Economic and Environmental Impacts of U.S. Corn Ethanol Production and Use

Douglas G. Tiffany

For many years, U.S. policy initiatives and incentives have favored the production of ethanol from corn. The goals have been to increase corn prices and farmer income, enhance rural employment through encouragement of value-added businesses, increase energy security, and produce additives and/or fuels capable of reducing tailpipe pollutants and greenhouse gases. The Energy Policy Act of 2005 established annual goals via a renewable fuels standard that would have increased production of ethanol and biodiesel to 7.5 billion gallons by 2012. That bill was superseded by the Energy Independence and Security of Act of 2007, which increased usage targets and specified performance standards for ethanol and other biofuels. The 2008 Farm Bill identified incentive payments for ethanol produced in various ways. The effects of these three laws have been magnified by rising crude oil prices, which helped maintain profits for corn dry-grind ethanol plants. This paper discusses environmental effects of corn ethanol production and use, energy balances of corn ethanol versus gasoline, subsidies for corn ethanol and gasoline, impacts of ethanol production on farmer decisionmaking, and effects of corn ethanol on food prices. (JEL Q4, Q42, R32)

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The period from 2005 through 2008 has probably seen some of the wildest swings in magnitude in the economics of agriculture, as well as the entire U.S. economy in the past century. In 2008 alone, record high prices for corn and other grains were followed by a record sell-off of these commodities, which accompanied the stock market sell-off of October 2008, a consequence of faulty regulation of currencies and financial instruments. These years saw dramatic shifts in agricultural income not seen since the early years of WWI or the years following the "Russian Wheat Deal" of 1972. From 1914 to 1916, German U-boats sank ships laden with grain and meat from the United States destined for war-torn Europe, reducing supplies of food crops and agricultural products when the United States was still neutral and trading with both sides. After the Russian Wheat Deal, the world suddenly became aware of the enhanced demand represented by entry into world markets of new players, including other Eastern European countries and China.

More recent history has been characterized by U.S. government policies that encouraged the production of biofuels (for several reasons) and high prices for commodities, including crude oil. This article reviews the history of and motivations for the policies encouraging corn ethanol production and how the original intent of these policies became magnified in a time of rapidly rising energy prices. Throughout the following discussion, it is important to distinguish the effects of corn ethanol production from the amplified effects of corn ethanol production resulting from crude oil price changes. These changes were driven by a rapidly growing demand for energy in emerging economies during wars or potential conflicts that have involved key petroleum-producing regions. Another factor of

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great importance is the financial community's use of futures markets for crude oil and other commodities as a hedge against further declines in the U.S. dollar.

The economic consequences of corn ethanol production in terms of environmental effects are discussed. The entire process, from the production of corn, to the fermentation and distillation of ethanol, to the distribution and effects of ethanol as a transportation fuel, also is addressed. A discussion and comparison of the energy balances for ethanol and gasoline are included, as is discussion of the net energy balance (NEB) of ethanol produced from corn grain and by other methods. This examination of life-cycle energy inputs and outputs reveals the net energy yields of biofuels and the fossil fuels they typically replace.

The subsidy rates on corn ethanol are quantified and compared relative to crude oil and the gasoline that can be derived from it along with the effects of corn ethanol on gasoline prices. The accumulated effects of corn ethanol production on corn prices and the ways in which these effects influence a farmer's decisions about crop choices for land under tillage or land that could be brought back into tillage are also discussed. Environmental issues certainly must be considered when land-use decisions are made. The levels of livestock feeding and the composition of livestock feed are also discussed.

Finally, corn ethanol's effects on consumer food prices are discussed. The price effects of ethanol's demand for corn have been dramatic; ethanol plants quickly grasped their greater ability to pay higher prices for corn than traditional markets for livestock feed, both domestic and foreign. Once again, a weak U.S. dollar exaggerated the effects of ethanol production by making U.S. corn a great bargain to foreign buyers, who maintained levels of buying even as prices rose.

POLICY HISTORY

The U.S. government has sponsored and supported the production of fuel ethanol in various ways over the years. During the Carter administration (when U.S. diplomats and embassy staffers were held hostage by Iran), sponsorship of ethanol found favor as the nation faced high crude oil prices caused by supply curtailment by the Organization of the Petroleum Exporting Countries. Later, crude oil prices fell, and the goal of developing alternative domestic sources of transportation fuel was put aside, taking with it the economic fortunes of a number of relatively small ethanol producers.

Environmental goals replaced energy security in the George H.W. Bush administration, when the U.S. Environmental Protection Agency (EPA) sought to enforce provisions of the 1990 Clean Air Act (EPA, 1990). Starting in 1995, the use of oxygenates, including ethanol produced from corn, became important as gasoline was modified to burn more cleanly in urban settings to reduce the adverse health effects of tailpipe emissions (i.e., criteria pollutants). Ethanol drew political support from farm groups who sought to create value-added enterprises that could reduce crop surpluses and raise corn prices.

Ethanol works very well as an oxygenate and serves the valuable role of increasing the octane of gasoline. However, the petroleum industry favored an oxygenate that they could produce (i.e., methyl tertiary-butyl ether [MTBE]) from relatively cheap natural gas and from the by-products of petroleum refining. Farm states generally favored, and some farm states (such as Minnesota) mandated, that ethanol be the oxygenate of choice over MTBE. The modern boom in fuel ethanol expansion shifted into high gear in 2005, when MTBE was banned by numerous states and when the U.S. Congress, in the Energy Policy Act of 2005 (EPA, 2005), failed to grant the manufacturers of MTBE liability protection from environmental damage and health claims.

ENVIRONMENTAL EFFECTS OF ETHANOL USE AND PRODUCTION

Effects of Ethanol Use

Ethanol's use as an oxygenate in gasoline was mandated by the 1990 Clean Air Act. In 1995, enforcement began as the U.S. EPA addressed air quality and the use of oxygenates. These programs, the Winter Oxygenate Fuel Program and the Reformulated Gasoline (RFG) Program, were initiated in response to evidence that poor air quality in certain regions of the United States was damaging human health. The Winter Oxygenate Fuel Program, with a requirement for gasoline with 2.7 percent oxygen content, was originally implemented in 36 areas of 23 states to reduce carbon monoxide levels that became dangerous in certain cities in the winter months. Many of these cities were at higher elevations or in western states (EPA, 2008). Today, improvements in engine performance and gasoline composition have left just nine areas in the country remaining in this program.

The RFG Program is more wide reaching; its requirements affect approximately 30 percent of the gasoline sold in the United States and the air quality of approximately 75 million U.S. residents. RFG must contain 2.0 percent oxygen. The primary goal of using this fuel is the reduction of emissions that contribute to ozone formation; an additional goal is the reduction of toxic emissions such as benzene (EPA, 2007).

The EPA staff has recently estimated that 7.5 billion gallons of ethanol will be needed to fulfill the requirements of the Winter Oxygenate Fuel Program, the RFG Program, and states' mandates for the period 2008-2022. This estimate assumes greater vehicle-miles traveled with higher miles per gallon in the latter years (Boledovich, 2008).

Further demand for ethanol may depend on future EPA efforts to reduce aromatics, which are used as octane enhancers in gasoline. At considerable expense, the EPA has already implemented stricter standards for stationary sources of hazardous air pollutant emissions, such as hexane and xylene, associated with tire production. In the future, the EPA may choose to reduce hazardous air pollutants further by implementing stricter standards for mobile sources of aromatics in gasoline, a common source of particulate matter of 2.5 microns or less (PM2.5). It has been estimated that replacement of aromatics in gasoline with another octane enhancer will cost $250 billion per year (Gray and Varcoe, 2005). Ethanol could be used as a replacement; the added costs would be more than offset by ethanol's cost advantage over other aromatic octane enhancers and by the net air toxic reductions resulting from ethanol use. To reduce 80 percent of the aromatics currently in gasoline, 25 percent of the content of today's conventional gasoline would need to be replaced. This replacement would represent 37 billion gallons of ethanol per year, approximately the goal for ethanol production in 2022 as articulated in the Energy Independence and Security Act of 2007 (EISA; Energy Information Agency [EIA], 2007a; Gray and Varcoe, 2005). Implementation of this change would require many more flexible-fuel vehicles (FFVs) in the U.S. fleet, or car manufacturers would need to modify warranty protection of vehicles using gasoline blended with ethanol at levels approaching 25 percent.

Effects of Ethanol Production

Production of ethanol and other biofuels is typically a more complicated process and leaves a larger footprint in terms of land use than does production of many fossil-fuel sources of energy. Production involves the cultivation of land before planting, spraying, harvest, and some level of primary tillage. Also, nitrogen fertilizer (which requires natural gas as the feedstock and as the fuel source) is typically applied. The other major nutrients that are typically applied, phosphorus and potassium, must be mined and refined and transported to farming areas. Energy used in the course of mining, manufacturing, or transportation is embedded energy. Overapplication of nitrogen, phosphorus, or potassium can result in movement of these nutrients from the fields and into waterways, especially in the cases of nitrogen and phosphorus. In the field, nutrients are released or mineralized in the natural process of decomposition of plant material that grew in previous years. Embedded energy is also used if irrigation is needed to grow the corn. Diesel fuel and electricity are the typical energy sources used to run the irrigation pumps.

At the ethanol processing plant or biorefinery, greater amounts of energy are typically required than were used in the growing and transporting of the corn to the plant. Hill et al. (2006) identified a 32 percent expenditure of embedded energy at the farmer's field and a 68 percent expenditure at the processing plant. The sources of energy at the processing plant are typically natural gas and electricity. In the United States, electricity is generated from a number of sources, but the primary source is coal. In a typical ethanol plant, natural gas is used for process heat to cook the corn mash formed after the addition of water to powdered corn kernels that had been ground by hammer mills powered by electricity. Two types of enzymes are used to sequentially enhance the flow of the mash and convert the starches to sugars. Fermentation is the process in which yeast converts the sugars to ethanol in a period lasting from 55 to 70 hours. As fermentation subsides, the ethanol is then stripped by high-temperature steam from the liquid whole stillage. The water is driven off from the wet stillage in distillation columns, and molecular sieves are used to remove the last of the water tightly held by the ethanol molecules. The unfermented solids of the corn kernels and yeast cells are removed by centrifuge machines and are eventually used as animal feed after being dried using natural gas as a heat source. In about one-third of processing plants, the carbon dioxide (CO_2) released by the respiring yeast is captured, chilled, and sold as a liquid for use in making dry ice or carbonated beverages. Approximately one-third of the energy used at dry-grind ethanol plants is allocated to the drying of the by-product, distillers' dried grains and solubles (DDGS).

CALCULATIONS OF NET ENERGY BALANCE

The amounts of embedded energy used in the life cycle of the entire process of ethanol production must be determined to calculate the NEB of corn ethanol. The energy used at the field level, at the biorefinery, and in transportation to the fuel distribution center must be added and compared with the energy found in the ethanol fuel and displaced by the by-product of processing that becomes animal feed (i.e., DDGS). (Most life-cycle analyses represent the energy of the feed by the amount of direct and indirect energy that the feed displaces by avoiding production of corn and soybean meal.) Argonne National Laboratory has reported the NEB of both gasoline and ethanol produced by the dry-grind process. Gasoline produces 0.81 British thermal units (BTUs) for each BTU of fossil energy applied in the process. Ethanol produces 1.36 BTUs for every BTU of fossil fuel used when the entire process of ethanol production by the dry-grind process and the credits for the by-products are considered (Hofstrand, 2007).

Figure 1 shows the analysis of a particular study (Hill et al., 2006) in which the NEB of corn ethanol was estimated at 1.25 to 1.0. This means that for every unit of energy applied in the process, 1.25 units of energy are recovered in fuel or feed. It is important to note that the results of calculations such as these are highly dependent on the assumptions accepted. It is also important to recognize that in a year of poor corn yields, the NEB would be reduced. This occurs because fewer bushels of corn are produced despite the use of liquid fuels to operate machinery and the embedded energy associated with the application of fertilizer, herbicides, and pesticides. The NEB of soy biodiesel is presented alongside that of corn ethanol. The various energy inputs and outputs from the processing of soybeans and soybean oil to make biodiesel are shown. The energy applied at the field (F) or plant (P) level is shown for both biofuels (Hill et al., 2006).

Another set of calculations was performed on a more elaborate ethanol plant that uses biomass (e.g., corn stover[1] or the concentrated wet stillage[2] from the ethanol production process) as fuel for process heat or even to generate electricity. Figure 2 shows the higher NEBs that result when process heat, electricity for running the plant, or electricity for sale to the grid are produced. Higher renewable energy ratios can be realized by more efficiently using biomass in more elegant and integrated systems. The conventional dry-grind ethanol plant represented in Figure 2 has a renewable energy ratio of 1.50 to 1.0, whereas a corn dry-grind ethanol plant using corn stover as a fuel for process heat, generation of electricity for plant operations, and electricity for sale to the grid performs with a threefold higher ratio, exceeding 4.5 to 1.0 (De Kam, Morey, and Tiffany, 2007).

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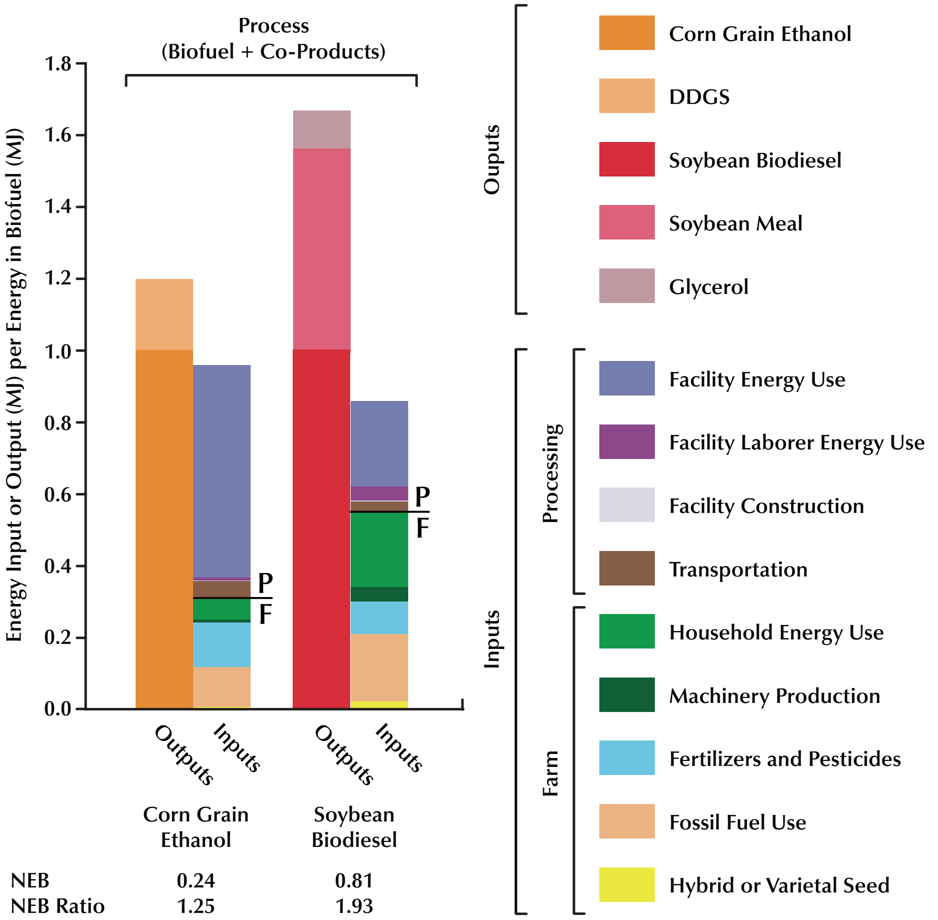
[1] Corn stover is the above-ground portion of the corn plant remaining after harvest of the grain.

[2] Concentrated wet stillage, or syrup, is a 30 percent solid material derived from the liquid portion of the stillage after the ethanol has been stripped away.

Figure 1

Net Energy Balance of Corn Ethanol and Biodiesel Fuel



NOTE: F, field level; P, plant level.

Related but more pertinent than determining the net energy ratio is the concept of determining the carbon footprint of biofuels and their relative effects on greenhouse gas (GHG) emissions. Emerging policies suggest it may soon be possible to be compensated for producing fuels with lower GHG footprints than others. This concept underlies efforts by California and other states to reduce the carbon footprint of their fuels. This standard of GHG reductions by biofuels was also delivered in the 2007 EISA, which established performance standards for advanced biofuels and cellulosic ethanol.[3] Advanced biofuels are required to reduce GHG emissions by 50 percent relative to gasoline, and cellulosic ethanol is required to reduce GHG by 60 percent relative to gasoline.

Figure 3 displays the reductions in GHG that can be achieved by production of ethanol in biorefineries using various technologies. Ethanol produced at many conventional dry-grind plants using natural gas and purchased electricity can be expected to reduce GHG by 19 percent. Cellulosic plants are predicted to reduce GHG by 86 percent,

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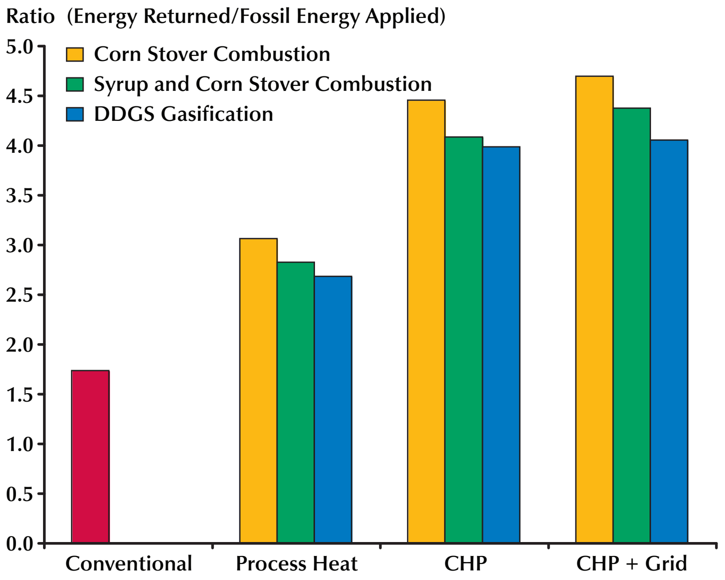
[3] Cellulosic ethanol is made from the non-starch, typically fibrous, structural parts of plants, in contrast to most ethanol, which is made from the starch contained in kernels of grain.

Figure 2

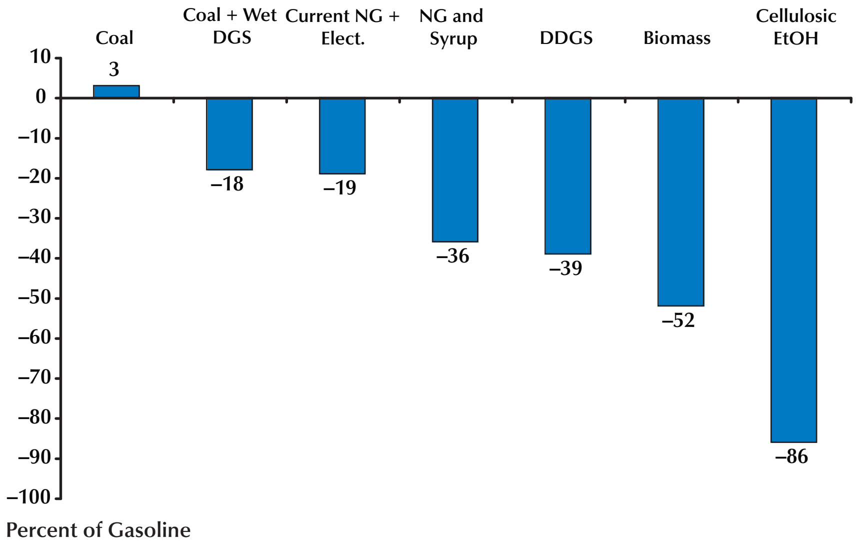
Renewable Energy Ratio (Lower Heating Value)



NOTE: CHP, combined heat and power.

Figure 3

Fuel Ethanol GHG Reductions Relative to Gasoline Well-to-Wheels GHG Emissions



NOTE: DGS, distillers' grain with solubles; NG, natural gas; EtOH, ethanol.

SOURCE: Wang, Wu, and Huo (2007).

which includes the production of a certain amount of electricity that displaces amounts of emissions from coal-fired power generation and other fossil sources. Plants that display intermediate improvement in GHG emissions are labeled "biomass"; they use woodchips, corn stover, or grasses to eliminate their requirements for process heat derived from natural gas. The figure also shows that coal-fired ethanol plants end up producing ethanol with GHG emissions 3 percent greater than gasoline, according to the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model used by Argonne National Laboratory (Wang, Wu, and Huo, 2007).

LAND-USE CONTROVERSIES

Changes in Land Use

The most controversial issues related to GHG emissions associated with biofuel production are the direct and indirect changes in land use that occur when additional lands are devoted to production of biofuels. Controversy revolves around the extent to which land-use changes, direct or indirect, will be applied when determining the GHG reductions that result from the production and use of ethanol. The way in which the state of California applies land-use changes when it implements its low-carbon fuel standard will be important information for firms seeking to produce biofuels for sale in that market because it will determine the premium that may be available to particular biofuels. A similar decision on appropriate accounting for direct and indirect land-use changes is also anticipated from the EPA.

In the February 29, 2008, issue of the journal *Science*, two articles touched on the land-use issue (Fargione et al., 2008; and Searchinger et al., 2008). Fargione et al. (2008) at the University of Minnesota examined direct land-use changes that would result if lands parcels with various climax vegetative covers were converted to cropland for production of biofuels. This research team used published literature to identify the amount of CO_2 and other GHG chemicals that would be emitted to the atmosphere if plants comprising the original vegetative material were tilled under with the organic matter, subsequently decomposed, and oxidized to release GHG. Representative vegetative covers in various climates of the world were assessed. In addition, the research team calculated the number of years required to recoup the CO_2 emissions resulting from conversion of the land to biofuel production and compared this with the annual reductions in CO_2 emissions resulting from the production and use of biofuels. For example, in Brazil, the conversion of cerrado grasslands to biofuel production would require 37 years of biofuel production to overcome the additional CO_2 emissions. In the United States, conversion of central grasslands to grow corn for ethanol production would require 93 years to recoup the CO_2 emissions from land conversion. The area with the longest carbon debt was determined to be the peatland rainforests of Indonesia and Malaysia, where conversion of land to palm oil plantations for biodiesel production would require 423 years to recoup the CO_2 emissions. In all, carbon debts were calculated for nine land cover climatic regions.

Searchinger et al. (2008; Princeton and Iowa State University) addressed indirect land-use changes resulting from biofuel production in the United States. These authors attempted to measure the amount of land, largely outside the United States, that would be converted to food crop production if ethanol production in the United States were to increase from 15 billion gallons per year to 30 billion gallons per year. They sought to measure the effect of increased U.S. domestic biofuel production on worldwide GHG emissions. A key assumption underpinning this research is that decreased production of food crops in the United States (due to production of biofuels) will result in higher commodity prices, signaling the possibility of profitable production of food crops elsewhere and prompting conversion of land to food crop production. By adding the GHG emissions of land-use conversion in foreign lands induced by market forces from using U.S. land for biofuels production, this paper reported that the production and use of ethanol from corn ethanol would result in net greater emissions of GHG than gasoline.

These research reports have attracted criticism for a variety of reasons. Some critics have expressed concerns about the rationale for determining land-

Table 1

Energy Information Agency and Koplow Estimates of Narrow Category of Subsidies

Energy beneficiary	Direct expenditures ($ millions)	Tax expenditures ($ millions)	Research and development ($ millions)	Federal electricity support ($ millions)	Total ($ millions)
Natural gas and petroleum liquids (EIA, 2007b)	—	2,090	39	20	2,149
Ethanol-low* (Koplow, 2007)	150	3,380	290	—	3,820

NOTE: *Koplow differentiated between the amount of subsidy for the VEETC under "low" and "high" estimates as follows: "[The] primary difference between high and low estimates is inclusion of outlay equivalent value for the volumetric excise tax credits. A gap in statutory language allows the credit to be excluded from taxable income, greatly increasing their value to recipients" (footnote to Table 4.1, p. 29).

use changes related to U.S. biofuel production, especially when the level of ethanol production used in the Searchinger et al. (2008) model (30 billion gallons) exceeds by a factor of 2.0 the goal set for corn-based ethanol production by the 2007 EISA (i.e., 15.0 billion gallons). Other critics assert that economic and cultural forces, such as population growth and unrelated efforts for resource development, were not taken into consideration. Such forces have been behind efforts to clear land since time immemorial, far in advance of the expansion of biofuel production. Still other critics have stated that land conversion in other parts of the world is not the result of orderly, calculated business decisions based on world grain prices but instead reflects desires to harvest native timber for quick cash by timber bandits.

SUBSIDY RATES FOR CORN ETHANOL COMPARED WITH OTHER FUELS

The topic of subsidies can be quite involved. The Energy Information Agency (2007a) of the Department of Energy reports subsidy levels with identifiable budget impacts that conform to the following categories for various types of energy:

- direct expenditures,
- tax expenditures,
- research and development, and
- electricity programs serving targeted consumers and regions.

Others, such as Koplow (2007), separate the levels into more encompassing categories of subsidies and require additional assumptions about tax liabilities of the recipients and market effects of any mandates, tariffs, loan guarantees, and other tax treatment items that may or may not be used. Some authors categorize substantial national defense expenditures and other categories as subsidies for crude oil and gasoline (International Center for Policy Assessment, 1998).

EIA figures for ethanol are lumped in the category "renewables." For gasoline, EIA figures are lumped in the category "natural gas and petroleum liquids." Table 1 presents the federal government's (EIA, 2007a) subsidy figures for 2007 for natural gas and petroleum liquids and Koplow's (2007) low subsidy estimates for similar categories for ethanol. Koplow distinguishes between low and high estimates because of the ability of a firm that receives a volumetric excise tax credit (VEETC) to use those payments and their marginal tax rates. Use of the low-estimate figure closely conforms to the assumption that most recipients of the VEETC will be able to use $0.51 per gallon of ethanol blended.

Considering that the United States used 142 billion gallons of finished gasoline and produced 6.5 billion gallons of ethanol in 2007, one can estimate subsidy levels of $0.015 and $0.588 per gallon, respectively, for gasoline and ethanol using these narrowly defined definitions of subsidies that are most easily documented (Renewable Fuels Association, 2008). However, the figure of $0.015 per gallon for gasoline is certainly overstated because some

Table 2

Estimated 2007 U.S. Ethanol Subsidies per Gallon of Ethanol Produced

Subsidy category	Estimate using low effect of VEETC ($ millions unless noted)
Market price support	1,690
Output-linked support	
Volumetric excise tax credit (low)	3,380*
Volumetric excise tax credit (high)	—
Reductions in state motor fuel taxes	410
Federal small producer tax credit	150*
Factors of production: Capital	
Excess of accelerated over cost depreciation	220
Federal grants, demonstration projects, research and development	290*
Credit subsidies	110
Deferral of gain on sale of farm refineries to co-ops	20
Feedstock production (biofuel fraction)	640
Consumption	
Credits for Clean Fuel Refueling Infrastructure	30
Total	6,940
Average subsidy per gallon of ethanol produced in 2007†	1.068

NOTE: *Categories recognized by the federal government.
†Based on 6.5 billion gallons.

of the subsidy funds are applied to natural gas.

The largest subsidy for ethanol is the tax expenditure (or loss of tax revenue) resulting from the VEETC, which was $3.38 billion in FY 2007. The amount of this subsidy exceeded subsidies offered to any conventional or renewable fuel in 2007 (EIA, 2008b). The VEETC was $0.51 per gallon through the end of 2008, with a reduction to $0.45 per gallon starting in 2009. This credit is not received by the farmers or the plants that produce ethanol; it is a credit that the firms blending ethanol with gasoline typically apply to their federal excise tax liabilities. The availability of this credit rewards sellers of gasoline as they buy, blend, and distribute ethanol in gasoline. The existence of the VEETC makes blenders of ethanol willing to pay a higher price for ethanol than they would have in the absence of this credit. Firms marketing gasoline blended with ethanol typically realize a benefit of $0.51 per gallon in addition to the marketable value of the BTUs of energy that are released with the burning of the ethanol. In this manner, the benefit of the VEETC is transmitted back to the ethanol producers in the form of a higher price for their product. Funding of $727 million for research and development was made available for all renewables in FY 2007 (EIA, 2008a); Koplow (2007) has identified $290 million of this as associated with improving processes in ethanol production.

Koplow (2007) has compiled a more extensive list of subsidies for corn ethanol using broader definitions than those used by the EIA. While there are, indeed, indirect transfers to firms and individuals associated with the production and use of corn ethanol that go beyond those listed by the EIA, Koplow includes several that are somewhat harder to quantify and compare fairly. Table 2 lists all of the categories that Koplow identified for ethanol in 2007 with the categories recognized by the federal government marked by an asterisk. Note that

Koplow recognizes the market price support category because the production levels mandated by the RFS amount to the creation of a market that is obligated to purchase a given amount of product without regard to the price.

Koplow (2007) recognizes the influence of the import tariff on foreign ethanol as a subsidy by reasoning that this barrier prevents the import of cheaper foreign ethanol to satisfy the mandated demand. He also recognizes and quantifies the reductions in state motor fuel taxes through waivers of state fuel excise taxes and sales taxes on materials for new construction of ethanol plants. In addition, Koplow notes that Internal Revenue Service regulations offering accelerated depreciation on assets and deferral of gains on sales of farm refineries are subsidies that benefit ethanol production, although they may not be used by many participants. Unequal participation also exists for credit subsidies that include loan guarantees by agencies of the federal government for ethanol development projects. In the category of subsidies that encourage the production of feedstock, he lists $640 million attributable to the biofuel fraction of corn production. The validity of this category is somewhat questionable because many crop-support payments have been cut as a consequence of high corn prices—partially because of ethanol demand. Finally, Koplow lists $30 million to help pay for the required installation of blending facilities by gasoline marketing firms. To the extent that the blending facilities help achieve RFG Program and Winter Oxygenate Program standards, human health benefits (which are hard to quantify) may partially offset the costs of the blending facilities. Based on Koplow's broader definitions, subsidies totaling $6,940,000,000 for ethanol in 2007 average $1.068 per gallon, substantially more than the $0.588 per gallon calculated using the EIA categories and the $0.015 per gallon attributed to gasoline.

Corn Ethanol Benefits to U.S. Consumers

While, on one hand, funds are expended or tax revenues are reduced as subsidies for ethanol production, the growth in production of this fuel offers certain monetary benefits to most consumers. Du and Hayes (2008) examined the monthly retail prices for regular gasoline over the period 1995-2007 and discovered that ethanol production within the five Petroleum Administration for Defense Districts in the United States resulted in retail gasoline prices that averaged from $0.29 to as much as $0.395 per gallon lower than they would have been absent the ethanol production capacity. In addition, their models indicated that added ethanol production capacity reduced the profitability of petroleum refineries by preventing dramatic price increases, which are often associated with an industry operating close to capacity. If the average $0.29 per gallon price reduction is applied to the 146 billion gallons of gasoline used in the United States in 2007, the benefit to U.S. consumers could have been $42.34 billion.

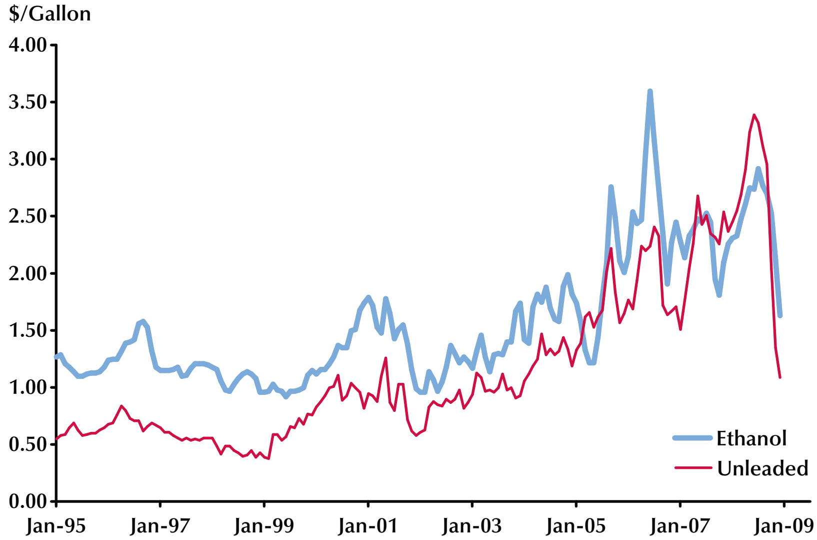
Based on the monetary benefit to consumers (measured by Du and Hayes, 2008) and the subsidies paid directly to the industry (using Koplow's, 2007, more expansive list of categories; see Table 2), one can calculate a net benefit to consumers of corn ethanol of $35.4 billion for 2007. However, it should be noted that the period Du and Hayes (2008) analyzed (1995-2007) was characterized by general prosperity, heavy consumption of gasoline, and high rates of refinery utilization. As the United States enters a period of lower demand for gasoline, the sponsored production of ethanol will probably not produce the same reduction in gasoline prices.

Farmer Decisionmaking

Before 2005, ethanol typically enjoyed a price premium on a per-gallon basis over wholesale gasoline (often $0.25 or more per gallon) because of the mandated markets for RFG and winter oxygenated gasoline (Figure 4; Nebraska Energy Office, December 2008 data). As individual states banned the use of MTBE as an oxygenate, ethanol gained that share of the market. The death knell for MTBE was sounded when the Energy Policy Act of 2005 failed to provide liability protection for MTBE producers. At this point, numerous gasoline marketers made the switch to ethanol and higher prices for corn and ethanol followed. With increasing supplies of corn ethanol on the market in 2006 and 2007, ethanol lost its price premium over gasoline. This was partly related to transportation constraints and a lack of blending facilities in some regions of the country.

Figure 4

Ethanol and Unleaded Gasoline Rack Prices per Gallon (Free on Board Omaha)



SOURCE: Nebraska Energy Office; www.neo.ne.gov/statshtml/66.html.

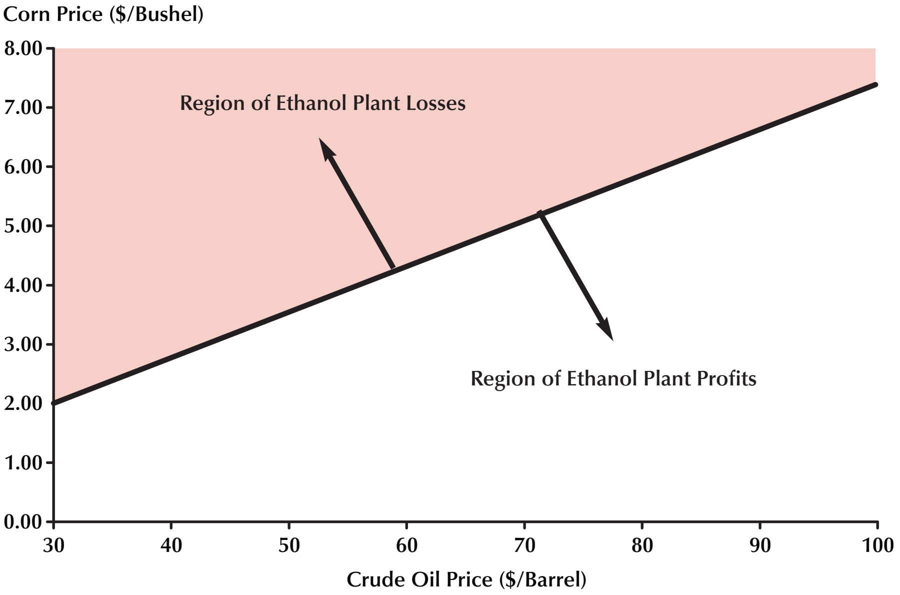
After ethanol lost its premium as a mandated oxygenate, its price came to reflect its role as an octane enhancer and as a BTU substitute for gasoline. As a substitute for gasoline, ethanol's price became directly related to the price of crude oil, which rose dramatically over the period beginning with the enactment of the Energy Policy Act in 2005 through the summer of 2008. Figure 5 shows the corn price that an ethanol plant of 50 million gallons per year capacity, built in 2007, with 50 percent debt can pay for corn and just break even assuming a natural gas price of $8.00 per dekatherm, full receipt of the $0.45 per gallon VEETC, and DDGS selling at 91 percent of the corn price. The figure also shows how price combinations of corn and crude oil can move the plant into either the profitable region (below the line) or the unprofitable region (above the line). Of concern to livestock producers, who purchase corn as animal feed, is the effect of the $0.45 per gallon VEETC, which when fully realized in the price of ethanol in the market, translates into an approximately $1.24 higher bid price per bushel of corn by ethanol plants. This figure can also be obtained by multiplying the tax credit available to the ethanol blenders by the typical yield of ethanol, which is 2.75 gallons per bushel of corn ($0.45 × 2.75 = $1.2375 per bushel). Figure 5 shows the effect that higher crude oil prices can exert on corn prices and ultimately, the desire to grow additional corn acres.

Figure 5 was constructed by first determining the price of wholesale gasoline for a range of crude oil prices. Then the BTU-equivalent price of ethanol (two-thirds of gasoline) was added to the VEETC of $0.45 effective for 2009. The resulting prices of ethanol as a subsidized BTU substitute for gasoline can be forced into a model for an ethanol plant of a certain size and debt percentage for assumed prices of natural gas, DDGS, and other expense items to learn the maximum price that the ethanol plant can pay for corn and produce zero profits. The line for each ethanol plant is unique due to its capital cost, the amount of debt it carries, and its opportunities to sell DDGS. As prices of natural gas, DDGS, or other revenue and expense items change, the line will shift up or down.

Figure 6 is from the United States Department of Agriculture *Agricultural Projections Report to*

Figure 5

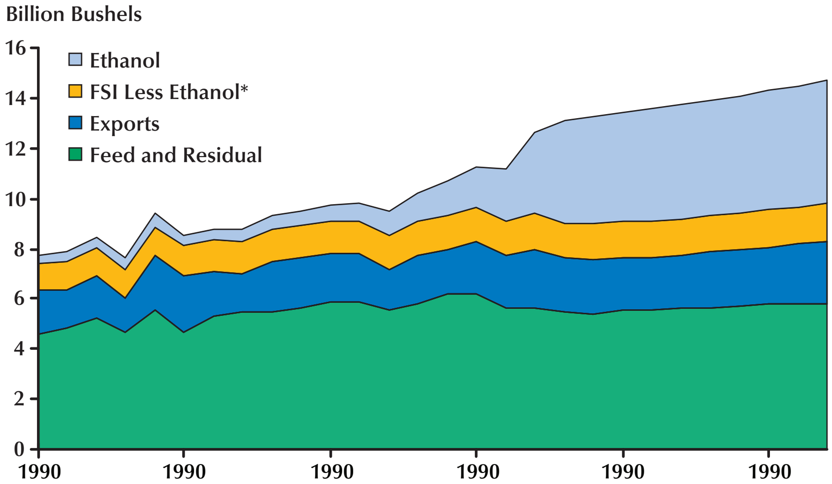
Breakeven Corn Price for Dry-Grind Ethanol Plants at Various Crude Prices with Full Receipt of $0.45 per Gallon VEETC



NOTE: Assuming 50 million gallon plant built in 2007 with 50 percent debt and costs of $8.00/dekatherm natural gas and DDGS 91 percent of the corn price.

Figure 6

U.S. Corn Use



NOTE: *Food, seed, and industrial less ethanol.

SOURCE: *USDA Agricultural Projections Report to 2017* (USDA, 2008).

Table 3

Average Land Characteristics in Iowa

Characteristic	Corn suitability ratings*	Highly erodible land†	Slope range (%)‡
Conservation Reserve Program (acres)	45.05	1.53	10.89
All Iowa land	61.87	2.17	7.33
Corn and soybeans	70.99	2.46	5.45

NOTE: *Most productive land is rated at 100.00 corn suitability rating.

†The highly erodible land categories are 1.0 for highly erodible, 2.0 for potentially highly erodible, and 3 for not highly erodible.

‡The slope (%) is based on the percentage difference in the number of feet of rise or fall per 100 feet.

SOURCE: Secchi and Babcock (2007).

2017 (USDA, 2008), which recognized the powerful influence of ethanol producers' increased corn demand to fulfill the objectives of the 2007 EISA.

The strong demand for ethanol intensified the demand for acres to produce corn. High corn prices and the expectations for their continuation allowed corn acres to outbid soybean, wheat, and hay acres. The higher prices for corn, which were partly responsible for lower or negative returns for livestock producers, may become the deciding factor for a number of small-scale producers who decide to exit hog, beef feeder cattle, and dairy operations. Although this exodus was already under way before corn prices increased because of higher demand from biofuels, the growing biofuel demand and the strong demand for exports may cause this process to continue. The full effect of greater production of ethanol may take some time to be fully realized because of the already advanced median age of numerous livestock producers.

To a certain degree, the enhanced price of corn induced by ethanol prompts the removal of acres from the Conservation Reserve Program[4] (CRP). Secchi and Babcock (2007) at Iowa State University examined this phenomenon using crop budgets and soil erosion models for a particular watershed in Iowa. Table 3 compares the quality of the land in the CRP program in Iowa with the quality of the land throughout the state and the quality of the land planted in corn and soybeans.

The Secchi and Babcock (2007) research team found the following:

i. At a corn price of $3.00 per bushel, landowners in the watershed region under study would be economically rational to keep the higher returns from their CRP contracts.

ii. At a corn price of $4.00 per bushel, some CRP landowners in the watershed region (for which levels of soil erosion were known) would be motivated to remove some of their land from the CRP program and pursue crop production (corn and other crops in rotation).

iii. At a corn price of $5.00 per bushel, much of the CRP land in the watershed region would return to crop production.

Secchi and Babcock (2007) used budgetary information for a particular area of Iowa to determine the returns on particular lands and to determine whether the landowners would be better off accepting prevailing CRP payments or taking their chances at growing crops. They also used the Erosion-Productivity Impact Calculator model to estimate soil erosion, nutrient loss, and levels of carbon sequestration on lands recruited back to crop production from the CRP. They concluded that higher corn prices would bring environmentally fragile lands from the CRP back into crop production and estimated that sediment losses would increase from baseline levels of less than 1 million tons per year over 2 million acres. A corn price of $5.00 per bushel would precipitate the conversion of

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[4] The Conservation Reserve Program pays a rental rate to farmers on erosion-prone land, generally for 10-year periods when the land is typically maintained in perennial grass production.

1,350,000 acres from the CRP to crop production, at a predicted loss of 5 million tons of sediment. If all the CRP acres in Iowa were converted to crop production, it is predicted that 9 million tons of sediment losses would occur.

EFFECTS OF CORN ETHANOL ON FOOD PRICES

In 2007, when U.S. retail food prices rose 4 percent above 2006 levels and twice as fast as overall core inflation (2.3 percent), consumers took notice. Corn-based ethanol drew substantial attention as consumers sought a culprit for higher prices at the grocery store. Higher corn prices were, in part, driven by demand to make ethanol and these higher prices effectively bid acres away from other crops that provided lower returns, such as soybeans, wheat, and hay. Foods experiencing the biggest gains in price were meats and dairy. Dairy prices rose 7.4 percent above 2006 levels. Prices of crop-based goods also increased; cereal and bakery products rose 4.3 percent, and fat and oil products rose 2.9 percent from 2006 to 2007.

However, it is important to note that in terms of overall retail food costs, the farm values of crops and livestock represent only 19.5 percent of total retail costs, whereas labor accounts for 38.5 percent. Transportation represents 4.0 percent, and the energy used to heat and cool stores, lockers, and freezers represents 3.5 percent. The highest farm share of retail food prices is commanded by beef at 45 percent, followed by pork and dairy at 31 percent. The farm share for fresh fruits and vegetables is 25 percent, while the farm share for cereals and bakery products is just 5 percent (Henderson, 2008).

Researchers at Texas A&M University (Anderson et al., 2008) produced a detailed report on ethanol's effects on food and feed in Texas. They reported increases in food prices and noted that only small percentages of retail food prices can be directly attributed to farm-level prices. They also noted the importance of beef feeding in Texas, a state that must import the majority of its corn. They report that corn and grain sorghum growers benefit from high corn prices when corn prices are squeezing profits from livestock-feeding operations.

Much to the chagrin of the governor of Texas, who had sought relief from the RFS, the economic modeling used for this report showed that relaxing the RFS would not significantly lower corn prices and provide meaningful relief to livestock producers. The report noted how the emergence and popularity of commodity index funds effectively drove traditional users away from farm commodity futures markets. This took away a risk management tool when it was needed the most (Anderson et al., 2008).

Ethanol expansion has cost U.S. consumers relatively little overall, but effects on foreign consumers have been more pronounced, especially for those countries sensitive to maintaining access to agricultural commodities on the world market. For example, South Korea's Daewoo Logistics is reportedly seeking a 99-year lease on 2.5 million acres of land in Madagascar to produce corn and other crops for Korean consumption. The production goal is 232 million bushels of corn within 15 years. This amount of corn is similar to South Korea's corn imports from the United States in 2005. China is seeking a similar land area for rice production in the Philippines, as well as a land area of unspecified size in the Zambezi Valley of Mozambique. Because rice is not typically consumed in Mozambique, most of the rice produced there would be destined for China. Efforts by developed countries to lease the productive capacity of developing countries may become a source of international friction if the host country faces struggles to provide adequate supplies of affordable food for its own people (Ray, 2008).

CONCLUSION

It is difficult to describe a perfect fuel that produces no adverse impacts during its production or use. This is the case with corn ethanol. However, it is a fuel that burns cleanly (due to its function as an oxygenate) and enhances octane. Anhydrous ethanol[5] can be readily blended with gasoline, the dominant fuel used in the United States for personal transportation in light-duty vehicles. As a blended fuel, ethanol can be accommodated in our logistics network, but not without additional cost. Ethanol's proclivities to attract moisture and its solvent qualities have prevented its transport in the U.S. fuel pipeline network; this shortcoming necessitates truck, rail, and barge transportation.

This article reviews the impacts (current and potential) of fuel ethanol used as an oxygenate and its role in reducing tailpipe emissions. At this point, production levels have expanded to satisfy demand for octane enhancement and as a mandated BTU substitute for gasoline. Production of corn ethanol and the ensuing increased demand for corn can pose environmental challenges if care is not exercised in bringing additional, and sometimes fragile, lands back into crop production. Use of corn by ethanol plants in times of rising crude oil prices can exact price pressure on livestock producers partly as a consequence of the VEETC.

Corn ethanol has a positive NEB when produced with dry-grind technology. However, it is well known that this technology can be improved in terms of GHG emissions by the use of biomass as a fuel source. GHG emissions and the process by which ethanol is produced in the future are likely to be keys to the financial success of this industry as efforts are made to document and benchmark production practices.

Ethanol is the recipient of direct and indirect subsidies. Its direct subsidies exceed those of gasoline, but some authors have recognized that its production has reduced gasoline prices by increasing fuel capacity overall and reducing gasoline price increases related to limitations in petroleum refinery capacity.

Up to this time, corn ethanol's effect on domestic food prices has been minimal. Food prices in certain foreign countries have been affected to a greater extent in some cases. Over the longer term, it appears developed countries will try to lease agricultural lands from less-developed countries. If relatively high corn prices persist, low margins for livestock producers may accelerate the exodus of many small-scale producers from livestock feeding and milking.

The U.S. Congress has taken measures to ensure that production of ethanol from the starch in corn grain does not advance beyond 15 billion gallons per year, or approximately 10 percent of our national gasoline usage. This measure is an effort to preserve more corn for domestic livestock producers. In addition, the EISA's performance standards and attractive subsidies and incentives for advanced biofuels and cellulosic ethanol may some day encourage production of ethanol without the use of corn grain.

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[5] Anhydrous ethanol is the type produced in the United States; it mixes very readily in various blends of gasoline. In the past, Brazil used hydrous ethanol directly in its cars; this type of ethanol does not mix well.

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