Bioethanol Production Pathways in the United States," Argonne National Laboratories, Oak Ridge, Tenn., 2006, *www.transportation.anl.gov/pdfs/TA/377.pdf*.

26 Because of an over allocation of carbon permits this year, current prices for carbon in the European Union have collapsed. However, longer-term carbon futures are trading in the range of €15 to €22 per ton of carbon dioxide equivalent (according to data from Evolution Markets' Weekly Greenhouse Gas Market Update). Depending on the dollar to euro exchange rate, this corresponds to prices ranging from $20 to $31 per ton.

27 Lower U.S. fuel prices will tend to increase fuel consumption somewhat, offsetting some of the carbon dioxide emission gains.

28 See endnote 21.

29 See endnote 22.

30 Dixon, P.B. and Rimmer, M.T., Dynamic General Equilibrium Modelling for Forecasting and Policy, North Holland Pub. Co., Amsterdam, 2002.

31 Documentation for the USAGE model is available at *www.monash.edu.au/policy/mon-usa.htm*.

32 The DOE forecasts incorporate the increase in the price of crude oil relative to the GDP deflator (the real price) from $40 per barrel to $60 per barrel between 2004 and 2006. Between 2006 and 2014, the DOE forecasts a fall in the real price to $47. Then, from 2014 to 2020, the real price is forecast to rise to $50 a barrel.

33 By making ethanol output part of the motor fuel industry, the price of ethanol is set the same as the price of all motor fuels. The model, therefore, does not track the price of cellulosic ethanol relative to gasoline, nor does it track prices of petroleum refining byproducts separately.

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