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Economics of Ethanol: Costs, Benefits, and Future Prospects of Biofuels

Proceedings of a conference co-hosted by the Federal Reserve Bank of St. Louis and the Weidenbaum Center on the Economy, Government, and Public Policy and the International Center for Advanced Renewable Energy & Sustainability, Washington University in St. Louis, November 14, 2008

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Editor's Introduction

Thomas A. Garrett

The Federal Reserve Bank of St. Louis cohosted a one-day conference, "Economics of Ethanol: Costs, Benefits, and Future Prospects of Biofuels," on November 14, 2008. Cohosts included the Weidenbaum Center on the Economy, Government, and Public Policy and the International Center for Advanced Renewable Energy & Sustainability at Washington University in St. Louis. The conference provided a nontechnical description of the major issues surrounding ethanol in the United States.[1] Academics, industry leaders, and policy experts shared opposing views on the role of government in the ethanol industry, the long-run viability of the industry, and the economic costs and benefits of increased ethanol production. The conference format consisted of presentations by academic scholars and a panel discussion involving policy experts and industry leaders. This issue of *Regional Economic Development* contains the papers, discussions, and panelist remarks from the conference.

THE U.S. ETHANOL INDUSTRY

Mark Stowers, vice president of research and development for POET, a company that produces ethanol, provides the keynote address. Stowers discusses the growth in the ethanol industry over the past several decades and the current status of the industry, the economic benefits of ethanol, the effect of government policy on ethanol and competing energy markets, and the prospects for alternative ethanol sources in addition to corn ethanol. He concludes with five factors critical to the widespread use of ethanol in the United States, including research and development, government support, and industry infrastructure.

THE PROFITABILITY OF CORN ETHANOL PROCESSING

In the first paper of the conference, Paul Gallagher examines issues critical to the profitability of corn ethanol processing, including the production and scale of corn ethanol processing and efficient production processes. Gallagher discusses how government policy and technological development can lead to a mature and profitable corn ethanol industry. He also describes several ways that reorganization of the ethanol industry could lead to greater profitability over the next several decades. Lastly, Gallagher outlines several strategies ethanol producers can use to reduce costs or increase revenues to maintain profitability.

In her discussion, Martha Schlicher describes the characteristics of a "perfect" fuel and suggests that ethanol has these characteristics. Schlicher discusses the evolution of the ethanol and alternative energy markets over the past several decades and argues that various government policies have contributed to the slow adoption of alternative fuels such as ethanol. Schlicher concludes by outlining several ways that changes in government support

1 Additional information about the conference can be found at http://research.stlouisfed.org/conferences/ethanol/index.html.

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would lead to a more viable and sustainable ethanol industry in the United States.

THE ECONOMIC CONSEQUENCES OF CORN ETHANOL AS A FUEL SOURCE

Douglas Tiffany examines the environmental effects of ethanol production, ethanol's energy balance with fossil fuels, the impact of ethanol production on food prices, and the effect of ethanol on farmers' production decisions. Tiffany also compares the subsidy rate of corn ethanol with that of other fuels and discusses changing land-use patterns as a result of ethanol production. He argues that production of corn ethanol and an increased demand for corn can pose environmental challenges if care is not exercised when bringing additional lands back into crop production.

In his discussion, Max Schulz acknowledges the validity of many points raised by Tiffany, but argues that the large government subsidies for ethanol do not create enough benefits to justify their cost. Specifically, Schulz questions the use of ethanol mandates because it is doubtful that significant volumes of our national oil consumption can be displaced with ethanol. He further cites a global increase in food prices and greenhouse gas emissions as reasons the benefits of our ethanol policies are not worth their costs.

THE IMPACT OF THE ETHANOL BOOM ON RURAL AMERICA

Jason Henderson explores the impact of the ethanol boom on rural communities. Although the large ethanol subsidies have increased economic growth and development in rural agricultural communities, the question remains whether ethanol is a viable strategy for continued economic development in rural areas. Henderson presents evidence that although crop prices have risen, the ethanol boom explains only some of the national increase in crop prices, net returns, and land values. The geographic concentration of ethanol production has led to some spatial changes in crop prices and livestock production. Henderson argues that the ethanol industry has helped nonfarm economic growth, but the gains have been less than initially claimed.

In his discussion, Seth Meyer focuses on the effects of ethanol production on commodity prices and the role that federal policy plays in the market for ethanol and other biofuels. He points out that measuring the effect of ethanol production on commodity prices is more difficult than some acknowledge. It is clear that ethanol and other biofuels have had an effect on commodity prices, but estimates vary considerably from a negligible impact to attributing most of the rise in prices to increased ethanol and biofuel production. Thus, the impact of ethanol on rural communities is deserving of more research. Meyer also argues that the success of ethanol as a viable industry is dependent on appropriate federal policies.

PANEL DISCUSSION: THE FUTURE OF BIOFUEL

The final session of the conference, a panel discussion, focuses on the future of biofuels. The panelists are Jerry Taylor from the Cato Institute, Rick Tolman from the National Corn Growers Association, and Nicholas Kalaitzandonakes from the University of Missouri–Columbia. They discuss the political economy of ethanol subsidies and regulation, whether ethanol can be a viable industry in the United States, and the prospects for other biofuels, such as those made from switchgrass and algae. The panelists represent different views on the role of government in ethanol production and the long-term viability of the industry. The panelists' remarks and opposing viewpoints sparked lively audience discussion.

ACKNOWLEDGMENTS

I thank the authors, discussants, and panelists for their participation. I also thank the Weidenbaum Center and the International Center for Advanced Renewable Energy & Sustainability at Washington University in St. Louis for their professional partnership in organizing this event.

The U.S. Ethanol Industry

Mark D. Stowers

Ethanol is vital to achieving greater American energy independence. It is today's only viable and available fuel that can be substituted for gasoline. Unlike oil, ethanol is renewable—it will never run out. As science moves from making ethanol from corn to producing it from corn cobs and other plant materials, ethanol will continue to be a sustainable and effective energy solution for the world. America's dependence on foreign oil causes enormous problems for Americans every day—raising the prices on everything from gas to groceries and sending money and jobs overseas. This article summarizes the state of the ethanol industry. (JEL Q20, Q21, Q28, Q40, Q42)

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POET, headquartered in Sioux Falls, South Dakota, is the largest ethanol producer in the world. POET is an established leader in the biorefining industry through project development, design and construction, research and development, plant management, ownership, and product marketing. The 20-year-old company has built 32 ethanol production facilities and currently manages 26 plants in the United States while marketing more than 1.5 billion gallons of ethanol and 4 million tons of distillers' grains annually.

Since 2000, POET has constructed 21 greenfield ethanol plants in seven states and completed six major expansions of existing facilities. The value of POET's design-build contracts since 2000 has exceeded $1 billion. Each project has been successfully designed, built, and managed by POET. These projects have resulted in the addition of more than one billion gallons of new fuel ethanol capacity per year.

The POET development model is unique. It started on the Broin family farm in Minnesota and has spurred the growth of investment by thousands of farmers and individual Main Street investors. POET's business model is to invest in, develop, design, construct, and manage ethanol production facilities. However, the facilities are independent limited liability companies (LLCs) owned by POET, individuals, and local farmers that provide the corn feedstock. POET employs the general manager and on-site technical engineer at each facility. All other employees are employed by the LLC. POET also has representation on the board of directors at each plant.

By leveraging business size and position, POET has created the most successful ethanol facilities in the industry. POET has achieved breakthrough progress beyond ethanol processing, extracting extraordinary new value from each kernel of corn.

ETHANOL INDUSTRY BACKGROUND

The ethanol industry now produces more than 10 billion gallons of fuel ethanol, representing 7 percent of the gasoline supply, and 70 percent of all gasoline sold contains some ethanol. Ethanol contributes more than $45 billion to the U.S. gross

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domestic product annually, has created more than 238,000 jobs, and has contributed $12 billion to consumers through lower transportation fuel prices. During 2007, 6.5 billion gallons of domestically produced ethanol displaced 228 million barrels of imported oil (Renewable Fuels Association [RFA], 2008a). As of February 1, 2009, 180 ethanol plants have been constructed with a production capacity of 12.2 billion gallons with an additional 1.5 billion gallons of capacity under construction. About 1.9 billion gallons of capacity is currently idled due to poor market conditions (RFA, 2008b).

ETHANOL BENEFITS

Ethanol has the highest octane rating of any fuel and keeps today's high-compression engines running smoothly. E10 (which is 90 percent gasoline and 10 percent ethanol) is a cleaner-burning fuel than straight gasoline. Ethanol-blended fuels do not leave gummy deposits on the fuel system and prevent wintertime problems by acting as gasline antifreeze. Since the 1980s, all automaker warranties have allowed the use of E10. Ethanol has been criticized for having fewer British thermal units (BTUs) per gallon than gasoline. However, ethanol's combustion efficiency compensates for some of its lower energy content. Ethanol's 113 to 115 octane rating compared with unleaded gasoline's 87 allows high-compression engines to perform just as well on fewer BTUs. The ethanol blends used today (E10 and E30) have little impact on fuel economy or vehicle performance.

Using ethanol as a vehicle fuel provides local and global benefits: It reduces emissions of harmful pollutants and greenhouse gases (GHGs). Ethanol is the only currently available solution for reducing GHG emissions from the current fleet of vehicles. Ethanol results in fewer GHG emissions than gasoline and is fully biodegradable, unlike some fuel additives. Production of ethanol requires one-third less fossil-fuel energy than gasoline, reducing GHG emissions. The higher the amount of ethanol blended with gasoline, the lower the GHG emissions. In 2007, ethanol use in the United States reduced carbon dioxide (CO_2)–equivalent GHG emissions by approximately 10.1 million tons, which is equal to removing more than 1.5 million cars from America's roadways (Wang, 2007).

Life-cycle analysis compares CO_2 emissions produced during the entire process of ethanol and gasoline production (field to wheels and wells to wheels, respectively). For ethanol these steps include growing the feedstock crops, transporting them to a production plant, producing the ethanol, distributing it, and burning it in vehicles. For gasoline these include extracting crude oil from the ground, transporting it to a refinery, refining the crude oil into gasoline, distributing the gasoline, and burning it in vehicles. Studies have shown that, when these entire life cycles are considered, using corn-based ethanol instead of gasoline reduces GHG emissions by 49 to 58 percent, depending on the source of energy for ethanol production (Liska et al., 2009).

ETHANOL PRODUCTION EFFICIENCY

Ethanol production efficiency has increased dramatically since the late 1980s when corn starch required cooking, enzymes inefficiently converted starch to sugars, and fermentation ethanol titers were 10 percent. Recently, the Argonne National Laboratory compared ethanol plants built in 2006 and 2001. Results showed a 6.4 percent increase in ethanol yields, 21.8 percent reduction in energy use, and 26.6 percent decrease in water consumption with the newer plants (Wang, 2007). Today POET ethanol plants produce ethanol at titers of 20 percent without cooking the starch and with enzymes that efficiently process starch for pennies per gallon of ethanol produced.

MID-LEVEL ETHANOL BLENDS

With the Energy Independence and Security Act of 2007 the U.S. government mandated a gradual increase in the country's use of renewable fuels such as ethanol until 2022, when the mandate reaches 36 billion gallons. However, because current government regulation restricts the ethanol blend to E10, ethanol producers will hit a regulatory cap—although they can produce enough ethanol to displace more than 10 percent of the fuel supply, no more than 10 percent may be used. Ethanol producers expect to hit this regulatory cap in 2009.

Multiple comprehensive studies have evaluated the effects of ethanol-gasoline blends above 10 percent ethanol, including, specifically, E15 and blends as high as E85. These studies involved over 100 vehicles, 85 vehicle and engine types, and 33 fuel-dispensing pumps and included a yearlong drivability test and over 5,500 hours of materials compatibility testing. One such study, West et al. (2008), a peer-reviewed report by the Oak Ridge National Laboratory for the Department of Energy (DOE), studied the effects of E15 and E20 on motor vehicles and small nonroad engines. This study compared E15 and E20 with traditional gasoline and concluded there were no significant changes in vehicle tailpipe emissions, vehicle drivability, or small nonroad engine emissions with either ethanol blend.

ETHANOL AND GOVERNMENT POLICY

Government support for ethanol levels the playing field in the heavily subsidized energy sector and is designed to reduce U.S. dependence on foreign oil, improve the environment, and foster rural development.

The Volumetric Ethanol Excise Tax Credit (VEETC) or "blenders' credit" was created as part of the American Jobs Creation Act of 2004. VEETC provides oil companies with an economic incentive to blend ethanol with gasoline. The tax credit totals 51 cents per gallon of pure ethanol; for example, 5.1 cents per gallon for ethanol in E10 (10 percent ethanol in gasoline). The VEETC provides market access for ethanol and provides significant benefits to U.S. taxpayers. In 2007 the blenders' credits totaled approximately $3.3 million. In the same year, the ethanol industry contributed $47.6 billion to the nation's gross domestic product, created more than 200,000 jobs, and generated an estimated $4.6 billion in tax revenue for the federal government. In addition, because of higher prices for agricultural commodities, expected direct-support payments to farmers (as provided through the Farm Bill) was approximately $8 billion less than expected (Urbanchuk, 2008). The VEETC is currently authorized through December 31, 2010.

U.S. ethanol imports are subject to a 2.5 percent ad valorem tariff, which is quite modest compared with the tariffs that other countries impose. For example, Brazil levies a 20 percent ad valorem tariff on ethanol imports. All ethanol blended with gasoline in the United States qualifies for the blenders' credit, regardless of the country of origin of the ethanol. To offset this and ensure that taxpayer dollars do not support foreign ethanol production, U.S. ethanol imports from non-Caribbean Basin countries are subject to a 54 cent per gallon secondary tariff. This tariff is in effect through December 31, 2010.

If the secondary tariff on ethanol imports were to be eliminated, ethanol imports would jeopardize the domestic ethanol industry that is already keeping gas prices lower. Many ethanol critics have suggested that the tariff should be discontinued. The removal of the secondary tariff would be harmful to the corn-based ethanol industry and also have a devastating impact on the developing cellulosic ethanol industry in that investors would likely not fund further infrastructure development. It is critical for the cellulosic ethanol industry to have a market opportunity while it is in its earliest development stages. If the United States were to subsidize foreign ethanol, it would significantly diminish the promise of cellulosic ethanol.

The Renewable Fuel Standard (RFS) was part of the Energy Independence and Security Act of 2007 and sets annual requirements for the amount of renewable fuels produced and used in motor vehicles. Under the bill, the RFS required 9 billion gallons of renewable fuels in 2008 and progressively increases to 36 billion gallons by 2022. Further, the bill requires advanced biofuels, such as cellulosic ethanol, to become an increasing portion of renewable fuels: from 3 billion gallons in 2016 to 21 billion gallons in 2022.

The RFS is important to the ethanol industry because ethanol is the only available near-term solution to two of our country's most pressing challenges: energy security and global warming.

Despite the obvious benefits, the RFS is needed to ensure that ethanol has market access. Without the RFS, it is highly unlikely that biofuels would ever be much more than a blending agent because oil companies would rather use their own product.

The RFS also helps to ensure a market for cellulosic ethanol. It calls for two-thirds of renewable fuels to be from advanced biofuels like cellulosic ethanol by 2010. Cellulosic ethanol already has a steep hill to climb to be commercially viable. Without an ensured market, it would be even more difficult.

MEETING A SIGNIFICANT AMOUNT OF DEMAND THROUGH CORN ETHANOL

Corn has been the predominant feedstock for the production of ethanol, and its main advantages are that (i) its abundance and oversupply result in lower costs for food, feed and, fuel products; (ii) starch, which is the major component of the corn kernel, is relatively easy to process; and (iii) the infrastructure for corn distribution is well established.

Seed companies' ability to continually improve corn yields represents the most important factor for corn's long-term viability as an ethanol feedstock. Based on the current corn yield of 150 bushels an acre (bu/acre) and historical trends for corn yield growth, projected corn yields are 180 bu/acre in 2022 and 200 bu/acre in 2030. Monsanto, for example, projects corn yields of 210 to 250 bu/acre by 2022 and 265 to 300 bu/acre by 2030 (Begemann, 2008). Using 300 bu/acre and the current 86.5 million U.S. corn acres, the projected annual corn production level for 2030 would exceed 26 billion bushels—double the 2007 corn production. If corn demand for food and feed in 2030 were to increase by 40 percent from the 2007 level, there would be enough corn to meet this demand *and* increase corn ethanol production by over 425 percent from the 2007 level—to 48.6 billion gallons (assuming a 6.9 percent increase in ethanol-processing efficiency by then).

COMMITMENT TO CELLULOSIC ETHANOL

According to a recent U.S. Department of Commerce International Trade Administration Study, "Energy in 2020: Assessing the Economic Effects of Commercialization of Cellulosic Ethanol" (Osborne, 2007), by 2020 there will be enough cellulosic feedstock available in the United States to produce nearly 50 billion gallons of cellulosic ethanol. At this production rate, over 1.2 million barrels per day of crude oil could be displaced while creating over 54,000 jobs in U.S. agriculture. In more practical terms, at this level of ethanol production the United States could eliminate all oil purchases from the Organization of the Petroleum Exporting Countries (OPEC) and the Middle East—eliminating the daily export of 1.4 billion U.S. dollars to overseas oil producers (based on oil priced at $120 per barrel).

Along with economic benefits, cellulosic ethanol offers significant environmental benefits. Each gallon of gasoline produces 25 pounds of CO_2-equivalent GHG emissions. By comparison, cellulosic ethanol reduces GHG emissions by a little more than 21 pounds of CO_2 per gallon—that's an 85 percent reduction. To monetize that benefit we can assign a value of $20 per ton of CO_2-equivalent GHG emissions based on current European futures prices for CO_2 equivalents. Accordingly, the use of a little more than 20 billion gallons of cellulosic ethanol would reduce the cost of GHG emissions by about 19 cents per gallon, or about $2.5 billion per year. Cellulosic ethanol's value to the U.S. economy, the environment, and national security is substantial. At POET we believe that cellulosic ethanol is real and achievable.

POET's commitment to cellulosic ethanol started eight years ago when our company developed proprietary fractionation and raw starch hydrolysis technologies. Specifically, these technologies allow POET to process corn starch more efficiently and economically. Our proprietary corn fractionation technology, or BFrac as it is referred to in the industry, allows the separation of the corn starch from the corn germ and corn fiber, the cellulosic casing that protects the corn kernel.

Another proprietary process called Broin Project X (BPX) processes the starch without cooking, resulting in (i) an 8 to 12 percent reduction in BTU consumption, (ii) greater conversion of corn starch to ethanol, and (iii) a high-nutrient density animal feed product, which we call Dakota Gold. This technology uses less fossil fuel than previous processes, yields more ethanol per acre of corn, and provides an animal feed product that can replace corn. The corn germ can be processed to produce crude or refined corn oil, which has multiple end uses ranging from cooking to biodiesel. The corn fiber, due to its high sugar content, can be processed to ethanol.

Important points to note about corn ethanol production plants are that they are (i) highly efficient, (ii) actually produce more than just ethanol, and (iii) serve as sources for cellulosic feedstocks.

POET began its efforts to develop cellulosic ethanol technology in 2002 with one of the first biorefinery grants from the DOE. The effort focused on what was termed then a "second-generation dry mill biorefinery," which sought to incorporate corn fractionation into a dry mill ethanol plant, processing the cellulosic corn fiber into ethanol and producing a higher-protein animal feed product. Quite honestly, this effort produced mixed results. POET was able to incorporate a corn fractionation system into a dry mill ethanol plant and to produce a higher-protein animal feed product, but the ability to process corn fiber to ethanol proved more difficult because of limited ability to break down the corn fiber into usable sugars and the lack of known microorganisms to ferment sugar into ethanol.

In 2006 a new strategy for cellulosic ethanol production was developed. The strategy uses existing corn ethanol plants to (i) capitalize on existing infrastructure (utilities, roads, rail lines, materials handling, and so forth); (ii) focus on corn cobs as the primary cellulosic feedstock to use the existing farmer (and often investor) network to collect cobs; and (iii) eliminate the use of fossil fuels by processing waste streams (that is, by-products of the cellulose-to-ethanol process) to generate energy for the entire plant. This "bolt-on" approach is designed to use the expansive ethanol base to enable rapid adoption of the cellulosic ethanol process. POET is implementing this strategy through Project LIBERTY, which is the creation of an integrated corn cellulose biorefinery.

Project LIBERTY will transform the POET biorefinery in Emmetsburg, Iowa, from a conventional corn dry mill ethanol plant into an integrated corn-to-ethanol and cellulose-to-ethanol biorefinery. Once complete the facility will produce 125 million gallons of ethanol per year, 25 of which will come from a feedstock of corn fiber and corn cobs. Also, the facility will produce 80,000 tons of Dakota Gold Corn Germ Dehydrated and 100,000 tons of Dakota Gold HP animal feeds annually. Project LIBERTY will produce 11 percent more ethanol from a bushel of corn through the corn fractionation process and 27 percent more ethanol from an acre of corn through the use of corn cobs. In addition, Project LIBERTY will reduce the biorefinery's need for fossil fuels by nearly 100 percent. The total cost of the project will exceed $200 million. It will create at least 30 new jobs at the facility, but more importantly, Project LIBERTY will demonstrate the profitability of cellulosic ethanol technology on a replicable commercial scale. POET's longer-term plans are to roll out this technology suite to other existing dry mills or new grassroots biorefineries. As partners with POET in Project LIBERTY, the DOE and the Iowa Power Fund will contribute up to 50 percent or $100 million in project costs. Project LIBERTY is expected to be operational in late 2011.

Cellulosic feedstocks can be agricultural residues such as corn cobs, rice straw, or corn stover (leaves, stalks, and cobs left in the fields after harvest). They can also be wood fibers such as forestry wastes or wood wastes or energy crops such as switchgrass or Miscanthus grass. Cellulosic feedstocks could also be collected from municipal waste. POET has selected corn cobs as the first cellulosic feedstock for the production of cellulosic ethanol because they offer significant technical, environmental, and economic advantages. They are typically left in the field as corn stover after the harvest of the corn kernels and are easy to separate because they are heavier than the stalk. They are rich in sugars yet can be removed from the field with little environmental impact because they offer little value as fertilizer. And they can be collected relatively easily by the same farmers who provide the corn grain to the ethanol plant.

Through work with collaborators and in particular the enzyme companies, POET continually improves the cellulosic ethanol process. Recent work at POET resulted in a process to break down corn cobs into simple sugars, resulting in a 60 percent increase in the yield of ethanol from cobs compared with just a few months earlier. With this process, corn-cob feedstocks are more easily digested by enzymes without creating toxic by-products, which results in significant amounts of sugars for fermentation to ethanol.

Significant progress has been made in producing ethanol from simple sugars through the discovery of better microorganisms and a better fermentation process. And, lastly, through POET's cutting-edge process engineering expertise, we have devised a synergistic concept that enables a conventional corn ethanol plant to transition into one that uses only cellulosic feedstock. Although these are important breakthroughs, further process improvements over the next few months are needed to make the process profitable.

ALTERNATIVE ENERGY AND CELLULOSIC ETHANOL

Alternative energy plays an important role in the cellulosic ethanol process. Because of the low nutritional value of cellulosic ethanol waste streams (the by-products of ethanol production), they cannot be used as animal feed products. The most favorable use of these streams is feedstock for solid-fuel boilers or anaerobic digestion.

POET is currently installing a solid-fuel boiler at its biorefinery in Chancellor, South Dakota, which will process up to 500 tons of dried wood chips from a waste pallet processor to produce steam for the plant. This biorefinery has also reached an agreement with the city of Sioux Falls to purchase landfill gas for the boiler. By using wood and landfill gas, 67 percent of the energy needs at the Chancellor plant can be met, decreasing the need for fossil fuels by the same amount.

POET's Project LIBERTY will also incorporate a solid-fuel boiler in its design. The feedstock for the LIBERTY boiler will be solid wastes from the cellulosic ethanol operation and additional corn cobs collected as part of the cellulosic feedstock. When coupled to an anaerobic digestion system to process the liquid wastes from the cellulosic operation, the boiler will supply nearly all of the energy needs for the cellulosic- and starch-based operations.

CRITICAL SUCCESS FACTORS FOR WIDESPREAD USE OF ETHANOL

The continued development and commercialization of cellulosic ethanol underscores the importance of the following[1]:

1. **The Existing Corn-to-Ethanol Business and Infrastructure.** Without a viable corn-to-ethanol industry, cellulosic ethanol will be delayed. The corn-to-ethanol industry can provide an existing network of corn growers; production knowledge; and product, market, and logistics knowledge to emerging cellulosic ethanol producers.
2. **The Renewable Fuel Standard.** The RFS provides an important target for cellulosic ethanol—a real and attainable target. Continued support of the RFS will demonstrate to the ethanol, transportation fuel, and financial industries that there will be a market for ethanol.
3. **Increased Usage of Ethanol and Greater Numbers of Flexible-Fuel Vehicles.** Recent important research (see Appendix B) supports greater concentrations of ethanol to replace gasoline—expanding the use of ethanol beyond its historical role as a fuel oxygenate. So called "mid-level blends" (those greater than E15) of liquid transportation fuels have shown no deleterious impact on vehicles in the current U.S. automotive fleet. These mid-level blends will further reduce our dependence on foreign oil, reduce our fuel costs, and help the environment.
4. **Governmental Support.** Governmental programs are necessary, especially during the

[1] For further study of the ethanol industry, see the resources noted in Appendix A.

early stages of the cellulosic ethanol industry's development, to enable financing at the grower/farmer level and to offer cellulosic ethanol producers incentives, loan guarantees, and market assurances. The maintenance of the VEETC and import tariffs on ethanol remain important so long as ethanol use in the liquid transportation fuels remains low and the purchasing power of oil refiners remains high.

5. **Continued Investment in Research and Development.** Significant cost reductions in the cellulosic ethanol process are required. The cost of enzymes still remains one of the most significant variable costs associated with the process.

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APPENDIX A

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Whitten, Gary. "Air Quality and Ethanol in Gasoline." Presented at the 9th Annual National Ethanol Conference *Policy & Marketing*, February 16-18, 2004; www.oregon.gov/ENERGY/RENEW/Biomass/docs/FORUM/Whitten2004.pdf.

APPENDIX B

Summary of Research Findings on Higher Ethanol Blends

Bonnema, Grant; Guse, Gregory; Senecal, Neil; Gupta, Rahul; Jones, Bruce and Ready, Kirk L. "Use of Mid-Range Ethanol/Gasoline Blends in Unmodified Passenger Cars and Light Duty Trucks." Minnesota Center for Automotive Research, July 1999; www.ethanol.org/pdf/contentmgmt/E30_Final_Report.pdf.

This one-year study evaluated the effects of E10 and E30 in 15 older vehicles in "real world" driving conditions and found that regulated exhaust emissions from both fuels were well below federal standards.

Egebäck, Karl-Erik; Henke, Magnus; Rehnlund, Björn; Wallin, Mats and Westerholm, Roger. "Blending of Ethanol in Gasoline for Spark Ignition Engines: Problem Inventory and Evaporative Measurements." Report No. MTC 5407, AVL MTC Tech Centre, Haninge, Sweden, 2005.

Researchers tested and compared evaporative emissions from E0, E5, E10, and E15 and found lower total hydrocarbon emissions and lower evaporative emissions from E15 than from E10 and E5. Specifically,

(i) no significant difference can be seen in regulated emissions when comparing the use of blended fuel (with up to 10 to 15 percent ethanol) with the use of neat gasoline, and
(ii) due to the gasoline dilution effect of adding ethanol, the emissions of benzene, toluene, ethylbenzene, and xylene blended with ethanol are lower than those from neat gasoline, which offers health and environmental benefits.

Haskew, Harold M.; Liberty, Thomas F. and McClement, Dennis. "Fuel Permeation from Automotive Systems: E0, E6, E10, E20 and E85." CRC Report No. E-65-3, Coordinating Research Council, Inc., December 2006; www.crcao.com/reports/recentstudies2006/E-65-3/CRC%20E-65-3%20Final%20Report.pdf.

Researchers evaluated the effects of E0, E6, E20, and E85 on the evaporative emissions rates from permeation in five newer California vehicles and found there was no statistically significant increase in diurnal permeation rates between E6 and E20.

Knoll, Keith; West, Brian; Clark, Wendy; Graves, Ronald; Orban, John; Przesmitzki, Steve and Theiss, Timothy. "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1." NREL/TP-540-43543; ORNL/TM-2008/117. National Renewable Energy Laboratory of the Oak Ridge National Laboratory for the U.S. Department of Energy, October 2008; http://feerc.ornl.gov/publications/Int_blends_Rpt_1.pdf.

This peer-reviewed study regarding the effects of E15 and E20 on motor vehicles and small nonroad engines concluded that compared with traditional gasoline neither E15 or E20 has significant changes in vehicle tailpipe emissions. The findings include the following:

(i) Regulated tailpipe emissions remained largely unaffected by the ethanol content of the fuel.
(ii) As ethanol content increased, oxides of nitrogen and nonmethane organic gases showed no significant change.
(iii) Nonmethane hydrocarbons and CO_2 emissions dropped slightly on average, although CO_2 did not change appreciably from E10 to E20.

Shockey, Richard E. and Aulich, Ted R. "Optimal Ethanol Blend-Level Investigation, Final Report." Energy and Environmental Research Center and Minnesota Center for Automotive Research for the American Coalition for Ethanol, October 2007; www.ethanol.org/pdf/contentmgmt/ACE_Optimal_Ethanol_Blend_Level_Study_final_12507.pdf.

Researchers studied the effects of ethanol blends ranging from E10 to E85 on motor vehicles and found that exhaust emissions levels for all vehicles at all ethanol blends tested were within the applicable Clean Air Act standards.

Roles for Evolving Markets, Policies, and Technology Improvements in U.S. Corn Ethanol Industry Development

Paul W. Gallagher

This article reviews changes in markets, technologies, and policies that affect corn ethanol profitability and industry expansion. Historically, the corn ethanol industry was stimulated by high petrofuel prices, successful corn and processing technology improvements, and government incentives, such as a blenders' tax credit and mandated markets defined by the leaded fuel ban and reformulated fuel. Presently, the corn ethanol industry has expanded slightly beyond the point of a normal capital return, which is defined by limits on corn resource availability and ethanol marketing infrastructure. A renewable fuel standard, included in a recent energy law, may eventually define minimum consumption levels for ethanol and, implicitly, production levels for corn ethanol. Potentially impending marketing changes, such as voluntary E20 (20 percent ethanol) sales or expanded sales of E85-equipped automobiles, may expand ethanol markets. Potential technology advances include growth of corn yields, corn-processing improvements for lower costs or higher revenue, and development of a corn-stover (leaves and stalks)–based biomass industry. Government policies to induce biomass-fuel capacity investment are economically justified and probably necessary if biofuel industry development remains a public priority. Still, more efficient policy approaches could be developed. (JEL Q11, Q42, Q48)

Federal Reserve Bank of St. Louis *Regional Economic Development*, 2009, *5*(1), pp. 12-33.

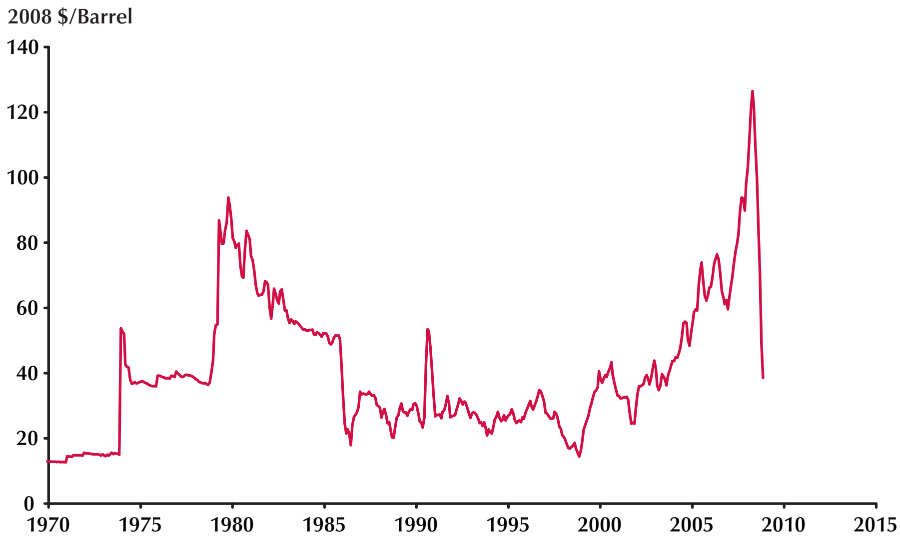
Profit assessments in the ethanol industry must account for market and policy developments in the fuel and corn industries because processors are positioned between both commodity markets. At the beginning of the twentieth century, biofuel-based industries such as ethanol were not feasible because a pound of corn could be sold on the market and exchanged for 5 to 7 pounds of petroleum at prevailing market prices. It made more sense to produce the corn for feed and food, sell it for cash, and buy petroleum to process for energy. The circumstances have since changed and today's scenario is quite different: One pound of corn can be exchanged for only about one pound of petroleum (Gallagher, 2004). A century of declining corn prices and increasing petroleum prices has radically changed society's technology options.

Still, the oil price spike of the late 1970s (Figure 1) is a major event responsible for the birth of the ethanol industry. Ethanol has recently emerged as an equal partner among corn-using industries during the oil price escalation of the early twenty-first century. Technologies that improve input costs or firm and marketing efficiency are equally important in explaining the ethanol industry's birth and expansion because investment in a new processing technology was required. In the ethanol industry, firm strategies have emerged during episodes of narrow profit margins.

Paul W. Gallagher is employed at the department of economics, Iowa State University.

Figure 1

Saudi Petroleum Prices (January 1970–December 2008)



This review of profitability in the ethanol industry considers the combination of developments in corn, fuel markets, and policy that led to the recent ethanol expansion. Also, an estimation of the contribution from past firm efficiency improvements is presented as one important factor contributing to the ethanol industry's development. For the present and intermediate future, overall profit and output growth rates in the industry will likely be moderate because of moderate supply growth for the corn input and widening ethanol price discounts to compete with gasoline. Thus, impending innovations in production and marketing practices are also reviewed for an indication of their profit-improving potential in the current economic environment.

THE MARKETING-GOVERNMENT-TECHNOLOGY MATRIX LEADING TO THE CURRENT U.S. ETHANOL INDUSTRY

Phases of the Ethanol Industry

Three phases of the U.S. corn ethanol industry are discussed: birth, development, and maturity.

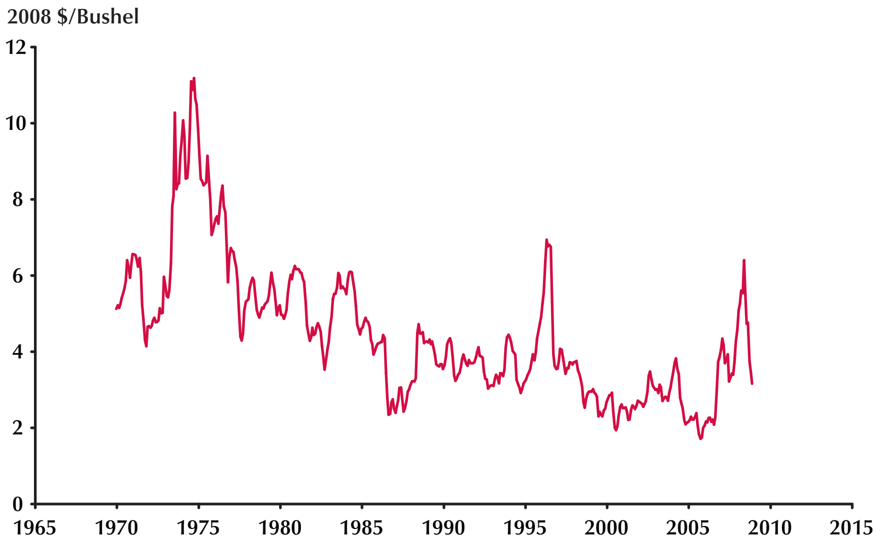
Birth. The right combination of petroleum market and corn market events contributed to the initial profitability and birth of the ethanol-processing industry. In the petroleum market, the Organization of the Petroleum Exporting Countries (OPEC) was still pursuing a high-price strategy as a hangover from the 1970s. Meanwhile, corn prices had declined considerably because the export boom of the mid-1970s had collapsed (Figure 2). A generous consumption subsidy in the form of a blenders' tax credit[1] was still needed to achieve profitability (Gill, 1987). Nonetheless, production in the new ethanol industry had expanded to nearly 0.75 billion gallons by 1989.

Development. OPEC changed its pricing strategy in the mid-1980s (Stauffer, 1994). Then petroleum and fuel prices declined, which resulted in a much narrower profit margin that allowed the ethanol industry to become more competitive.

[1] A mixture (blend) of 10 percent ethanol and 90 percent gasoline is suitable for most automobiles with gasoline engines. Initially, the U.S. government granted a partial exemption to its gasoline excise tax when an ethanol blend was sold because ethanol was typically more expensive than gasoline. The partial exemption is equivalent to an ethanol consumer subsidy (Gallagher, Shapouri, and Price, 2006b).

Figure 2

North Central Iowa Corn Prices (January 1970–December 2008)



Although this period was not profitable for ethanol processing, the groundwork for future ethanol profitability was laid. Three events stand out in this developmental phase.

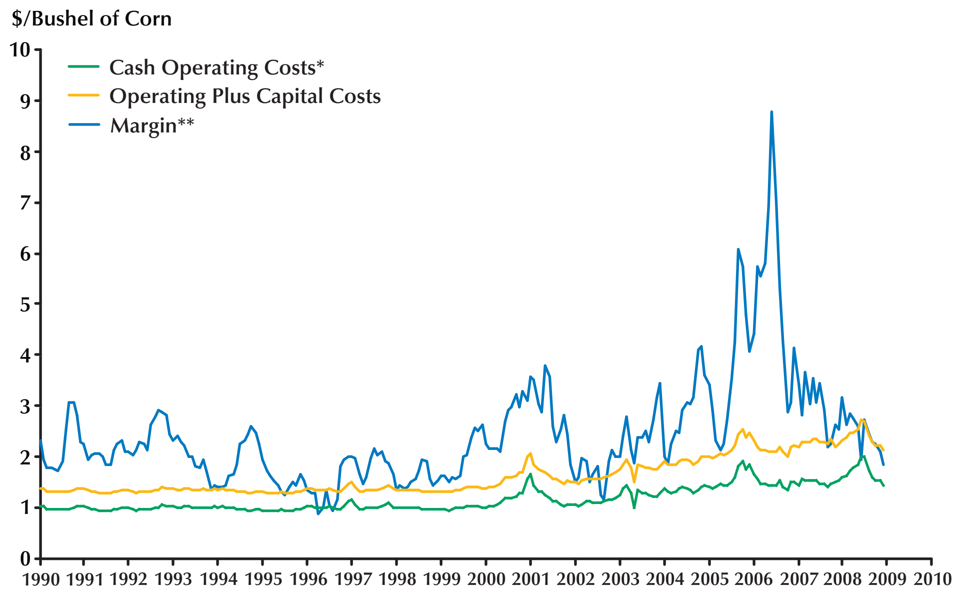
First, the ethanol industry initiated a series of improvements that enhanced profitability with the existing market prices for fuel and corn. For instance, ethanol yields increased 10 percent between 1984 and 2007. The processing yield increase elevated profits by $0.31 per bushel. Further, operating expenses decreased by about 50 percent since the late 1980s—energy efficiency improved, labor needs declined, and the cost of processing enzymes dropped (Gallagher, Shapouri, and Brubaker, 2007); the reduction in operating costs was $0.38/bu. Finally, dry mill processors discovered that they could reduce their average capital costs, or capital costs per unit of capacity, by increasing the size of their plants (Gallagher, Brubaker, and Shapouri, 2005; Gallagher, Shapouri, and Brubaker, 2007). Elsewhere, I have estimated that annual capital costs declined by $0.27/bu by increasing the plant size from 4 million bu/yr to 19 million bu/yr. Together the yield improvements and costs reductions increased the processing margin by $0.96/bu.

Second, since 1980 the corn market has slowly but steadily changed so that ethanol processing is now profitable. Specifically, corn production has grown steadily with yield growth (~224 million bu/yr) while demand growth has remained relatively stable (110 million bu/yr). Export demands have fluctuated from year to year but have exhibited no growth since 1980. Moderate feed demand growth reflected saturation of American diets, limited success of trade negotiations in developed country meat markets, and the shift in livestock feed rations toward more protein (Gallagher, 2000). Since 1980, new corn supplies have gradually pushed corn prices down and pushed marginal corn farmland into other crops. Otherwise stated, the cumulated excess supply growth of corn could supply about 8.0 billion gallons of new ethanol capacity without increasing corn prices. In contrast, ethanol capacity grew by about 1.5 billion gallons by 2000.

Third, ethanol demand and prices got a major boost when a legislated oxygen standard was introduced to reformulated fuel in 1994 as part of the

Figure 3

Corn Ethanol Processing Margin and Costs for Dry Mills with Current Technology (January 1990–December 2008)



NOTE: *Includes electricity, fuel, labor, and chemicals. **Ethanol revenues plus DDG revenues less corn costs.

1990 Clean Air Act (Gallagher et al., 2003). In effect, the oxygen standard required that ethanol or methyl tertiary-butyl ether (MTBE, an additive) be blended in the gasoline "recipes" used for cleaner fuels in major urban areas with smog problems. This requirement increased the ethanol demand and capacity by 0.90 billion gallons (Gallagher, Otto, and Dikeman, 2000).

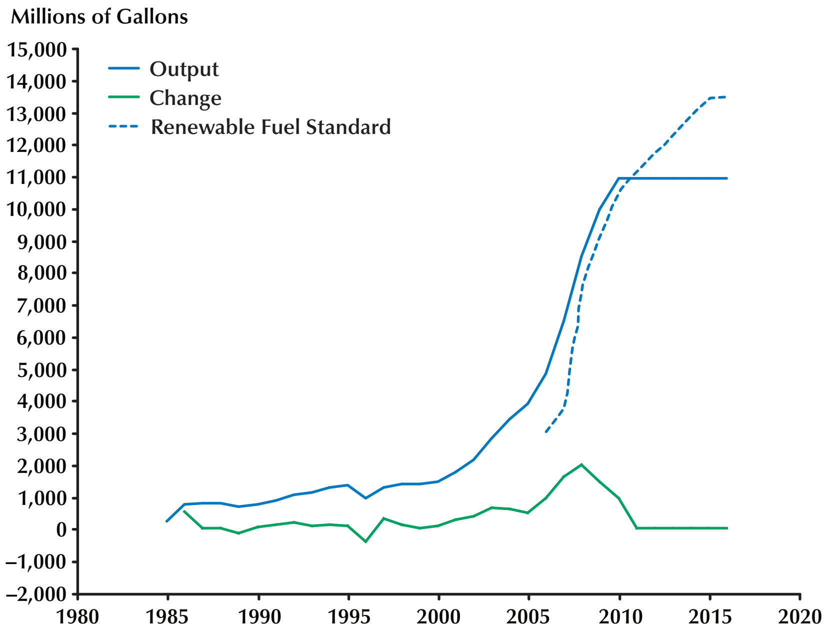
Maturity. Two events in fuel markets triggered the large-scale expansions of the twenty-first century. First, a "de facto" national ban on the use of MTBE, the petroleum industry's chemical for the oxygen standard of reformulated fuel, evolved through a series of public events. The national ban evolved partly because several major states banned MTBE after it was found in groundwater supplies (Gallagher et al., 2000). Then the petroleum industry was unable to obtain a waiver removing their liability for leaking tanks, so the industry decided to phase out MTBE. Ethanol, initially sharing the reformulated fuel market, is still benefiting from a demand boost because of the MTBE phase-out—the increase will add a total of 3.5 billion gallons of ethanol demand when the 1998 level of MTBE production is completely phased out. By 2000, ethanol-processing margins had increased (Figure 3). Further, returns on an equity investment increased to respectable levels (~20 percent). Consequently, ethanol output expanded to annual production levels of about 1 billion gallons.

Second, petroleum prices crossed the threshold of competition where ethanol could compete directly with other additives in the petrochemical industry (Gallagher et al., 2006a). By 2006, processing margins widened, and the return on an equity investment in an ethanol plant reached eye-catching levels—60 percent—using current corn prices and spot market ethanol prices.

A stunning expansion in ethanol output has since occurred; output is about 8.5 billion gallons for the recently completed 2007-08 corn marketing year (Figure 4). Also, the Renewable Fuels

Figure 4

U.S. Ethanol Production (and Changes)



Association (RFA, 2008) reported in October 2008 that ethanol production capacity is 10.26 billion gallons, and the capacity will be 13.66 billion gallons when the processing plants currently financed or under construction are completed.

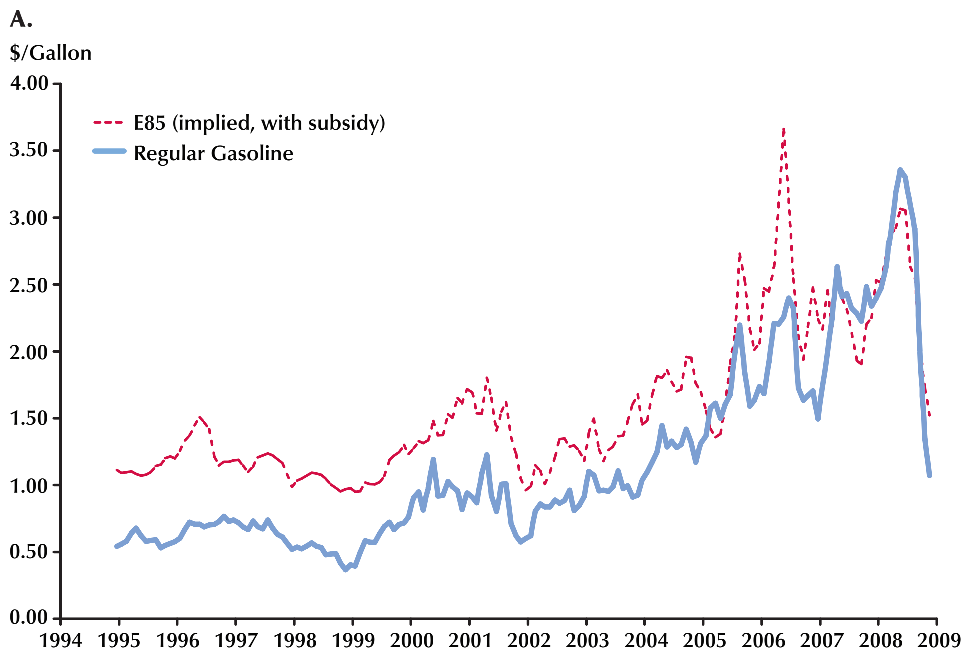
THE ETHANOL INDUSTRY'S CONTRIBUTION TO RESOLVING THE GAP BETWEEN CORN DEMAND AND ETHANOL PRODUCTION CAPACITY

Economic theory suggests that an expanding industry pushes product prices down and input prices up, at least to the extent that product demand and input supply curves are not perfectly elastic. Indeed, wholesale ethanol prices have declined relative to gasoline prices—and even in absolute terms recently (Figure 5). Also, corn prices at the farm level have escalated from typical levels of $2.50/bu a few years ago to $5.00/bu recently. Although several developments are responsible for recent price increases, ethanol expansion was an important cause.

Market equilibrium occurs because declining output prices and increasing input prices squeeze processors' profit margin to the point that the marginal processors' return is exactly offset by their costs. Indeed, the data do suggest an upward-sloping processing supply curve with respect to the processing price (margin): Ethanol price increases (or corn input price decreases) represent upward movements along the processing supply curve (Figure 6 and Appendix A). For instance, the October 2008 average processing margin less operating cost (M_t; see Appendix A) was $0.72/bu after corn prices fell to $3.73/bu, which is $0.02/bu above the point of capital cost return. Accordingly, processing near 80 percent utilization could be expected, keeping ethanol prices at moderate levels. During November and December 2008, the margin was $0.136/bu to $0.293/bu less than the annual capital cost on a new plant investment. Hence, most plants continue to operate, but new capacity

Figure 5

Wholesale Fuel Prices in Iowa (January 1995–December 2008)



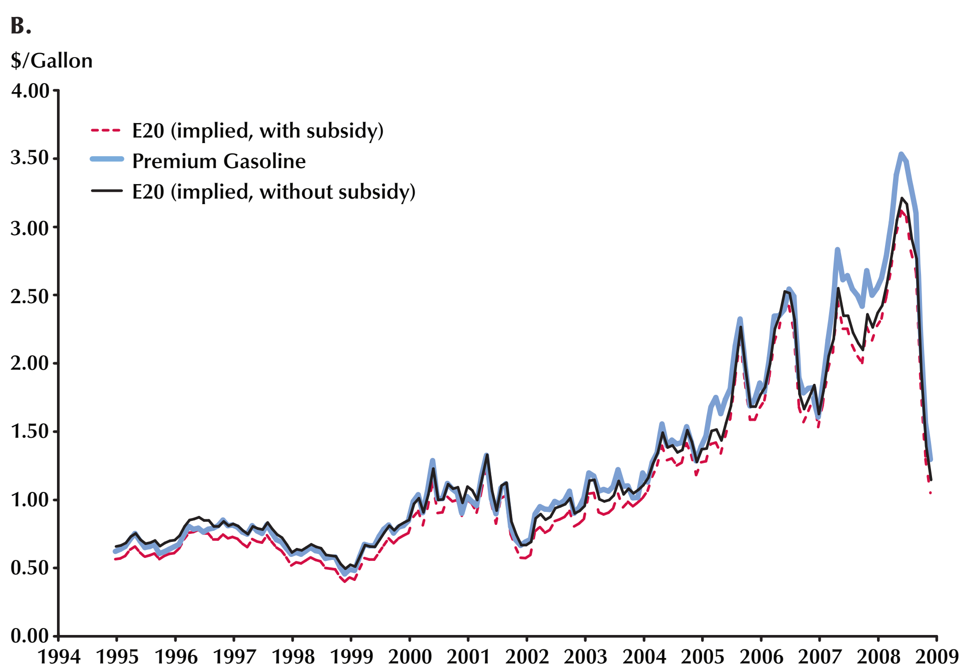
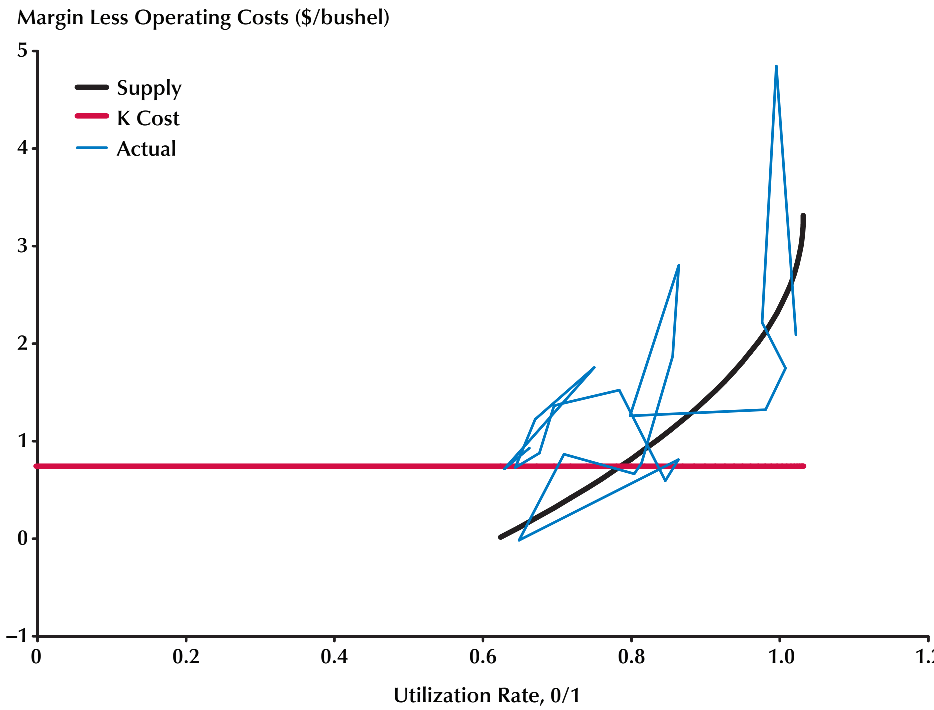


Figure 6

Ethanol Processing Supply, Unit Capital Cost, and Processing Equilibrium



plans were discouraged, as profits were not adequate to repay the annual capital investment cost of $0.70/bu.[2]

Another point to consider in estimating how long it will take to restore a balance between ethanol capacity and corn supply is the balance between corn production growth and ethanol output growth. Some exploratory calculations are given in Table 1. These calculations exploit three assumptions: (i) an 80 percent utilization rate by ethanol processors continues, (ii) planned capacity is brought online at the recent historical rate but no new production plans are developed (see Appendix A and equation (A2) for profitability calculations), and (iii) trend rates of production and feed demand growth continue.

Starting with the recently completed 2007-08 crop year, corn production growth of 2,539 million bushels was very large, partly because an additional 10.0 million acres of corn were planted. However, the actual demand growth for 2007-08 was only 1,636 million bushels, so there was a market surplus of 903 million bushels. For subsequent years, 80 percent of ethanol capacity utilization implies a growth in processor demand of 598 million bushels for 2008-09 and 568 million bushels for 2009-10. The external corn production growth between 2008-09 and 2009-10 (325 million bushels) is calculated as the trend yield growth (2.77 bu/acre/yr) on the existing corn land base plus a small allowance for increasing acreage devoted to corn.

The yearly market surplus for 2007-08 was 903 million bushels, but a deficit in production growth is likely for 2008-09 and 2009-10. Thus, falling inventories could be expected as surpluses and inventories are used to fill the demand of additional ethanol plants. However, the external production growth driven by corn-yield growth will begin to

[2] Editor's note: The author has updated prices for this publication since the presentation of the paper in November 2008.

Table 1

Anticipated, Actual, and External Changes in Corn Demand and Production

Variable	Anticipated changes	Actual changes*	External changes		
			Anticipated	Anticipated	Anticipated
Crop year	07/2008	07/2008	08/2009	09/2010	10/2011
Demand					
Feed	110†	455‡	110	110	110
Exports	0†	300	0	0	0
Ethanol	1,681§	881	598	568	36
Subtotal	1,791	1,636	652	678	340
Production	1,664¶	2,539	325#	325	325
Difference	127	903	–327	–353	179
Cumulation**		903	576	223	402

NOTE: Data assume 80 percent utilization of corn-processing capacity ($2.00/gal ethanol and $5.00/bu corn).

*Office of Chief Economist's Staff, 2008.

†Trend rate of increase 1980-2006.

‡An increase of 176 million bushels can be attributed to meat export expansion.

§Per e-mail from R. Wisner and W. Tierney, December 29, 2006.

¶A trend yield increase of 2.77 bu/acre times an acreage base of 81.3 million acres (planted) in 2006, plus an anticipated planted acreage increase of 10.0 million acres times a trend yield of 145 bu/planted acre.

#A trend yield increase of 2.77 bu/acre times an acreage base of 93.5 million acres (planted) in 2007, plus an anticipated planted acreage increase of 0.46 million acres times a trend yield of 145 bu/planted acre.

**Implied inventory increase and/or price decline when positive.

catch up with the ethanol-induced expansion in corn demand by the 2010-11 crop year. The production growth exceeds demand growth slightly (by 179 million bushels) when ethanol processors are operating at 80 percent of capacity. At that point, increased profit margins pushed by declining corn prices could begin to lift capacity utilization rates of ethanol processors above the 80 percent rate. Overall, the calculations in Table 1 suggest that the net growth of the corn supply will catch up with the planned ethanol capacity in about 3 years.

Clearing Up Some Misconceptions

The 2007-08 corn market year was one of major forecasting mistakes and other market surprises. First, a mood of hysteria prevailed when planting decisions for the 2007-08 crop year were made. To illustrate, recall that some analysts were suggesting a 32 billion gallon corn ethanol industry by 2014 (Elobeid et al., 2006). If such a decade-long expansion occurred at a linear rate, 3.1 billion gallons of additional ethanol (or 1,150 million bushels of corn) would have been required every year for a decade. Another private forecast anticipated an ethanol production increase of 4.5 billion gallons (1,681 million bushels) for the 2007-08 crop year (Tierney and Gidel, 2006). Even the widely watched United States Department of Agriculture (USDA) *Supply and Demand* report estimated ethanol expansion of 3.4 billion gallons (1,250 million bushels), which was 41 percent above the actual expansion (Office of Chief Economist's Staff, 2007, 2008). It is likely that errors occurred in the corn area (acres planted) and inventory allocations for the 2007-08 crop year. Further, corn prices were likely destabilized; the demand overestimate ensured higher prices and increased inventory carryout, but larger carryin and lower prices for the subsequent market year (Hyami and Peterson, 1972).

Second, the actual feed expansion of 455 million bushels was much higher than long-term trend growth (110 million bushels) or early USDA projections would have indicated. Of the actual expansion in feed demand, 175 million bushels can be attributed to the feed needed for an expansion of U.S. meat exports in pork, chicken, and beef. Both the domestic livestock and foreign livestock components of corn feed demand expanded more rapidly than anticipated.

Third, corn export growth had been nonexistent for 20 years, but the 2007-08 crop year saw a 300 million bushel expansion and a record export level. The shift in corn exports can be explained mostly by events and policy decisions in the European Union (EU) and China. The EU had a production shortfall of 257 million bushels between the 2006-07 and 2007-08 crop years. Furthermore, the EU made up almost all of the domestic production shortfall by increasing imports by 234 million bushels. This is a well-known feature of EU policies—entire shortfalls are made up on the world market because domestic prices are insulated from fluctuations in world commodity markets. China had no production shortfall. However, given their rapidly growing population, and perhaps the opportunity for a quick profit by the state trading enterprise, exports from China declined by 184 million bushels. Even though the U.S. corn export increase may have been sold to other countries, the shift in export position by the EU and China can explain most of the increase in U.S. export demand for corn.

The total demand shock that some analysts feared did actually occur: The total demand shift, initially forecast at 1,791 million bushels, was 1,636 million bushels. However, many accounts hold the ethanol industry responsible. The main point is that all three groups—meat exporters, large corn-trading countries, and the ethanol industry—cannot all expand at the same time. The corn market is not large enough, as price behavior in the past year has shown.

Corn inventory increased (by 320 million bushels) during 2007-08. At first glance, an inventory increase is not typical in a tight corn market. But was the inventory higher than a well-functioning competitive market would have delivered? Offsetting factors complicate the answer. For instance, inventory holders with good foresight probably could accumulate some inventories to cover the anticipated bulge in ethanol demand over the next three years or so, but several other factors point to the possibility of excess inventory. Specifically, the extent of the future demand expansion was overestimated, so futures prices were high. Also, corn futures prices are systematically biased upward in comparison with the actual cash prices in subsequent periods (Appendix B), so inventory holdings based on the futures price were likely too high. Finally, there was speculation related to macroeconomic concerns about commodity inflation, which would encourage higher inventories unrelated to events in the commodity market. A quantitative analysis of the offsetting factors could be definitive. In the meantime, circumstances seemed to point toward overaccumulation of corn inventories in the 2007-08 crop year.

Fortunately, corn producers responded with more acreage in corn than many thought possible. And good fortune prevailed with an actual production increase that more than offset the demand expansion. Prices were quite high for the 2007-08 marketing year, but they were still considerably lower than they would have been had a production shortfall occurred on top of a simultaneous expansion in three market segments and excessive inventories.

REORGANIZING THE ETHANOL INDUSTRY FOR THE TWENTY-FIRST CENTURY

Production Changes

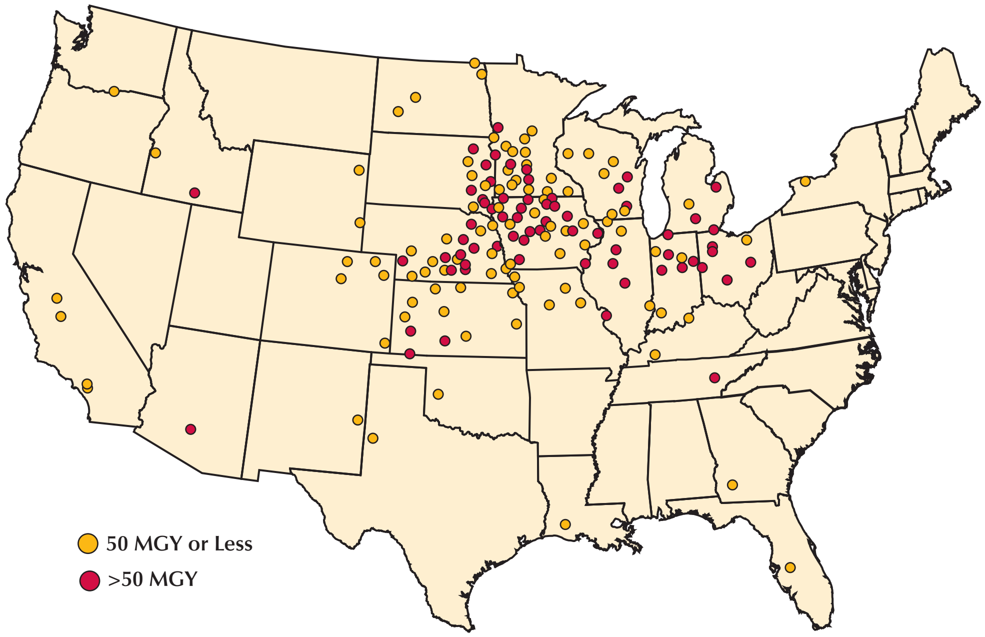
The ethanol industry has changed considerably during its expansion. First, production has become more concentrated in the Midwestern United States (Figure 7). Second, the ownership structure has become less concentrated, which encourages fuel pricing with competitive profit margins. Third, ethanol markets have become more national in scope. Arguably, all of these changes have improved economic performance of the Midwestern economy and provided substitutes for imported fuel.

Location of Production. Most new plants in the rapidly expanding ethanol industry were placed

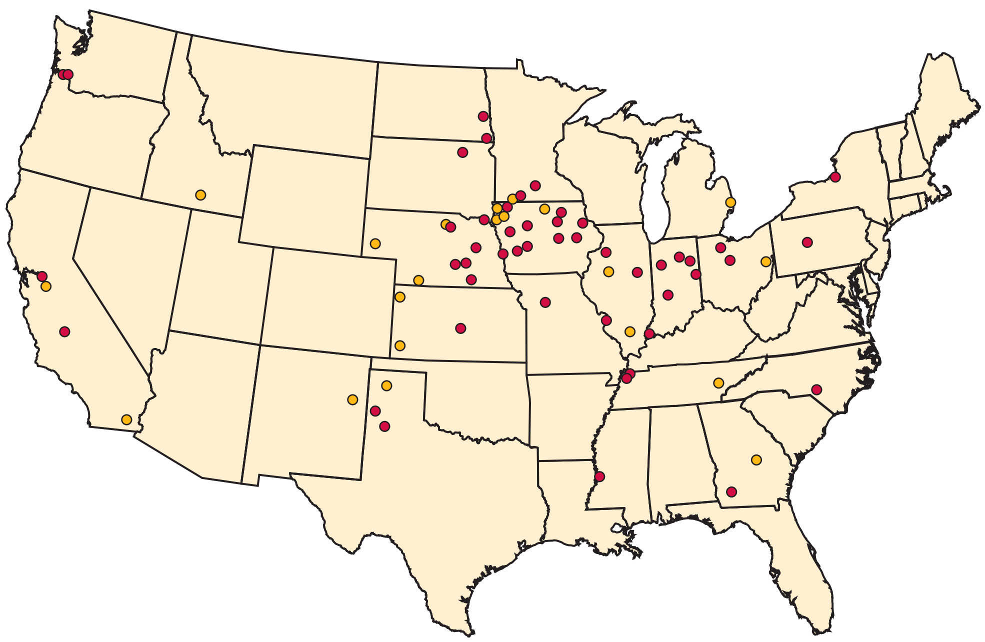
Figure 7

Ethanol Biorefinery Locations

A. Currently Operating Ethanol Biorefinery Locations



B. Pending Ethanol Biorefinery Projects: Construction, Expansions, and Announcements



SOURCE: Renewable Fuels Association and Department of Economics, Iowa State University.

Table 2

Ownership of U.S. Ethanol Capacity in 2000 and 2008

	December 2000		December 30, 2008		
Ownership	Operating (million gallons)	Share (0/1)	Operating (million gallons)	After building (million gallons)	Share (0/1)
Large firms					
Abengoa	0	0	168	344	0.026
Archer Daniels Midland	797	0.397	1,070	1,620	0.122
Hawkeye Renewables	0	—	440	440	—
POET (Broin)	7	0.004	1,467	1537	0.116
VeraSun	0	—	7,80	880	0.066
Subtotal (large firms)	804	0.401	3,925	4,821	0.364
Small firms					
Farmer/local	529	0.264	1,698	1,898	0.143
External	681	0.339	5,216	6,516	0.493
Subtotal (small firms)	1,210	0.603	6,914	8,414	0.636
Total—United States	2,007	1.000	10,839	13,235	1.000

in the Midwest, where corn input supplies are ample and cheap. Specifically, 65 percent of ethanol plants are now located in seven Midwestern states (Iowa, Illinois, Indiana, Minnesota, Missouri, Nebraska, and South Dakota).

The production expansion has provided a larger economic base for the rural Midwest. The direct effects of ethanol expansion include wages at the processing plant, farm income derived from additional corn sales, and expanded local transportation. Secondary effects include multiplier effects in retail and service sectors. Local economy benefits of about $0.20/gallon and reduced fuel consumption expenditures offset the cost of ethanol subsidies (Gallagher, Otto, and Dikeman, 2000).

Some ethanol plants are now near product markets. Locations in Texas, Oregon, and Washington are near ethanol markets and by-product distillers' grains (DG) feed markets. Here, the higher corn costs are offset by the DG drying costs avoided by local feed markets. Also, ethanol transport costs are avoided for refiners with blending requirements from the renewable fuels standard (RFS). Five percent of the ethanol plants in the United States are in Texas, Oregon, California, and Washington.

Ownership Structure. The ethanol industry that has emerged from the rapid expansion has a less concentrated ownership structure. Three equally large firms combined now control about 40 percent of the market, and each has about 12 percent of the market. In contrast, one firm alone controlled 40 percent of the market in 2000 (Table 2). The remaining smaller firms represented about 60 percent of the market in both periods. However, the share of locally owned firms (i.e., firms owned by residents or farmers in the local community where the plant is located) today is 12 percent—down from 26 percent before the expansion in 2000. Externally owned firms now (as of 2008) supply about 47 percent of the capacity, a heightened presence in the industry. Dispersed firms and diverse ownership encourages competition in the ethanol market.

Ethanol Markets. Distinguishing between additive and commodity fuel markets for ethanol is useful in understanding episodes of ethanol premiums or discounts relative to gasoline. In the additive market, blending restrictions on scarce quality attributes (e.g., octane and/or oxygen) can create market premiums for ethanol over commodity gasoline (Gallagher et al., 2003). In the commodity fuel market, because high ethanol concentration reduces fuel economy, the market discounts ethanol relative to gasoline (Gallagher, 2007).

Historically, ethanol sold at premiums over gasoline during the replacement of MTBE. More recently, ethanol premiums have turned to discounts relative to gasoline as marketed ethanol volume surpassed the MTBE replacement threshold. Initially, larger sales volumes had to deal with transportation bottlenecks. More recently, ethanol discounts relative to gasoline have stemmed from lower-valued uses in E10 and E85 (see Figure 5).

In the coastal urban areas of the United States, federal regulations were probably responsible for oxygen-based ethanol premiums. For instance, reformulated fuel has an oxygen content standard that is satisfied by a 5.5 percent ethanol blend in Environmental Protection Agency (EPA)–designated markets. For instance, the major population centers in New York, California, and Texas are required to follow the restrictions of reformulated fuel. Even though the oxygen standard was repealed in the Energy Policy Act of 2005, ethanol demand remained high (2.0 billion gallons) in these major population centers during 2006.

Much of the ethanol is voluntarily blended in the Midwest (with subsidy).[3] It has been blended at 10 percent concentration (E10) for 20 years because EPA regulations assume that 10 percent is the maximum level that is compatible with conventional gasoline engines and ignition systems (EPA, 1995). More recent blends of ethanol (up to 85 percent ethanol concentration [E85]) can be used in gasoline engines with modified fuel and ignition systems. Both products are available at retail gasoline outlets around the Midwest. Six million flexible-fuel vehicles (FFVs, which are E85-compatible) are currently in use in the United States. These FFVs could consume up to 6.0 billion gallons of ethanol if fully fueled by E85 blends (based on 15,000 miles driven per car/yr and an average of 15 mpg). Since 2005 and through 2010, blenders of E10 and E85 receive a blenders' credit on the U.S. gasoline excise tax equal to $0.51/gallon of ethanol used (RFA, 2009).

During the past two years, ethanol price discounts against gasoline have been common (see Figure 5A). Further, the discounts have tended to widen as the volume of ethanol marketed has increased. In fact, my estimate of the ethanol price elasticity (E) of demand with a fixed gasoline price is $E = 1.0^4$ (see Appendix A, Ethanol Price Discounts). The implication is that revenues tend to remain about constant with increased marketed volume. Reasons for this price discounting include the fact that the requirements of the octane deficit and the E10 market in some Midwestern states have been surpassed. Also, the marketing and consumption infrastructure for using higher ethanol concentrations (gas stations and FFVs) is limited. Marketing practices and government policy are likely to evolve with the combination of price discounting and expanding supplies.

The recent situation was useful because wide price discounts encourage construction of E85 retail outlets. In addition, a subsidy encourages construction of E85 retail fueling stations.[4] But accelerated adoption of FFV technology by consumers will occur only with sustained consumer incentives, such as E85 retailing margins that more closely reflect gasoline retailing margins or a consumers' income tax credit for using ethanol instead of a blenders' tax credit. Rapid adoption of FFV technology given the market conditions of December 2008 is unlikely—Iowa's wholesale price for regular gasoline of $1.06/gallon was slightly higher than the implied wholesale E85 price, but only after the $0.51/gallon is subtracted from the weighted ethanol-gasoline price of $1.51/gallon.

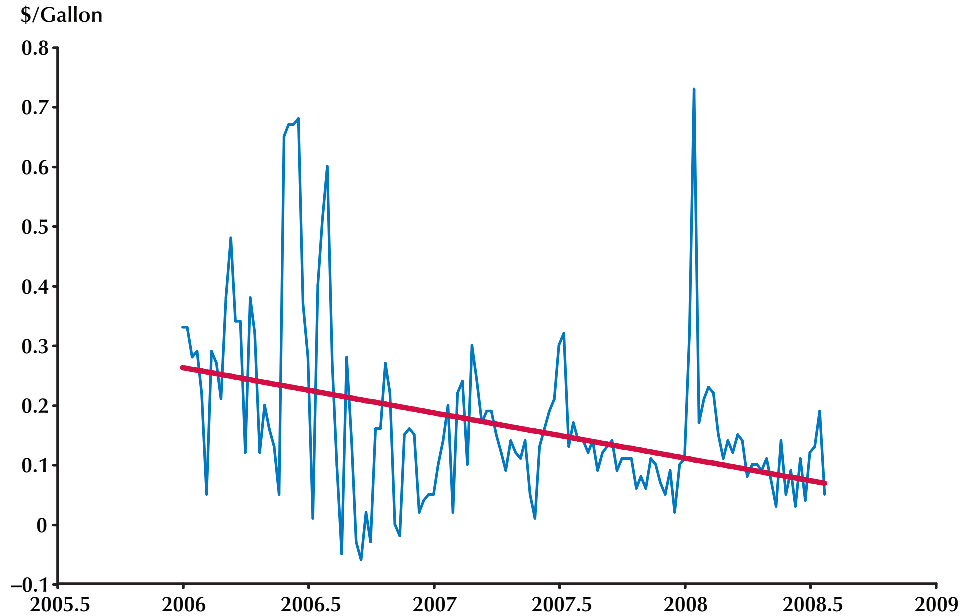
Another alternative is voluntary or mandated use of E20 (20 percent ethanol blend in gasoline) in non-FFV vehicles. A drivability study suggests that E20 could be used in conventional automobiles without mechanical problems (Kittleson, Tan, and Zarling, 2007). A preliminary emissions test of E20 in 13 late-model (2002 and 2007) vehicles found that (i) there were no statistically significant increases in EPA-regulated auto emissions and some of the regulated emissions actually decreased and (ii) the catalytic converter was consistently cooler for all vehicles, except for a subset of lean-running vehicles during a wide-open-throttle hill-climbing

[3] At moderate and high gasoline prices, ethanol is competitive without the subsidy; but at low gasoline prices, an ethanol subsidy is required to maintain competitiveness (Gallagher et al., 2006a).

[4] A 30 percent income tax credit up to $30,000 is available until 2010 to businesses that install clean-fuel (including E85) vehicle-refueling equipment (RFA, 2009).

Figure 8

Spot Ethanol Price Difference: Texas Less Iowa



experiment (West et al., 2008). Incidental fuel economy calculations from these two studies are mixed; however, a test of late-model vehicles suggests that fuel economy holds up with E20 (Shockey et al., 2007). The E20 blend remains a competitive substitute for premium gasoline with the market conditions of December 2008—Iowa's wholesale price for premium gasoline was $1.29/gallon and corresponding E20 prices were $1.14/gallon without the subsidy and $1.06/gallon with the subsidy (see Figure 5b).

Marketing policies that encourage E20 or E85 use may reduce ethanol price discounting against gasoline by encouraging ethanol-for-gasoline substitution and expanding ethanol demand. However, additional testing to determine vehicle classes and locations that are suitable for E20 is still needed.

The Renewable Fuels Standard. Impending consumption mandates are a second avenue that could boost future ethanol price and demand. Since 2004, an RFS potentially mandates minimum consumption levels for renewable fuels. A minimum level for corn ethanol consumption is also implied but has not yet bound the minimum level of corn ethanol demand (EPA, 2008; *Federal Register*, 2008; Christian, 2008). Similarly, minimum corn ethanol demand from an RFS is not likely to bind supply for the next few years, according to my calculations based on the 2008 policy rule (Table A1). The existing RFS minimum consumption levels for renewable fuels will likely not constrain the ethanol supply until after 2011 (see Figure 4). If the corn supply continues to grow, however, margins would improve and increase capacity utilization rates toward 100 percent.

The RFS seems to function as a government "investment signal" that defines a potential minimum market size in the future. Indeed, as noted in Table A1, by 2016 the corn ethanol required for the RFS (13.5 billion gallons) almost exactly matches the "after building" capacity shown at the bottom of Table 2 (13.2 billion gallons). Hence, the RFS has been a second-best investment policy that signals potential government support of ethanol prices and offsets some of the risk associated with biofuels investment. The risk justification for the RFS fits to the extent that there are no well-functioning futures markets for forward pricing.

Presently, the RFS also influences the spatial pattern of ethanol use and prices. Refiners now have a renewable volume obligation (RVO) to (i) prove their own ethanol blending at the refinery (refiners can fulfill their RVO through the purchase of ethanol with renewable inventory number [RIN] certificates) or (ii) prove another blender's use of ethanol through the purchase of that blender's RIN number (RFA, 2008; EPA, 2007).

A look at recent spot market price spreads between Texas and Iowa shows how prices may have been influenced by policies and rapid expansion of ethanol consumption. Initially, margins were wide, but recent margins are about equal to ethanol transportation costs from Iowa to the Texas Gulf Coast, about $0.05/gallon (Figure 8). Finally, the recent market value of RIN certificates was also about $0.05/gallon. Apparently, arbitrage has forced equality between the cost of transporting ethanol with an RIN number to a coastal refinery and the market purchase price of an RIN certificate.

Table 3

Ethanol-Processing Firms: Proposed Strategies for Increased Profits

Strategies	Cost reduction or net revenue increase ($/gal)
Cost-reducing technology	
High-starch corn	0.130*
Biomass power	0.191†
Revenue-increasing technology	
Dry fractionization	—
Quick germ process	0.039‡
Fiber extraction	—
Business reorganization	
Improved diversification	0.072§
Local producer/processor	0.042¶

SOURCE: *Gallagher, Schamel, Shapouri, et al. (2006a, p. 125).
†Gallagher, Schamel, Shapouri, et al. (2006a, p. 127).
‡Taylor et al. (2001).
§Gallagher, Shapouri, and Brubaker (2007, p. 76).
¶Gallagher, Shapouri, and Brubaker (2007, p. 75).

FIRM-LEVEL STRATEGIES TO REDUCE PROCESSING COSTS OR INCREASE REVENUES

Today's narrow margins have induced the development of new technologies and new firm organizations. Seven approaches are listed in Table 3. Together, these modifications have the potential to reduce ethanol production costs by at least $0.50/gallon. However, some of these cost reductions merely offset recent cost increases that have occurred elsewhere. Further, individual firms may use only some and not all of the new technologies.

Early adoption of high-starch corn varieties for ethanol processing is likely because no capital outlay is required. Typically, high-starch corn will increase the ethanol yield and revenues but decrease by-product (DG) yield and revenues. On balance, the ethanol yield gain from a starch increase offsets the DG loss.

Most new technologies require capital expenditure to retrofit the plant. For instance, biomass power requires the installation of a boiler or gasifier in the ethanol plant instead of gas turbines and market purchases of electricity—a choice that could increase ethanol-plant costs by 50 percent. However, the long-term benefit—replacing more expensive natural gas—could reduce processing costs by as much as $0.19/gallon.

Another capital-using, but potentially profitable, set of technology options separates elements from the DG by-product stream. The dry fractionation process for a dry mill, which separates bran, grits, and germ in the initial grinding phase, requires additional capital investment, but additional revenues are obtained by producing ethanol from the fiber and a food-grade corn oil from the germ. There are also other processes that extract oil from the DG stream with a smaller capital investment (Taylor et al., 2001). Reduced fiber and oil content in DG is more palatable to livestock and can be fed at a higher (feed per animal) rate.

Retrofitting an ethanol plant to produce butanol is also a possibility. Weighed against the cost of conversion, the benefits would be the increased price for butanol. Butanol is an attractive blending agent to some gasoline processors because its lower vapor pressure allows more butane use in the fuel.

Modifying the business organization also has profit-increasing potential. For instance, the interest rate charged to an ethanol enterprise in a well-diversified portfolio should be about 3 percentage points lower than a stand-alone ethanol enterprise because the risk premium is lower. In turn, the reduced interest cost would translate to a $0.07/gallon reduction in annual capital costs for the premium.

Finally, a producer-owned enterprise with a combination of firm and cooperative practices could increase the overall farm/processor return in the local production area by about $0.015/gallon. The increase occurs because the input market area of the processor can be extended beyond the boundary of the traditional competitive firm for higher joint profits.

SUMMARY AND CONCLUSION

In the broadest sense, the ethanol industry owes its existence to increasing petroleum prices and a highly successful corn technology industry that sustained corn yield growth in a stagnant market for two decades. The industry has been supported along the way by a complete array of government policies: Consumption subsidies, import duties, and minimum consumption requirements have all supported the demand for ethanol during the industry development phase.

During the past few years, the ethanol-processing industry overexpanded somewhat. First, ethanol sales are large in relation to existing marketing infrastructure and ethanol-using technology. Second, the ethanol-processing expansion is somewhat larger than the corn input market that can be sustained without large-scale displacement of competing uses of corn. Signs already indicate that new capacity plans for ethanol will not be brought to the market for a while. Instead, existing capacity plans will likely be completed. Also, existing plants will likely operate below capacity for a few more years before the balance between ethanol capacity and corn supply is restored.

For the near future, a shift from mandated regional use defined by the RFS and toward voluntary marketing of E85 and E20 in the Midwest may improve ethanol sector profits and economic efficiency generally. Consumer use of E20 is expected to grow because currently the price of this premium-grade fuel is lower than comparable gasoline, even with recent low gasoline prices. However, EPA regulations that limit ethanol blending to 10 percent in conventional automotives must first be relaxed. In preliminary testing, E20 drivability and emissions results are encouraging, but further evaluation is needed to precisely define the automobiles and locations compatible with E20 use.

Improved production management that squeezes more profits from the existing capacity warrants closer scrutiny in the near future. Given the success of past innovations, the early adopters of new technologies are expected to thrive. Innovations by processors will reduce the margin between corn ethanol and gasoline markets, which in turn, will reduce fuel prices and improve consumer welfare and increase corn prices and improve farm incomes.

The longer-run prospects for corn ethanol expansion will be defined by technologies, market events, and policy choices. For instance, more rapid ethanol growth would be possible with accelerated corn yield growth. But eventually, profitability would still be restored if petro-fuel markets remained above recent thresholds of ethanol competition and corn yields grew at historical rates.

On the other hand, corn ethanol expansion may hinge on some complex policy choices in the corn market. For instance, whether the United States should continue to accommodate the destabilizing behavior of our large trading partners is debatable. Similarly, a prolonged meat export expansion, if it should occur, could carry some adverse consequences. To wit, our land may be approaching its manure-carrying capacity after decades of already expanding meat exports. Also, the expansion of meat exports would likely reduce the carbon dioxide balance and future policies may begin to limit carbon emissions. In contrast, an expanding ethanol industry could improve the carbon balance. A balance of payments gain from petroleum import substitution is also likely.

The development of stover-to-ethanol technology would benefit society in several ways. Use of the sustainable portion of the stover supplies would increase ethanol production in the Corn Belt states by 12 billion gallons and, in turn, increase the U.S. fuel supply by 4 percent of petroleum production and reduce U.S. petroleum prices by 6 percent, yielding a net annual welfare gain to the U.S. economy of $3.2 billion (Gallagher and Johnson, 1999). Importantly, feed/food and fuel production could become complementary instead of potentially competitive because corn and stover are joint products (National Research Council, 2000).

If left to market forces, the rate and scale of the development of biomass ethanol processing (such as stover-to-ethanol) could be impeded, which underscores the need for government involvement. First, industrial policy could prevent the duplication of investment and dilution of returns under competition and therefore improve the public good by encouraging development of new processing technology at a lower cost (Krugman, 1983). But later, new patents could define monopoly power for technology owners and retard adoption. Second, increased biofuel development/usage would have positive externalities for the environment; for instance, corn ethanol contributes to improvements in greenhouse emissions (Gallagher and Shapouri, 2009). Also, ethanol has contributed to urban air quality improvements (Gallagher et al., 2008). Third, private sector evaluations of the fuel markets do not fully account for the potential of biofuels to stem the macroeconomic instability imposed by petroleum markets and OPEC market power (Gallagher and Johnson, 1999). Fourth, government involvement may lessen the fear of the substantial risks in biofuel processing in the volatile fuel and agricultural markets, thus encouraging innovations. Fifth, new fuel-processing investments directed solely by oil sector profits would deliver the highest profits for petroleum resources—and perhaps for the world economy—but U.S. interests would not necessarily also be served.

The United States now pursues two policies that promote the development of biomass-processing capacity. First, the RFS defines minimum levels of biomass-fuel production for the next 15 years (RFA, 2007). Second, government subsidies for the construction of a few biomass-processing facilities have been provided (U.S. Department of Energy, 2007). Generally speaking, capital subsidies may make more economic sense than market mandates because (i) the full extent of the public commitment is defined up front with a capital subsidy and (ii) the annual revision of minimum production levels in a political process under the RFS is discarded in favor of a market-based determination of fuel production. A shift toward the capital subsidy, and away from the production mandate, would likely improve economic efficiency.

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APPENDIX A

Processing Supply Estimate

A statistical estimate of the processing supply function is denoted as follows:

$$U_t = \underset{(12.6)}{0.6262} + \underset{(3.5)}{0.2505}\ M_t - \underset{(2.3)}{0.3841}\ M_t^2.$$

$R^2 = 0.50$

root mean square error = 0.099

The numbers in parentheses below the coefficients are t-values.

Variable Definitions

U_t = utilization rate = Qe_t/S_t

Qe_t = ethanol production (billions of gallons)

S_t = ethanol production (billions of gallons)

M_t = margin less operating costs ($/bu of corn processed)

$$M_t = Pe_t\ Ye_t + Pdg_t\ Yd_t - Pc_t - Cop_t$$

Pe_t = ethanol price in Iowa ($/gallon)

Ye_t = ethanol yield (2.7 gallons/bu corn)

Pdg = DG price ($/lb)

Yd_t = Dg yield (1.75 lb/bu)

Pc_t = Corn price ($/bu)

Cop_t = operating (non-corn) costs ($/bu)

Capacity Adjustment

The estimate of ethanol capacity investment suggests that capacity responds to profits. ΔS_t, the rate of capacity increase, will slow and eventually cease when zero profits are sustained.

The estimate is

$$\Delta s_t = \underset{(2.9)}{0.0433\pi_t} + \underset{(5.1)}{0.697\Delta s_{t-1}}$$

$$R^2 = 0.77 \quad Root\ \ MSE = 0.070.$$

Historical Period (Annual Data): 1987-2008

Variable Definitions

$\Delta s_t = s_t - s_{t-1}$, and $s_t = \ln(S_t)$

$\pi_t = M_t - k_t$

k_t = unit capital cost ($/bu corn processed)

The constant, which suggests a steady rate of capacity increase when profits are zero, was not statistically significant in preliminary regressions, so it was discarded.

To see how capacity might adjust after 2008, notice that

$$S_t/S_{t-1} = e^{0.043\pi}(S_{t-1}/S_{t-2})^{0.697}.$$

Next, notice that S_{08}/S_{07} = 1.36, and suppose that $\pi_t = 0$ is sustained for several years. Then (1 plus) the percentage increase in capacity for the next 5 years would be

2009: $1.36^{0.697} = 1.24$,

2010: $1.24^{0.697} = 1.16$,

2011: $1.16^{0.697} = 1.11$,

2012: $1.11^{0.697} = 1.07$, and

2013: $1.07^{0.697} = 1.05$.

Thus, the rate of capacity increase would be only 5 percent after the 2012 crop year.

Suppose prices fall to variable costs ($\pi_t = -0.7$). Then (1 plus) the percentage increase in capacity for the next 5 years would be expressed as follows:

2009: $0.97 \times 1.36^{0.697} = 1.21$,

2010: $0.97 \times 1.21^{0.697} = 1.11$,

2011: $0.97 \times 1.11^{0.697} = 1.04$,

2012: $0.97 \times 1.00^{0.697} = 1.00$, and

2013: $0.97 \times 1.07^{0.697} = 0.97$.

Thus, capacity decreases by 3 percent after the 2012 crop year.

Ethanol Price Discounts

In a market with well-informed consumers and uniform blending of ethanol into gasoline, the percentage price discount of ethanol compared with gasoline is positively related to the ethanol blending rate (Gallagher, 2007). Statistically, the ethanol price discount can be explained by ethanol's share of the gasoline marketing volume:

$$\begin{aligned} d_t &= -0.589 + 12.96 X_t \\ &\quad\;(30.7) \quad (16.57) \\ R^2 &= 0.95 \quad Root\ MSE = 0.15. \end{aligned}$$

Historical Period (Monthly Data): 2000-08

Variable Definitions

$d_t = (Pg_t - Pe_t)/Pg_t^r$, where

Pg_t = wholesale price for regular gasoline in Iowa (\$/gallon)

Pg_t^r = retail price for regular gasoline in Iowa (\$/gallon)

$X_t = De_t/Dg_t$

De_t = ethanol demand in period t (billions of gallons)

Dg_t = gasoline demand in period t (billions of gallons)

In general, the price elasticity of ethanol demand from the price-discount estimate is

$$E_{Qe.Pe} = -\frac{1}{12.96}\frac{Pe}{Pg^r}\frac{1}{X}.$$

Using data from October 2008 yields the following:

$$E_{Qe.Pe} = (-0.0769)(0.75)/(1/0.0646),\ or\ E_{Qe.Pe} = 0.893.$$

Table A1

RFS for Renewable Biofuel and Its Components

Year	Renewable biofuel*	Biodiesel credit	Ethanol imports†	Corn ethanol production	Soy oil for biodiesel (bil lb)	Biodiesel production (bil gal)‡	Biodiesel RFS credit§	Actual anticipated corn production
2006	4.00	0.73	0.19	3.09	3.10	0.43	0.73	4.86
2007	4.70	0.73	0.22	3.75	3.10	0.43	0.73	6.49
2008	9.00	0.73	0.47	7.80	3.10	0.43	0.73	8.49
2009	10.50	0.73	0.55	9.22	3.10	0.43	0.73	9.97
2010	12.00	0.73	0.64	10.63	3.10	0.43	0.73	10.93
2011	12.60	0.73	0.67	11.20	3.10	0.43	0.73	10.93
2012	13.20	0.73	0.71	11.76	3.10	0.43	0.73	
2013	13.80	0.73	0.74	12.33	3.10	0.43	0.73	
2014	14.40	0.73	0.77	12.90	3.10	0.43	0.73	
2015	15.00	0.73	0.81	13.46	3.10	0.43	0.73	
2016	15.00	0.73	0.81	13.46	3.10	0.43	0.73	

NOTE: All production data listed in billions of gallons unless otherwise stated.

*Defined by Energy Independence and Security Act (2007).

†Six percent of corn ethanol production.

‡0.43 bu/gal biodiesel = 3.10 billion lb soy oil × (0.985 lb biodiesel/1 lb soy oil) × (1 gal biodiesel/7.114 lb biodiesel).

§1.7 × biodiesel production.

APPENDIX B

In a widely used test of future market performance, Tomek and Gray (1970) proposed a regression comparison of actual post-harvest cash prices and the futures price quotation in the planting period for delivery in the post-harvest period. To update, we used the following regression:

$$Pc_{t+1} = \alpha + \beta Pf_t^{t+1} + \varepsilon_t,$$

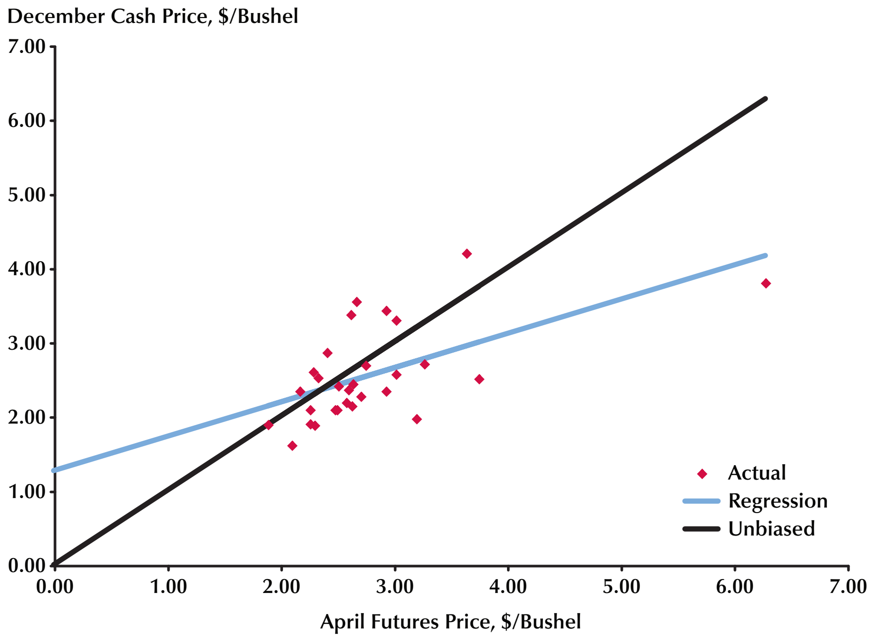
where Pc_{t+1} is the actual corn cash price (December futures price) on December 11 (November 18 for 2008) of the following crop year, Pf_t^{t+1} is the April 30 corn futures price for delivery in the following December, and ε_t is a random disturbance term.

The idea is that the parameters take on particular values when the futures market is performing adequately. Specifically, $\alpha = 0$ and $\beta = 1$ when futures prices are an unbiased forecast of the upcoming market price.

The significance of this result is that economic agents who use the futures price as an expected price can shed the risk associated with production or inventory holding under uncertainty (Holthausen, 1979). Further, the producer who sees future output on future markets will, on average, produce the same output or hold the same inventory as a risk-neutral agent.

Figure B1

Corn Futures Prices, Cash Prices, and Cash Price Predictions



We estimated the following price relationship for the 1980-81 to 2007-08 period:

$$Pc_{t+1} = 1.269 + 0.462 Pf_t^{t+1}$$
$$(3.6) \qquad (3.8)$$

$$R^2 = 0.32 \quad DW = 2.01 \quad s = 0.52.$$

t-Tests reject the unbiased futures price hypothesis. The statistic is $t_\alpha = 3.0$ under the null hypothesis that $\alpha = 0$. Similarly, the test statistic is $t_\beta = 4.37$ under the null hypothesis that $\beta = 1$.

The upshot is that the springtime futures price tends to be above the actual cash price, especially when futures prices are above their mean for the historical period (Figure B1), so corn producers can increase their average returns by forward pricing in the futures market. In contrast, corn users such as ethanol plants will reduce their average returns by forward pricing in the futures market.

Oddly, the variability in the springtime futures price is higher (SD = $0.80/bu) than the variability of the December cash price (SD = $0.63/bu). Hence, routine hedging by producers or consumers would tend to be more risky than unhedged sales or purchases on the cash market.

For comparison, Tomek and Gray (1970) found that the corn futures market performed well over the 1952-68 period. That is, estimated values approximately verified the unbiased forecast result with $\alpha = 0$ and $\beta = 1$. Furthermore, the SD of the cash price exceeded the SD of the futures price, so using the futures reduced price variability.

Overall, results suggest that the corn futures market performed better in the 1952-68 period. For reasons to explain the difference, notice that trading was limited to futures contracts in the early period and speculators focused mainly on upcoming corn market conditions. In contrast, options and derivatives trading was prevalent over the past two decades. Further, speculation on the macroeconomic inflation rates in commodity markets has become commonplace in recent years.

Commentary

Martha A. Schlicher

If we could create the perfect fuel, what would that be? It would be a fuel that would burn clean, improving the quality of our air. It would be a fuel that comes from many diverse, renewable resources so that we wouldn't be dependent on any one source and sources would never be depleted. It would be a fuel derived from readily available resources that have alternative uses, meaning that a raw supply infrastructure is already in place—and ideally, from which multiple products, in addition to fuel, could be made. It would be a fuel that would be miscible with current fuels, which would allow for its ready and economical use in existing vehicles and with the existing fuel-delivery infrastructure.

Time is not an ally and so our perfect fuel would be able to be produced immediately, bypassing Nobel Prize–winning science, unresolved technology issues, and uncertainty. Our fuel would be produced close to where it would be used, on a small enough scale that barriers to entry would be minimized, fuel costs to transport the product would be low, and the risk of centralized supplies or production to our national security would be lessened. It would be a fuel that would run as efficiently, or even more efficiently, than gasoline does today with little or no vehicle modifications. And finally, it would be a fuel that would readily break down in soil or water, which would dramatically reduce the environmental consequence of an accidental spill.

Does such a unique combination of attributes exist? Or is the list of desired criteria too lofty to ever achieve and thus sentences us to a future of gasoline and its negative consequences?

Astonishingly, a fuel that meets all of these criteria exists today. Ethanol from corn will provide U.S. vehicles more than 10 billion gallons of their fuel consumption in 2009. In the next several years, ethanol from a multitude of other feedstocks (such as garbage, wood chips, and unused plant material) could greatly increase our domestic renewable fuel production.

Despite the already significant contribution to our ongoing fuel needs and tremendous prospects for future contributions in only a few short years, ethanol's brightest days may be in the rearview mirror (of a car fueled by Mideast and Venezuelan oil).

How could a source that today meets so many of our objectives for a perfect fuel become so unpopular? How could the United States forgo a substantial and growing renewable fuel source for concepts that "may deliver something better, someday"?

The concept of ethanol as a renewable fuel was believed to be the ultimate vehicle fuel solution as far back as the turn of the last century with great agriculturalists like George Washington Carver, great industrialists like Henry Ford, and great inventors like Thomas Edison (Kovarik, 1998). The idea was revitalized in the 1970s during the Arab oil embargo when we feared for the security of our oil supplies (Shapouri, Duffield, and Graboski, 1995). The idea came back again in the mid-1980s when corn growers realized their net return from burning a bushel of corn was greater than from selling it to the feed market (Dorn, 2005).

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The idea made sense and the time was right. Energy costs were high, with corn worth more as a fuel than as a feed. Agricultural corn productivity continued to gain with no increased outlet and thus corn prices continued to languish. And standard production technologies for corn-based ethanol had been optimized such that plants could be built in an assembly-line fashion to run reproducibly and reliably.

The U.S. ethanol industry started when farmers, livestock producers, local businesses, and cooperatives pooled their own capital and invested in new-generation corn-based ethanol plants. Their objectives were clear: Increase demand for their product and create new revenue opportunities. What could not have been fully understood at the time was the positive impact of these plants on the environment and on revitalizing rural communities by creating jobs, new income, and new tax sources.

Growth of the corn-based ethanol industry was evolutionary, initially with plants averaging 20 million gallons per year (MGY) of production capacity (Hettinga et al., 2009). These early cooperatives were firmly rooted in rural agriculture. They were composed of local equity investment and agricultural debt providers who understood the cyclical nature inherent in agriculture and the low margins that could be expected from a commodity business. The majority of this growth was in the western U.S. Corn Belt where corn yields were high, local livestock production could use the animal feed coproducts, and local and regional markets could use the ethanol. Rail lines built to ship grain to California could also deliver ethanol and the animal feed resulting from ethanol production.

Modest plant construction allowed corn productivity growth to keep pace with the increased demand for corn (Korves, 2008). In other words, while farmers consistently increased their productivity (yields) in small increments each year, the small incremental growth of ethanol plants and the corn supply they required was not disruptive to corn supply and demand.

The ethanol produced in those early plants helped to meet the reformulated gasoline requirements in clean-air attainment zones and began to make its way into broader E10 (gasoline mixed with 10 percent ethanol) and E85 (gasoline mixed with 85 percent ethanol) applications. Investors were satisfied with their modest returns because of the ancillary benefits: a local alternative market for their corn, jobs for their community, and incremental expenditures for other services the plant required. The hardware store, the corn grower, the grocery store, the bank, the restaurants, the municipal government, and the local environment all benefited.

Demand for ethanol rose as states' clean-air requirements began to phase out gasoline oxygenate additives suspected of causing cancer (methyl tertiary-butyl ether [MTBE]), turning instead to ethanol. This new demand was accelerated by federal legislation that prescribed renewable fuels as a component of the gasoline blend. The 2005 Energy Policy Act (EPACT; Energy Policy Act, 2005) provided a renewable fuel standard (RFS) requirement for major petroleum blenders to blend 7.5 billion gallons per year (BGY) of renewable fuel (largely ethanol) with gasoline by 2015. More importantly, the act provided no limited liability protection for the use of MTBE. Because of the mandatory requirements to blend fuels to meet clean-air requirements, the oil industry now needed to blend fuels above the minimum level stipulated by the RFS. They rapidly exited their MTBE contracts and moved into ethanol, which briefly drove up the price of ethanol from less than $2.00 gallon in November of 2005 to $4.00 per gallon and higher prices by June 2006 (Center for Agricultural and Rural Development [CARD]).

Federal legislation created a clear marketing opportunity, and new investors from outside traditional agriculture entered the market. These new investors augmented local investors, which allowed equity to be raised more quickly. Many of these new investors also brought their knowledge and expertise from other industries and were astonished to find that the modern ethanol production technologies lacked many of the advancements commonplace in other process manufacturing facilities.

While many investors were interested in dramatically improving the process and energy efficiencies of new ethanol plants with readily available technology, they were quick to learn that established financing structures prevented funding of anything but a standard plant design template. Debt providers for new plants wanted a "sure thing" to quickly exploit the market opportunity. Improving plant technology and efficiency was not their motive for entering the market. Although higher debt loads were allowed to accommodate higher construction costs in a booming market, significant incremental operational requirements that added cost were also brought in. These requirements often included the use of external providers for corn merchandising, risk management, ethanol marketing, and coproduct marketing. Senior debt covenants limited incremental capital investment, which further restricted the adoption of significant technological improvements that experienced industrial manufacturers viewed as fundamental to the industry's future operational and financial success.

Providers of ethanol-processing equipment were also slow to push new and better technology because the new owners were positioned to buy quickly from the preestablished menu. The "old stuff" was clearly in high demand, commanding a premium, and selling in volume. Providers were having difficulty meeting demand and resources were not available to invest in the future. Reminiscent of Henry Ford's first Model T assembly lines, you could purchase and finance any process design "as long as it was black."

While it was expected that Wall Street's deep pockets would bring modern technology investments that would positively evolve the plants, this was not the case. New owners faced a dilemma: a choice of available project financing if they accepted the current state of technology, or an inability to finance their projects if they tried to improve them. Most invested, believing they would first pay off their debt and then add the diversification and enhancement capabilities core to a successful industrial production facility.

Logistical efficiencies remained despite growth of the industry because ethanol plant coproducts could now directly substitute for corn transported to cattle feed markets. These coproducts, containing all the protein, fat, and fiber of corn in a more concentrated form, cost less to transport per pound of nutrient value. West Coast markets matured, and southern and eastern ethanol and feed markets began to develop. Thus, plants began to spring up in the eastern Corn Belt with eastern-serving rail service. U.S. ethanol production capacity increased 30 percent from the end of 2005 to the end of 2006 (Renewable Fuels Association [RFA]). The large volume of corn-based ethanol now entering the distribution channel was beginning to take market share from petroleum refiners.

The nonagricultural state environmental groups became concerned that the growth of corn-based ethanol forced more land into cultivation and negatively affected our global carbon footprint. A groundswell of interest had also developed from earlier Department of Energy (DOE) work about the promise of using "wasteland" (nonproductive land) for the production of biomass crops that could "eliminate all the problems associated with corn based ethanol." Environmental groups, academic groups, DOE scientists with looming job cuts, and states with vast acres of nonproductive land coalesced to create broad-spread bipartisan support for a bill that would limit corn-based ethanol and pin future promise on alternative feedstocks and fuels.

In December 2007, the Energy Independence and Security Act (EISA) of 2007 was enacted, mandating 15 BGY of ethanol by 2015—up from the 7.5 BGY mandated in EPACT—and 36 BGY of renewable fuels by 2022 (EISA, 2007). Fifteen BGY was allowed for corn-based ethanol, and the remainder was allocated to cellulosic and other advanced biofuels (defined as any renewable feedstock except corn-based starch to ethanol). A ceiling was placed on corn-based ethanol because it was believed the need for corn for both food and fuel was causing additional land to go into agronomic production with speculated negative environmental consequences. EISA mandated that renewable fuels must demonstrate a carbon footprint 50 percent to 60 percent better than conventional gasoline and that new corn-based ethanol production facilities must demonstrate a footprint 20 percent better than gasoline.

In his February 2007 State of the Union speech, President George W. Bush proclaimed that 36 BGY of renewable fuel production, outlined in the yet to be passed Energy Bill, would allow us to eliminate three-quarters of all the oil currently imported from the Middle East…as if the 16 BGY associated with cellulosic ethanol was right around the corner.

The bill misrepresented what was possible given the current state of the science, providing the American public with a false understanding of the current potential of renewable fuels. The new law additionally served as a lightning rod to those already opposed to renewable fuels to organize and actively oppose its vision and the tangible reality of 15 BGY from corn-based ethanol.

Most astonishingly, the new bill provided the framework for the demise of the existing corn-based ethanol industry, which would effectively end the cellulosic-based industry before it was ever allowed to start. The bill neglected to offer a plan providing for the transition from an existing technology (corn-based ethanol) to the experimental technology (cellulosic ethanol) or for a certain channel for the product. Such a plan would have ensured a steady and increasing volume of renewable fuel to meet the requirements established in the RFS and a distribution system for it.

First, the vast operational efficiencies available to corn-based ethanol through available technology were bypassed for an alternative fuel that is literally still on the drawing boards. Second, the bill lacked a viable implementation plan to provide a mechanism for blending the renewable fuels mandated into the existing gasoline supply. Third, the bill created an ill-defined requirement for biofuels to achieve life-cycle greenhouse gas reductions relative to gasoline produced in 2005, including any indirect impact of the use of the land for biofuel production. Finally, the 15 billion gallons of corn ethanol allowed by the RFS immediately created a real and significant threat to the oil industry.

The EISA capped corn-based ethanol volume via a false premise that inaccurately compared it with other fuels while failing to recognize the well-known fact that corn ethanol performance could substantially improve with modest investment in available technology. In determining RFS-required volumes, the bill compared today's nascent corn-based ethanol industry with the mature sugar cane–based ethanol industry and the theoretical cellulosic ethanol industry in its risk/reward assumptions. This was one of the most frustrating aspects of the bill—it included narrowly selected measurements of the impact of renewable fuels, with limited extrapolation of their future potential, and then used these assumptions to dictate volume limits 15 years into the future.

For example, because sugar cane–based and cellulosic-based ethanol combust their by-products to fuel their plants, with the RFS measurements they are credited with minimizing fossil fuel use. In contrast, corn-based ethanol production is not recognized as having the same ability to minimize its fossil fuel use, even though this possibility exists. With this comparison, the bill wrongly relies on old corn ethanol technology performance and willfully ignores not only the new corn ethanol technology but also the current scientific and technological work that will result in commercial application during the life of the bill. And while legislators overlooked the potential of an industry already providing more than 9 BGY with outdated technology, future manufacturing concepts yet to be proved were not so burdened. As noted, sugar cane–based and cellulosic-based ethanol were again assumed to use their by-products to fuel their plants. Never were the technologies of a corn-based ethanol plant, with the adoption of technologies commercially viable today, used as the basis of comparison with either sugar cane– or cellulosic-based technologies. This yawning recognition gap in the opportunity for continued adoption of new technologies—allowing corn-based ethanol to deliver in the near term the same environmental benefits as cellulosic-based ethanol when it moves out of the laboratory and into commercial application—was completely missing from the 2007 EISA.

In addition to capping the volumes of allowable corn-based ethanol, the base number of gallons allowed was assumed "mature" and incapable of improving over time such that additional gallons could be warranted. Second, DOE funding was focused on an initiative to create a future technology. *No funding* was provided as a bridge from the current technology to that future state. This gap created the real and significant potential for the demise of the existing ethanol industry. With no future corn-based ethanol industry, no outlet above 10 BGY of production would be required, thereby eliminating the need for infrastructure development to ensure a future outlet for cellulosic ethanol technologies. This, by definition, capped our commitment to renewable fuel at a volume less than 10 percent of our gasoline usage and well below our imported volume of oil.

Why is corn ethanol's success essential to cellulosics? Although cellulosic ethanol remains a promising future fuel for reducing our dependence on gasoline as a vehicle fuel source, the time required for cellulosic ethanol to overcome significant feedstock, logistical, and production issues is not insignificant and well beyond the time allotted for production volumes established in the RFS. Additionally, the first significant volume of cellulosic ethanol is likely to come from the fiber already brought into existing corn ethanol production facilities as a part of the corn kernel. This type of cellulosic ethanol is not a new concept and, in addition to wood chips, is the nearest-term viable means of producing cellulosic ethanol. It is important to note that efforts have existed since the oil crisis of the 1970s to demonstrate its commercial viability. In 1993, the DOE National Renewable Energy Laboratory (NREL) declared its technology for converting corn cellulose ethanol ready for commercialization (NREL, 1993). Fifteen years and billions of dollars later, corn cellulose is still not ready to be produced on a commercial scale. And this technology, requiring only process-conversion technology development, will be ready long before the incremental work required to develop energy crops still in the developmental stages.

The current corn-based ethanol industry provides a means of developing the infrastructure required for cellulosic ethanol distribution. With lower costs of production and a real product to distribute, corn-based ethanol should be in a position to bear, along with the petroleum industry, the costs for infrastructure development.

The Energy Bill did not adequately address the infrastructure challenges of a 36 BGY RFS. This created a constraint for market growth and thus a supply/demand-driven market demise via margin erosion. The RFS of 36 BGY implied that 36 BGY of renewable fuels would be blended into the existing petroleum base of 140 BGY of gasoline-based transportation fuel. Gasoline infrastructure today allows for the blending of ethanol up to 10 percent in conventional vehicles, or roughly 11.6 BGY. This number excludes states that do not allow blending at 10 percent and small refiners not required to blend.

Higher use of E85 would create a significant incremental outlet for ethanol. However, while a blenders' credit of $0.51/gallon was created in EPACT and retained in EISA (reduced to $0.45/gallon in 2009) for the petroleum industry to add the infrastructure required for full incorporation of E10 and adoption of E85, there has been little to no adoption of E85 by the major oil companies.

With ethanol distribution today limited to E10, the size of the market for E10 is entirely dependent on the RFS floor (10.5 BGY in 2009) when ethanol prices (including the blenders' credit) exceed gasoline prices and is capped when gasoline prices exceed ethanol prices by the ability to blend E10: today approximately 12 to 13 BGY. Additionally, because petroleum blenders are allowed to "carry over" a portion of their blending requirements, even with an RFS floor, use of higher blend levels when ethanol's price is low allows blenders to underblend when the ethanol price is high. With 2008 use well above the RFS, petroleum blenders' 2009 mandatory blending—at an ethanol price greater than gasoline—could be 1 to 2 BG less than the 10.5 BG mandated.

As the Energy Bill was passed, incremental ethanol capacity was already under development because its lead time from construction to operation is more than two years. Thus, despite significantly reduced margins and production already above and beyond the new RFS schedule, the industry, with already committed capital, moved from 56 plants in 2000 producing 1.8 BGY to more than 180 plants in 2008 capable of producing more than 10 BGY (RFA). Thus, installed ethanol plant capacity was on line to meet the RFS mandate for 2009, 2010, and beyond. All capacity now became vulnerable with production volumes above the RFS and the lack of a "blending home." Older plants faced higher operating costs and inefficient logistics; newer plants faced higher debt loads. No plants were positioned to have the capital available or accessible to add technological innovations to improve their base assets.

Rapid industry capacity growth created speculation about the dramatic increase in the renewable fuel industry purchasing a portion of the annual U.S. corn crop, which led to corn market speculation that resulted in skyrocketing corn prices. Further, a poor European wheat harvest, increased global demand for grain, and dramatic flooding across key parts of the U.S. Corn Belt combined to create uncertainty about 2008 corn production. High and erratic corn pricing resulted, surpassed only by new highs in the price for oil and gasoline at the pump. Food companies raised prices to protect margins and were quick to cast the blame on fuel-based ethanol's demand for corn despite the small cost of grain to their total product cost (Rosenfeld, 2008).

Oil companies were further threatened by the growing volume of ethanol reducing their refining capacity needs. Food companies were threatened by an alternative demand for their feedstock that increased prices. A well-funded, well-organized campaign convinced consumers and legislators around the world that corn-based ethanol was causing starvation and food riots. An organized, fact-based information campaign was never conceived by the fragmented and poorly funded ethanol industry. Many of the anti-ethanol campaign messages are now taken as fact by legislators, the media, and other stakeholders.

Seizing another opportunity to increase the vulnerability of the industry, those opposed to corn-based ethanol began a similar campaign related to the life-cycle assessment requirements outlined in the Energy Bill. A campaign suggesting that land used for fuel instead of food production was not being appropriately penalized for its global warming impact in determining the fuel's environmental benefits. Because this criterion had never been used to determine any alternative use—say, the impact of a new subdivision, an acre grown for nonhealthy versus healthy food, or a marginal acre used for cellulosic instead of food production—new theories about how to make this determination were placed on the back of—and remain on the back of—corn-based ethanol.

The number of U.S. farm acres has largely remained flat and total tonnage of protein, fat, and fiber available for food consumption is greater than at any time in U.S. history (despite the increase in corn-based ethanol production), yet it is now believed important that an environmental penalty be assigned to corn-based ethanol in the form of the indirect land impacted—that is, the land forced into production, from the U.S. use of a portion of its corn crop for corn-based ethanol. The ongoing debate about how to determine and assign indirect land use environmental impacts in the form of its global warming impact to corn-based ethanol production—first to corn and then to cellulosic ethanol—successfully creates further uncertainty about the future of renewables, effectively stalling future investment to improve the base industry or to create incremental capacity.

Despite all this, the mid-2008 U.S. Department of Agriculture (USDA) production reports were beginning to indicate that corn yields were on track for another bumper crop. At the same time the economy began to falter, high gasoline prices led to a precipitous drop in fuel consumption and miles driven, and corn prices plummeted from a high of $7.99/bushel in late June to $5.40 in mid-August (Platts, 2008). Ethanol companies, unable to lock in margins owing to the lack of a forward market from the oil companies for ethanol, were caught with corn cost positions exceeding ethanol sales prices. A number of these companies, with significant exposure, took large write-offs, required additional capital infusions from shareholders, or declared bankruptcy. With the ethanol supply continuing to exceed mandated demand and at a price above which discretionary blending of ethanol is unattractive, ethanol margins remained razor-thin and often negative.

Stalled construction, a lack of new construction, and continued bankruptcies continued to reduce available capacity, leading to production 20 percent below available capacity (Caldwell, 2008). A lack of confidence in the future of the industry limited interest in acquisition of existing facilities or the investment required to transform these facilities into true biorefineries that could also produce food and eliminate their fossil fuel use.

Cellulosic start-ups began to announce delays in technology development, the ability to access and develop feedstock, and the ability to secure financing. The DOE publicly indicated that the near-term RFS goals for cellulosic ethanol would not be met (U.S. Energy Information Administration, 2008). In addition, overcoming the cellulosic technical hurdles to meet the RFS-mandated volume and meeting the timeline objectives outlined in the Energy Bill are proving difficult. Corn-based ethanol could most certainly help to bridge this gap, even if the industry is held to the same global warming reduction impacts possible with cellulosics, yet we have turned our back on it. Thus, while oil and gasoline imports continue, more than 2 BGY (>20%) of the existing available capacity for corn-based ethanol is idled and estimates suggest another 2 BGY reduction is possible.

All of this is happening when a simple solution exists. Instead of the DOE and the USDA funding only the speculative and basic research needs of a future industry, they could, in addition, provide grants and loan guarantees for the adoption of currently available and commercially demonstrated technologies in existing corn-based production facilities. These facilities would be those with a demonstrated ability to produce fuel and an interest in and ability to incorporate readily available technologies. These technologies would allow corn-based ethanol to deliver environmentally and economically viable ethanol with a 50 percent reduction in the carbon footprint impact—an impact that today is already 40 percent better than gasoline (Mueller and Copenhaver, 2008). This approach would bridge the time gap and technological innovation required for the introduction of cellulosic ethanol and other advanced biofuels today. This would allow time for the development of the blending infrastructure and regulations required to blend above the 10 percent level, it would ensure continued diversification of our fuel supply, and it would allow time for the development of the innovations so critical to the future of our energy independence.

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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).

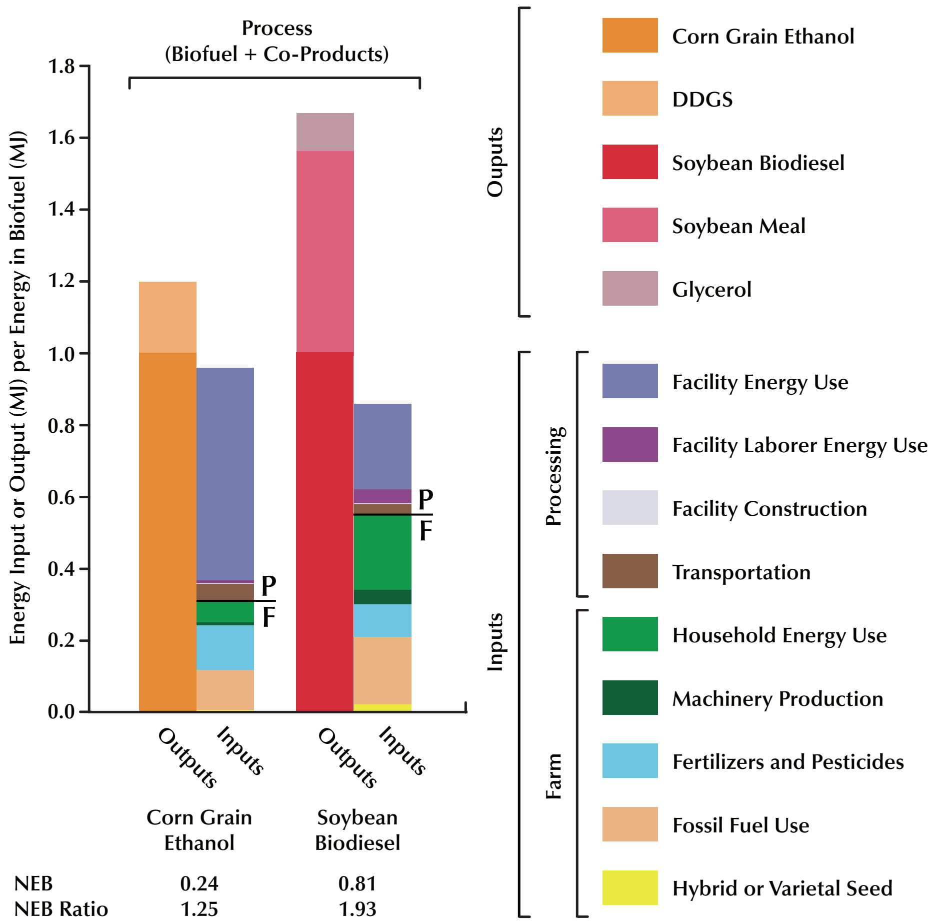
Another set of calculations was performed on a more elaborate ethanol plant that uses biomass (e.g., corn stover[1] or the concentrated wet stillage[2] from the ethanol production process) as fuel for process heat or even to generate electricity. Figure 2 shows the higher NEBs that result when process 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).

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.

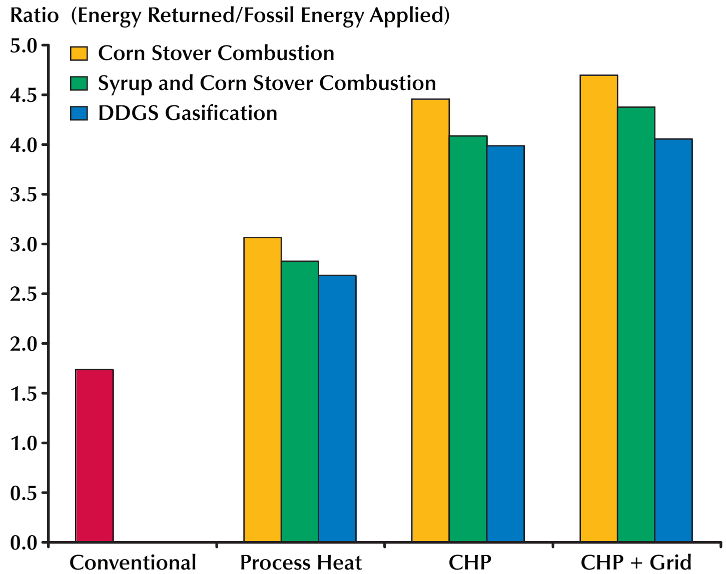
Related but more pertinent than determining the net energy ratio is the concept of determining the carbon footprint of biofuels and their relative effects on greenhouse gas (GHG) emissions. Emerging policies suggest it may soon be possible to be compensated for producing fuels with lower GHG footprints 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,

[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

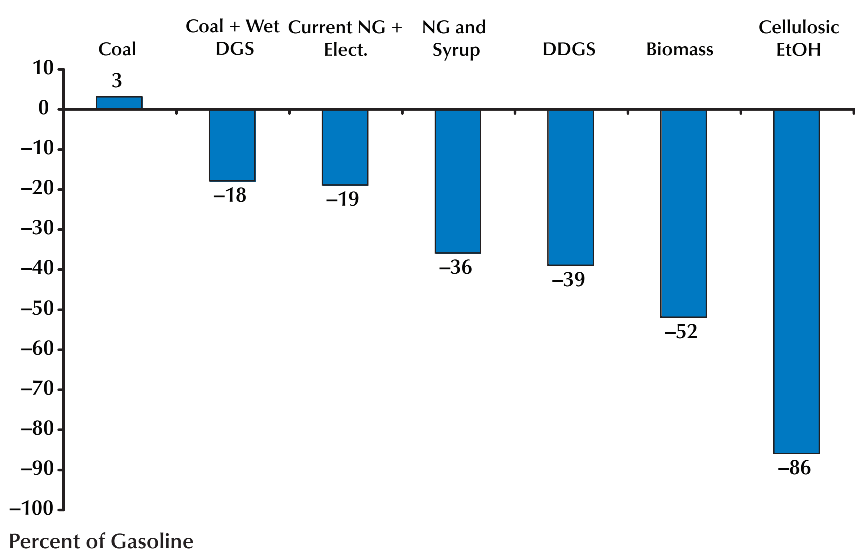
Renewable Energy Ratio (Lower Heating Value)



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.

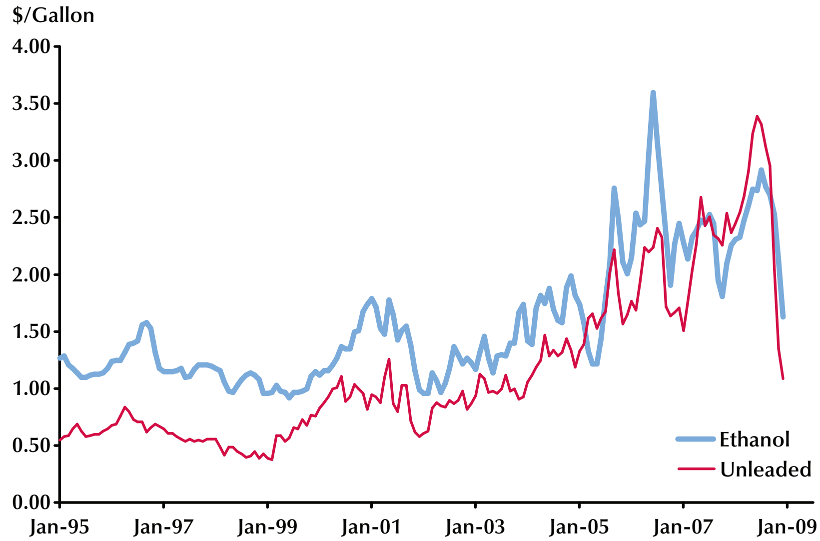
Based on the monetary benefit to consumers (measured by Du and Hayes, 2008) and the subsidies paid directly to the industry (using Koplow's, 2007, more expansive list of categories; see Table 2), one can calculate a net benefit to consumers of corn ethanol of $35.4 billion for 2007. However, it should 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.

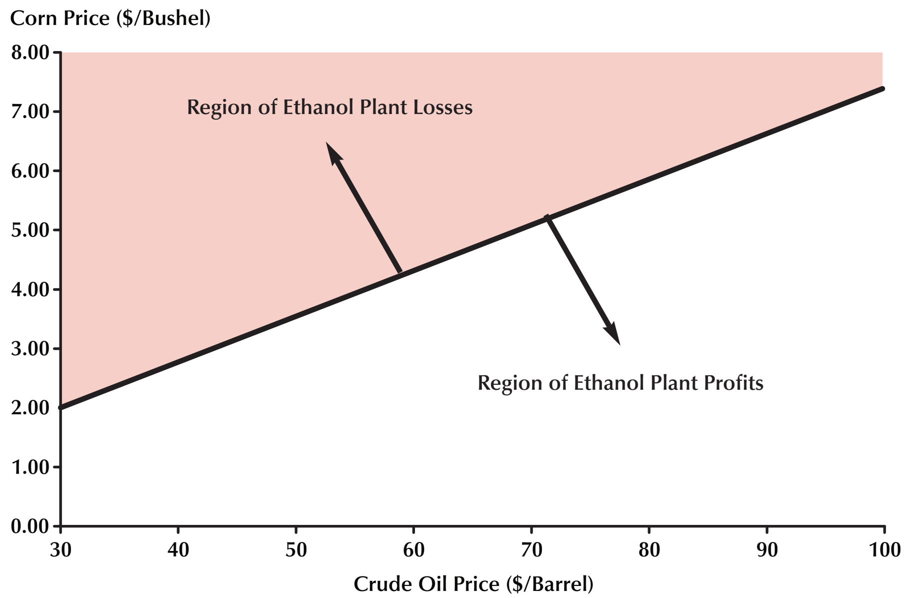
After ethanol lost its premium as a mandated oxygenate, its price came to reflect its role as an octane enhancer and as a BTU substitute for gasoline. As a substitute for gasoline, ethanol's price became directly related to the price of crude oil, which rose dramatically over the period beginning with 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

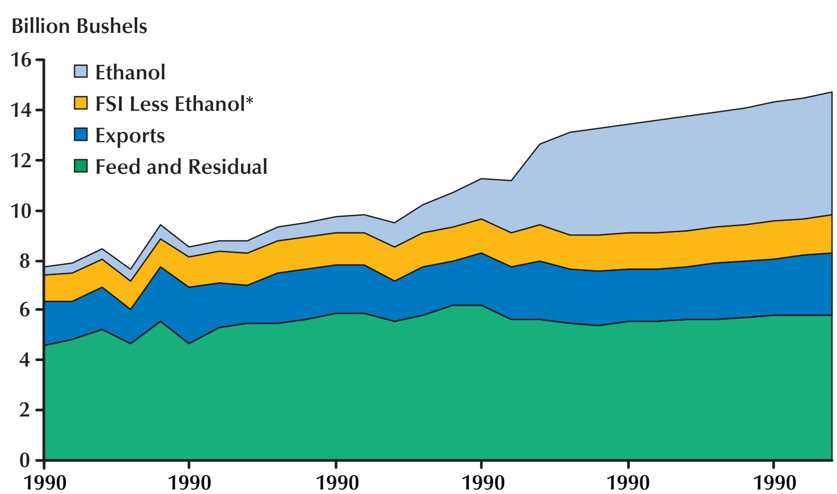
Breakeven Corn Price for Dry-Grind Ethanol Plants at Various Crude Prices with Full Receipt of $0.45 per Gallon VEETC



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.

[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.

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

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.

[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.

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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Commentary

Max Schulz

University of Minnesota Professor Douglas Tiffany's article (2009) provides a valuable treatment about the economics of ethanol production and use. The debates on biofuels in Washington in recent years have too often been focused on slogans and sentiment rather than facts and figures. Professor Tiffany's article brings very useful detail and expertise to a topic that touches on issues ranging from energy, the environment, and agriculture to national security and foreign relations.

While I take issue with some of his conclusions, Professor Tiffany is to be commended for addressing several of the alleged negative implications of federal ethanol mandates. At the same time, however, he doesn't adequately address the core concern that has compelled those mandates: namely, whether we can displace significant volumes of our national oil consumption with ethanol.

Although this conference takes place shortly after the election of a new president, it is a valuable exercise to review the recent history of ethanol policy under George W. Bush to provide insight for charting ethanol's future course. Conventions of public disclosure demand I note that I served for nearly five years in the George W. Bush administration at the U.S. Department of Energy (DOE). However, the policies discussed here began to be implemented largely at the end of my tenure at the DOE. Furthermore, it will be clear that my views represent no endorsement of the biofuels policy embarked on (with the president's support) in the comprehensive energy legislation passed by Congress in 2005 and 2007.

The push to boost the share of ethanol in our fuel supply will go down as one of President Bush's legacies, albeit an unfortunate one. This development was a signature initiative of his second term. Ironically, Bush's first term, which placed a large focus on energy policy issues, did very little to encourage ethanol use and certainly didn't hint at the sort of mandated expansions that would occur in 2005 and 2007.

When President Bush took office in 2001, the country was dealing with the shocks of the California energy crisis. There were also signs that domestic natural gas production was plateauing; more and more holes were being drilled to produce the same amounts of gas. There were clear indications that global demand for oil would increase, while our capacity to develop it at home was hindered by regulations and moratoria on exploration.

Among the first orders of business for President Bush was to issue a comprehensive energy policy that encompassed a host of various possibilities (National Energy Policy Development Group, 2001). It encouraged the development of domestic oil and natural gas resources, as in Alaska's Arctic National Wildlife Refuge (ANWR). But the Bush energy plan was much more than that. Emphasizing that no one energy program or approach, including ANWR, was a silver bullet, the plan highlighted the necessity of a fully rounded energy policy.

The president's National Energy Policy (NEP) promoted a variety of energy technologies, fuels,

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and processes. It called for the expansion of nuclear power; renewable energy research for wind, solar, and biomass; energy efficiency and conservation; clean coal and carbon capture; building a twenty-first-century electricity grid; as well as investments in infrastructure upgrades from wires to pipelines to liquefied natural gas terminals and tankers.

In fact, despite political criticism that the president's plan focused solely on ANWR, it devoted as much (if not more) attention to efficiency and conservation as it did to expanded oil drilling in Alaska. But what was really curious was what the NEP did *not* emphasize: biofuels. Ethanol was mentioned only in a cursory fashion, essentially noting its role as an additive in gasoline. There was no indication in the president's comprehensive energy plan of the importance that he would later assign to it.

The overall theme of the president's sweeping plan was energy security. Far more than just considering energy as an economic or environmental matter, the NEP considered energy as a component of national security. Then came September 11, 2001, which put the energy security/national security nexus into sharper focus. It provided even more impetus for the notion that we must take a national security approach to our energy policy decisions. In the back of everyone's mind was the fact that the terrorists who perpetrated the 9/11 attacks and subsequent acts of violence were funded (indirectly, but funded nonetheless) through the revenues reaped by national oil companies in the Middle East. The Organization of the Petroleum Exporting Countries (OPEC) dictatorships got rich selling us the oil we use to power our transportation sector. In return, for instance, the Kingdom of Saudi Arabia used that money to establish the Wahhabi schools and mosques that supported the 9/11 bombers and other international terrorists.

Against this backdrop, consider the upward creep in oil prices over the past eight years. The wealth transfer to regimes in Saudi Arabia, Russia, Venezuela, and Nigeria was worrisome enough when oil was trading at $35 per barrel. But as oil prices soared to well over $100 last summer, the massive transfers of wealth lining the pockets of some very bad actors seemed particularly egregious. Even in the current economic environment, with the price of oil having retreated considerably from its mid-summer highs, the national oil companies of OPEC (not to mention their like-minded allies in Moscow) are reaping huge sums from the global oil market that can be put to nefarious purposes.

It was in this context that the federal government took a significant policy leap with the 2005 and 2007 energy bills. We moved from a position where the government encouraged ethanol use as an additive to meet clean air goals to one where ethanol would be used to displace gasoline use and lower our consumption of foreign oil.

In 2005, the White House endorsed a renewable fuels standard that mandated the use of 7.5 billion gallons of ethanol and biodiesel in our fuel mix by 2012 (Public Law 109-58, 2005 [also known as the Energy Policy Act of 2005]). By the time of the 2007 legislation, President Bush was pushing even harder to expand that mandate nearly fivefold by 2022.

The chief impetus for President Bush and for allies in Congress was a stated desire to displace foreign oil imports. The environmental goals or the goals of helping the economies of Midwestern states, to the extent these goals were discussed, were far less important than the energy independence angle. Even so, the environmental argument still has its champions. Green groups have advocated increased biofuel usage for years. But without the Bush administration driving the issue from a national security angle, we simply would not have seen the extreme mandate for biofuels that was passed in the 2007 legislation.

What is striking at a conference dedicated to discussing the various economic and environmental consequences of ethanol is to consider that Congress and the Bush administration originally paid so little heed to what those consequences might be. Goals certainly were discussed—from energy independence and energy security to the hope we might produce fuel at home instead of buying from Middle Eastern sheiks. However, discussion of the practical consequences of such a fairly dramatic policy shift was sorely lacking.

Washington's ethanol debates were carried out largely by reference to the legislation's goals, not its likely ramifications. Little thought was given to consequences for consumers. Not considered was how a law mandating ethanol usage might affect farmers' choices of crops to plant, or what it might do to world food markets given that the United States produces 40 percent of the global corn supply and is responsible for more than two-thirds of the world's corn exports (U.S. Department of Agriculture, 2009). What the legislation might mean for the environment was barely discussed, other than the occasional broad platitude that use of renewable ethanol instead of gasoline would cut emissions.

The rush to mandate ethanol's usage in our fuel mix in 2005, and then to supersize that policy in the subsequent 2007 energy bill (Energy Information Agency, 2007), was much like taking a running jump off the diving board without checking to see if there's water in the pool. It turns out there wasn't much water in the pool. The near-term consequences so far have been, simply, unfortunate for everyone but certain groups of farmers and agribusiness concerns.

The global increase in food prices tops the list of unfortunate consequences. Professor Tiffany addresses this issue somewhat in his article, noting the record prices for corn brought on partly because of Washington's ethanol mandate. He correctly notes that the values of crops represent only a portion of the cost of food. "Up to this time," Professor Tiffany writes, "corn ethanol's effect on food prices has been minimal." He cites consumer price index (CPI) numbers, noting that 2007 U.S. retail food prices rose 4 percent over 2006 levels.

Our ethanol policies seem to have had a more harmful effect than Professor Tiffany allows. For one thing, he could have noted the continued increase in the CPI for retail food prices throughout the course of 2008. With six weeks left in the year, it looks as if the CPI will show a 5 percent to 6 percent increase over last year's prices, meaning an overall increase of nearly 10 percent over 2006 prices.[1] That's a significant rise.

The jump in crop prices has been dramatic, as well, at least before the recent economic downturn. In early 2008, corn prices were basically double from the previous year. Not just corn has been affected. One consequence of the federal government's varied efforts to prop up the price of corn (to increase the use of biofuels) has been farmers choosing to plant corn in place of other crops. So with land for other crops moved to corn production, the prices of those displaced crops have increased. Earlier this year, the price of wheat was triple what it sold for the year before. Soybean prices doubled, as did the price of rice.

One can argue about the effect of such dramatic increases in crop prices on the retail cost of food. But what cannot be argued is that food prices have indeed increased over the past two years. Their effect on the American economy may be said to have been relatively minimal—but that has to do with the fact we are a wealthy country. If the problems with our financial system and our monetary policies are put aside, the economy is fundamentally sound.

That is to say, we are a productive nation. We have created great stores of wealth for the vast majority of Americans. As such, we have been able to weather the effects of any number of troubling developments in recent years: 9/11, corporate scandals at Enron and WorldCom, Hurricanes Katrina and Rita, the 2005 blackout in the Northeast, flooding here in the Midwest, and rising energy prices, not to mention the spike in food prices. These events all have taken some toll, but generally our economy has proven pretty resilient.

Citizens of poorer nations are not as capable of taking an economic punch as are we. As a result, riots over spiking prices for food have erupted in Egypt, Haiti, Mexico, Indonesia, and elsewhere. The effect of U.S. and European biofuels mandates on other nations as prices for crops have skyrocketed is one that perhaps could have been explored by Professor Tiffany in what is a fairly laudatory article about ethanol.

Fortunately, the alarms over biofuels' effect on global food prices are being raised again and again. This fall, the Food and Agricultural Organization of the United Nations (2008) called for a review of biofuels subsidies and mandates because of their contribution to rising food prices.

The International Food Policy Research Institute similarly voiced concerns (von Braun, 2008), as did the Organisation for Economic Co-operation

[1] The year-end figure was 5.5 percent for 2008, so the overall increase was 9.72 percent, or roughly 10 percent.

and Development (2008), which wonders if the "cure" of biofuels is worse than the diseases it is supposed to address.

In July, the World Bank suggested that biofuel policies were responsible for nearly three-quarters of the increase in global food prices, with higher energy costs, the weak U.S. dollar, and increased transportation and fertilizer costs making up the difference (Chakrabortty, 2008). The World Bank study seemed to confirm an earlier International Monetary Fund report making similar claims (Mercer-Blackman, Samiei, and Cheng, 2007).

And what of the environmental impact on the developing world's biofuel policies—specifically, the demands for land? U.S. farmers planted a record 94 million acres in corn in 2007, yielding a record 13 billion bushels. And for all that, it displaced just 3 percent of our total oil consumption (Tucker, 2008).

It isn't that difficult to imagine what would be required to make a truly significant dent in our oil consumption. Two researchers at the Polytechnic University of New York did just that in a 2006 *Washington Post* op-ed article. James Jordan and James Power came to the conclusion that "Using the entire 300 million acres of U.S. cropland for corn-based ethanol production would meet about 15 percent of the demand" (Jordan and Powell, 2006, p. B07).

That's a theoretical figure, to be sure. But to date, I haven't seen credible numbers suggesting we can produce enough biofuels to make a worthwhile dent in our oil demand while also growing the crops used for traditional uses.

If it's theoretical to us in the United States, however, in other parts of the world the clearing of land for biofuels production is causing significant environmental damage. In Indonesia, forestland is being cleared at alarming rates to plant palm oil crops to cash in on the artificial demand for biofuels. The result is a massacre for many endangered animals, such as the orangutan.

Perhaps worse, depending on one's view on global warming, is that the land-clearing aspects of biofuel production arguably increase greenhouse gas emissions. That was the conclusion of two reports in *Science* magazine. One article noted that growing biofuels necessarily leads to deforestation, which eliminates some of the planet's most effective carbon sinks (Searchinger et al., 2008). In the other article, lead researcher Joseph Fargione claimed that even though biofuels are a potential low-carbon energy source, land clearing sped up carbon emissions and that "for the next 93 years you're making climate change worse" (Rosenthal, 2008).

It isn't just the land that is being affected. The National Oceanic and Atmospheric Administration (NOAA), in conjunction with Louisiana State University, has sounded the alarm about a growing dead zone in the Gulf of Mexico, an algae-filled area with oxygen levels too low to maintain marine life. Since 1990 this dead zone has averaged about 4,800 square miles. NOAA warns it could expand to 8,800 square miles, largely because the recent flooding in the Midwest and the increased use of fertilizers to grow more corn have washed nitrogen and phosphorus downstream into the Gulf (NOAA, 2008).

In his paper, Professor Tiffany notes that "it is difficult to describe a perfect fuel that produces no adverse impacts during its production or use." Quite right. Such a characterization applies to every fuel and energy technology we use, each of which has some drawbacks or dangers. Coal has to be dug out of the ground in a laborious process and transported—often hundreds of miles—to be incinerated, which is a dirty process. Our nuclear fuel cycle leaves the problem of radioactive waste. Our oil use enmeshes us in foreign entanglements, not to mention that burning it emits pollutants as well as greenhouse gases. Wind turbines require huge tracts of land and pose serious aesthetic considerations. The manufacture of solar panels requires the use of highly toxic chemicals, and using the panels also requires large amounts of land for solar farms and other optimal conditions. Hydropower distorts landscapes and natural environments.

The question we must ask with all of these energy options is whether it is worth putting up with the hassles involved for what we get out of them. The risks and environmental impacts associated with nuclear power and coal are of a far greater scale than those for windmills, but they also are capable of generating vastly greater amounts of reliable power than windmills. Over the course of a century, we developed the production, delivery, and refining system for petroleum because, in the end, gasoline has proven to be the best, most durable, most available, most flexible fuel for powering our transportation sector.

By and large these things occurred because of decisions made by the market, not by government. Certainly there have been government involvement and distortions in energy markets since shortly after the gusher at Spindletop, yet the energy system that has matured to service the internal combustion engine has done so organically.

For all the benefits of ethanol, many spelled out by Professor Tiffany, those benefits cannot make ethanol economically viable without explicit government sponsorship. Such sponsorship takes many forms—from direct and indirect subsidies to tariff protection to mandates ordering its use. One certainly can argue over the magnitude of our biofuel policy's effects: Did prices rise this much or only that much? Was the environmental insult this large or slightly smaller? Much harder to contest is the notion that with just about any calculation, corn-based ethanol forever will be incapable of supplanting a significant amount of our oil consumption.

Cellulosic ethanol holds promise and will not carry the baggage associated with corn-based ethanol. But it's far less evolved technologically than corn-based ethanol at this point.

Following the road set by President Bush and Congress, we should see continued adverse economic and environmental impacts. This will certainly be the case in the near term until a workable process for cellulosic ethanol is invented. Even if that happens (a questionable proposition), it is worth considering that there likely will be other similar, unforeseen adverse consequences if technology advances allow the United States to ramp up cellulosic ethanol production.

Barring an unlikely change of heart by policymakers in Washington, we should expect our economy, not to mention consumers in other, poorer regions of the world, to continue weathering these assaults. And for what? To displace negligible amounts of America's oil consumption.

At some point, we should ask ourselves if the benefits of our ethanol policies are worth the disruption and economic pain they cause. Given ethanol's inability to substitute in any meaningful way for our current oil consumption, I would argue they are not.

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The Impact of the Ethanol Boom on Rural America

Jason Henderson

Since 2005, surging U.S. ethanol production has helped reshape the rural economy. Ethanol production has increased nonfarm activity in many rural communities. Moreover, increased ethanol production contributed to rising crop prices, increased net returns, and a jump in cropland values both nationally and regionally. However, rising crop prices cut livestock revenues by boosting feed costs. As a result, while ethanol proponents tout the benefits emerging from the ethanol industry, opponents rail against its adverse side effects. Although the expanding ethanol industry has made a sizable impact on the rural economy, that impact has not been as large as initially estimated. (JEL Q1, Q4, R4)

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In 2006, the ethanol industry emerged as a major influence both in and on the U.S. farm economy. Changes in U.S. energy policy in 2005 bolstered the demand for ethanol. In 2006, the surge in crude oil and gasoline prices boosted ethanol profits. The result was a perfect storm for the farm community, where ethanol production and biofuels helped fuel sharp gains in corn prices that spilled over into other agricultural commodities. The promises of the ethanol industry had been fulfilled.

However, the ethanol boom has since faded. Current ethanol production capacity is higher than the demand mandated in the Revised Renewable Fuel Standard for 2008 (Environmental Protection Agency, 2008). Ethanol prices have fallen, shrinking profit margins and trimming forecasts of ethanol production. As the ethanol industry matures, what is the lasting impact on rural communities?

This article describes the economic effects of the ethanol industry on rural communities. Nationally, although crop prices have risen, the ethanol boom explains only part of the national increase in crop prices, net returns, and cropland values. The geographic concentration of ethanol production has led to some spatial changes in crop prices and livestock production. The ethanol industry has helped spur nonfarm economic growth, but the gains have been less than initially touted. As a result, the economic effects of the ethanol industry are probably not as large as most people expected.

FARM SECTOR IMPACTS

Ethanol's primary economic impacts emerge from the farm sector. Coupled with historically high export activity, U.S. ethanol demand has contributed to record high crop prices and strong farm income gains. However, the less-desirable side effects in the farm sector abound, including increased feed costs (from higher crop prices), lower livestock profits, and structural changes in agricultural industries.

Since 2006, U.S. ethanol production has surged. The phaseout of methyl tertiary-butyl ether (MTBE)

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Table 1

Net Returns to U.S. Corn Production (dollars per acre)

Variable	2005	2006	2007	2008 forecast	2008 forecast (without ethanol expansion)
Total production costs	386.88	409.74	443.97	567.36	567.36
Variable	186.37	205.98	228.99	335.15	335.15
Fixed	200.51	203.76	214.98	232.21	232.21
Total revenues	359.27	477.61	658.99	624.97	527.95
Market revenues	296.00	453.26	634.62	600.6	503.58
Average yield (bushel/acre)	148.0	149.1	151.1	154.0	154.0
Farm price (bushel)	2.00	3.04	4.20	3.90	3.27
Government receipts	63.27	24.35	24.37	24.37	24.37
Net returns	(27.61)	67.87	215.02	57.62	(39.4)
Net returns less variable costs	158.76	273.85	444.01	289.82	192.8

NOTE: All variables except average yield are expressed as dollars per acre.

SOURCE: Production costs were obtained from USDA data at www.ers.usda.gov/Data/CostsAndReturns/testpick.htm. Average yield and farm price data were obtained from the "World Agriculture Supply and Demand Estimates–February 2009" at http://usda.mannlib.cornell.edu/usda/current/wasde/wasde-02-10-2009.pdf. Government receipts data were obtained from FAPRI at www.fapri.missouri.edu/outreach/publications/ag_outlook.asp?current_page=outreach.

in several key gasoline markets fueled a surge in ethanol demand and a spike in ethanol profits. The industry quickly responded and by 2008, U.S. ethanol production capacity had reached 10.7 billion gallons, up from 3.6 billion gallons in 2005. Expanding ethanol production translated into a sharp rise in corn demand. Despite near–record high corn production, the ethanol industry is expected to consume 32.7 percent of the 2008 corn crop, up from 14.4 percent in 2005.

In combination with rising export activity, elevated ethanol demand contributed to record high corn prices. By 2008, robust demand was straining U.S. corn production and prices soared to record levels. According to the U.S. Department of Agriculture (USDA), the annual farm price for the 2008 corn crop is expected to reach $3.90 per bushel, up from $2.00 per bushel in 2005.[1] High corn prices also contributed to strong gains in other crop prices as the market competed for planted acres. For example, average annual farm prices for soybeans and wheat are expected to jump more than 60 and 100 percent, respectively, from 2005 to 2008.

Research indicates that ethanol production has a significant impact on corn prices. Based on a quarterly corn price model, a 1 percent increase in ethanol production led to a 0.16 percent increase in corn prices (Fortenbery and Park, 2008). Since 2005, ethanol production has increased by 197.2 percent, which according to the model would lead to a 31.6 percent increase in corn prices (197.2 * 0.16 = 31.6). Based on 2005 corn prices of $2.00 per bushel, corn prices should have risen to $2.63 per bushel, well below current corn price estimates. As a result, ethanol production has contributed to rising corn prices, but other factors such as export demand have also contributed to price increases (Fortenbery and Park, 2008). Moreover, as recent studies indicate corn prices respond to energy prices—the correlation between corn and crude oil prices has strengthened in recent years (Tyner and Taheripour, 2008).

With increased production and record high prices, crop revenues have risen sharply in recent years. On a net basis, corn revenues per acre are expected to rise well above 2005 levels (Table 1).

[1] The average farm price is obtained from the "World Agriculture Supply and Demand Estimates–February 2009" (USDA, 2009).

Table 2

Rail Summary: 2006-08 and 2016 Marketing Years

Variable	2006	2007	2008	2016
Ethanol production (billion gallons)	5.8	9.4	11.2	15.0
Number of projected rail carloads				
Ethanol production	119,347	190,816	227,755	306,122
Distillers' dried grains with solubles	26,338	41,650	49,533	66,576

SOURCE: USDA, "Expansion of U.S. Corn-based Ethanol from the Agricultural Transportation Perspective" in *Ethanol Transportation Backgrounder*, September 2007; www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5063605&acct=atpub.

The surge in market-based revenues more than offsets the declines in government payments, primarily from countercyclical payments[2] and higher input costs, emerging from energy-based inputs such as fuel and fertilizer. However, ethanol did not contribute to all of the revenue gains from corn production. In fact, based on the model estimates discussed previously, increased ethanol production from 2005 to 2008 contributed 63 cents to the price of a bushel of corn. Assuming no increase in ethanol production and the loss of 63 cents *ceteris paribus*, corn prices would decline to $3.27 per bushel and net returns would turn negative, roughly equivalent to 2005 levels.

Ethanol production has been found to influence both local and national corn prices. In analysis of basis patterns that measure changes in the difference between local cash prices and national prices, an ethanol plant raised corn prices by 12.5 cents per bushel on average (McNew and Griffith, 2005). Price increases tended to be greater at the plant site, ranging from 4.6 to 19.3 cents per bushel. As a result of transportation cost savings, other research has estimated that corn prices fall 0.2361 cents per bushel for every mile farther from an ethanol plant (Gallagher, Wisner, and Brubaker, 2005).

Increased crop profits quickly translated into higher land values. Nationally, U.S. cropland values rose 12.5 percent in 2006 and an additional 10.4 percent in 2007, the strongest gains since the 1970s.[3] The largest gains emerged in the Northern Plains and the Corn Belt, where cropland values jumped almost 20 percent in 2007. Even within major corn production regions, cropland value gains rose faster in locations in closer proximity to an ethanol plant (Henderson and Gloy, forthcoming). In the Federal Reserve District of Kansas City, farmland value gains were almost double in locations within 50 miles of an ethanol plant. The larger land value gains near ethanol plants reflected the capitalized value of the stronger crop prices and net returns to corn production closer to the ethanol plant (Henderson and Gloy, forthcoming).

The rapid expansion of ethanol production has also altered transportation and storage patterns in some parts of the Corn Belt. After the surge in ethanol production, anecdotal reports indicate that ethanol producers experience more difficulty shipping final products by rail. Ethanol production has also altered the shipping flows of grain. In fact, in 2006, the state of Iowa expected to import corn to meet industry needs for rising ethanol production (Roe, Jolly, and Wisner, 2006). On a national basis, reaching the 15 billion gallon mandate by 2016 is expected to increase ethanol rail shipments and dried distilled grain shipments by more than 150 percent above 2006 levels (Table 2). Grain storage patterns have also changed as local producers

[2] Under the countercyclical payment program, government subsidy payments are triggered when crop prices fall below specified levels. In 2005 and 2006, crop prices in general were low, triggering larger payments under the countercyclical payment program. The rise in crop prices in 2007 and 2008 above the trigger prices led to lower countercyclical payments. In 2005 and 2006, countercyclical program payments topped $4.0 billion annually. In 2008, countercyclical program payments are projected to fall to $720 million after dropping to $1.1 billion in 2007.

[3] USDA farmland values are measured as of January 1. As a result, reported increases from 2007 to 2008 reflect 2007 land value increases.

and grain storage facilities are needed to store more grain for year-round processing at ethanol plants.

The livestock sector has probably been the most strongly affected by rising crop prices. Higher crop prices have led to major gains in feed costs. The USDA indicates that in September 2008, cattle feed costs increased 52 percent and broiler feed costs rose 64 percent over the previous year (USDA, 2008). Feed costs rose less rapidly for cattle producers as they are better able to replace corn with distilled grains, a by-product of ethanol production, in cattle feed rations. Rising feed costs have boosted the breakeven price from livestock feeding: Cattle and hog feeders operated in the red for most of 2008. Still, it is important to remember that rising crop prices are driven by other factors, such as robust export activity, in addition to the ethanol boom.

Ethanol production has contributed to shifts in cattle feeding operations. Livestock numbers have declined in response to higher feed costs and declining profits. With higher feed costs, livestock feeders often slaughter more animals at lower weights to reduce costs. In fact, the number of heifers and gilts sent to slaughter increased in 2007 and slaughter weights for cattle and hogs declined.

The production of distilled grains may have contributed to a modest shift in feeding locations. Distilled grains are a by-product of the ethanol industry and are a partial substitute for corn in cattle feed. However, unlike corn, distilled grains quickly spoil and are difficult to transport. As a result, as was expected, the price of distilled grains fell sharply near ethanol plants and reduced the feed costs of local cattle feeders. With lower feed costs, cattle feeders near ethanol plants would enjoy larger profits and expand production, whereas feeders farther away would cut production. In fact, policymakers in the Corn Belt were touting ethanol production as a way to spark an expansion in the livestock industry. The large-scale shifts in cattle feeding, however, have yet to emerge. From 2005 to 2008, cattle feeding costs in Nebraska and Texas rose 9.3 and 9.5 percent, respectively.

In general, ethanol production has contributed to higher corn prices at the national and local levels. However, other factors, such as export activity, have also contributed to higher prices. Still, higher feed costs are straining profit margins for the livestock industry. Few shifts in the geographic location of livestock production have emerged, although local corn prices and farmland values have risen more in locations closer to an ethanol plant.

NONFARM IMPACTS

While ethanol production has led to mixed impacts on the farm sector, it has led to increased nonfarm activity. Ethanol production stimulates nonfarm activity initially from new plant construction and then through ongoing plant operation. Although ethanol plants do help stimulate nonfarm activity in rural places, the benefits are probably not as large as some initial projections.

Over the past few years, several economic impact studies have been conducted on the ethanol industry. The economic impacts touted in these studies are heavily dependent on the assumptions embedded in the model. As a result, the economic impacts vary with the local labor force, crop production impacts, the local business environment, the economic multipliers used to calculated indirect impacts, changes to industries from ethanol production, and induced impacts (i.e., changes in household spending from additional income to the region).[4]

Ethanol's first nonfarm economic impact occurs during plant construction. Construction activity has the potential to stimulate economic growth in the local community as new workers are hired and various inputs are used for plant construction. However, these impacts are temporary and eliminated after plant completion. A study of four Missouri ethanol plants indicated that the construction phase produced a total of 2,098 construction jobs (Pierce, Horner, and Milhollin, 2007). However, other studies do not model the economic impacts of the construction phase because the jobs are temporary and often filled by out-of-state workers with many of the other services and goods used during construction imported from outside the region (Swenson, 2008). Regardless, the increase in temporary workers does provide an economic boost at

[4] Most economic impacts studies use input-output analysis to model economic impacts. IMPLAN is the program commonly used to conduct the analysis (available at www.implan.com).

Table 3

Economic Impact Estimates for a 100 MGY Capacity Ethanol Refinery

	Hamilton, Illinois		Kankakee, Illinois		Iowa		
Type of impact	Output ($ million)	Jobs	Output ($ million)	Jobs	Output ($ million)	Jobs	Value-added ($ million)
Direct	214.6	39	214.6	39	227.0	46	35.5
Indirect	14.6	97	27.2	152	25.3	95	11.0
Induced	1.6	17	5.7	59	2.0	29	1.2
Total	230.8	153	247.5	250	254.2	170	47.7

SOURCE: Low and Isserman (2009); Swenson (2008).

local restaurants and hotels as temporary workers find places to eat and sleep.

The long-term direct economic impacts from ethanol emerge from the continued operation of the ethanol plant. First, ethanol plants employ people to operate the facility. In general, ethanol plants typically employ between 35 and 45 people. Smaller plants (50 million gallons per year [MGY] capacity) employ roughly 35 people; larger plants (100 MGY capacity) employ more than 40 people (Swenson, 2008; Low and Isserman, 2009). As the size of new plants increases due to economies of scale, the number of workers needed in the ethanol industry could decline if larger plants replace older, smaller plants.

Second, ethanol plants produce ethanol and distilled grains, which boosts overall economic activity in the community. Economic activity often is measured on a gross basis in terms of output (sales) and on a value-added, net basis, measuring the wages and salaries paid to workers, returns to proprietors, investors, and indirect tax payments above and beyond the costs of inputs. Recent studies indicate that a single 100 MGY ethanol plant would boost direct output (gross sales) for the county in which the plant is located by roughly $215 to $227 million dollars and value-added activity by $35.5 million dollars (Table 3).

The direct economic impacts from ethanol plants are expected to ripple through the economy and support increased industry activity and boost household spending. The size of these industry and household impacts depends heavily on the size of the economic multipliers in the local economy. Disagreements over the economic impacts of the ethanol industry vary with the assumptions surrounding the economic multipliers. The biggest economic assumption is the impact on crop production in the region. Studies assuming larger production impacts have larger economic multipliers. Recent economic impact studies (Swenson, 2008; Low and Isserman, 2009) have reduced economic multipliers associated with the ethanol industry (Table 4). Recent studies assume that the local production response is muted because most of the highly productive agricultural farmland is already in production. As a result, most of the changes in crop production will be the substitution of corn for other crop production (Low and Isserman, 2009).[5]

In terms of output, industry (indirect) impacts are much larger than household (induced) impacts. For example, in Iowa, a 100 MGY ethanol plant had an indirect multiplier of 0.11, meaning that for every dollar of output, the ethanol plant stimulated an additional 11 cents in industry output (see Table 4). In contrast, household spending is expected to rise 1 to 3 cents for every dollar increase in output from an ethanol plant.

Industry and household impacts, however, varied with the local business environment and size of the economy. For example, the industry multiplier for a 100 MGY plant was 0.13 in Kankakee,

[5] Many initial studies assumed a fixed-proportions input-output model that does not incorporate various types of potential substitutions in local economic activity (Low and Isserman, 2009).

Table 4

Output and Employment Multipliers from Ethanol Plants

Economic study	Output multiplier	Employment multiplier
Nebraska (Petersan, 2002)		
40 MGY ethanol plant		
Industry (indirect)	0.28	1.90
Household spending (induced)	0.09	0.95
Total	0.37	2.86
Iowa (Swenson, 2008)		
50 MGY ethanol plant		
Industry (indirect)	0.11	2.14
Household spending (induced)	0.02	0.66
Total	0.13	2.80
Iowa (Swenson, 2008)		
100 MGY ethanol plant		
Industry (indirect)	0.11	2.07
Household spending (induced)	0.01	0.63
Total	0.12	2.70
Hamilton, Illinois (Low and Isserman, 2009)		
100 MGY ethanol plant		
Industry (indirect)	0.07	2.49
Household spending (induced)	0.01	0.44
Total	0.08	2.92
Kankakee, Illinois (Low and Isserman, 2009)		
100 MGY ethanol plant		
Industry (indirect)	0.13	3.90
Household spending (induced)	0.03	1.51
Total	0.15	5.41

Illinois (year 2000 population 3,029), compared with 0.07 in Hamilton, Illinois (year 2000 population 25,561). With a much larger and more complex economy, Kankakee has a greater ability to provide more inputs to the ethanol plant and thus a higher indirect multiplier (Low and Isserman, 2009).

A similar pattern emerges from employment, or job, multipliers. Indirect industry multipliers are larger than induced (household spending) multipliers (see Table 4). In addition, larger, more-complex economies are expected to enjoy larger multipliers than small rural economies. It is important to note that rising output and household spending would boost tax revenues at various levels.

LONG-TERM IMPACTS

The ethanol industry is expected to provide valuable future contributions to rural communities. Because expectations regarding the contribution of ethanol plants to economic output have declined recently, the biggest challenge might be shrinking profit margins in ethanol production. Ethanol is a policy-driven market and changes in policy will shape its long-term survival.

The long-term impacts of ethanol production clearly depend on the viability of the ethanol industry. Some analysts indicate that ethanol profitability will rise and fall with crude oil prices. In fact, ethanol prices do move with crude oil prices. How-

Figure 1

Ethanol and Corn Price Spreads

NOTE: Calculation based on Commodity Research Bureau data. The spread shows the net return from the sale of a gallon of ethanol after paying for the corn used to produce it. One bushel of corn is assumed to yield 2.8 gallons of ethanol. Spread = Ethanol Price – (Corn Price/2.8).

ever, corn prices—the largest ethanol production costs—also are moving with ethanol and crude oil prices. Recent history shows that even with record high crude oil prices, ethanol profits have narrowed significantly. Since 2006, ethanol profits have sharply declined as corn prices have risen faster than ethanol prices. The ethanol-corn price spread, which measures the net returns to ethanol after paying for corn, is just one indicator suggesting that profit margins have fallen (Figure 1). The biggest sign of struggles in the ethanol industry is the recent idling of several ethanol plants under construction and the bankruptcy of VeraSun Energy Corporation (McEowen, 2008).

Policy issues probably hold the key to ethanol profitability. As the food-versus-fuel debate intensified, the appetite for ethanol subsidies diminished. A decline in ethanol subsidies and the elimination of the tariff on Brazilian ethanol is expected to lead to lower ethanol production (Thompson, Meyer, and Westoff, 2008). Yet the biggest impact could emerge from the elimination of the ethanol mandate (Westoff, Thompson, and Meyer, 2008).

The reduction in ethanol production and the closure of ethanol production plants could lead to lower economic impacts on rural communities. In general, idling plants would lead to lower crop prices and reduced capitalized returns to cropland at the local level as local demand shrinks. Lost output and employment at the ethanol plant could ripple throughout the local economy, leading to additional job losses and reduced business activity and household spending.

As the ethanol industry works through its own troubling times, which ethanol plants are most susceptible to close? Are older, smaller plants or newer, larger plants in the best position to weather current strains in ethanol profits? Older, smaller plants should have already paid a large proportion of their fixed costs, whereas new, larger plants should have lower fixed costs because of economies of scale. In either case, closures of either type of plant will produce economic losses. However, smaller, older plants with local investors tend to have higher induced impacts on the local economy as local investors spend more money locally

(Swenson and Eathington, 2006). As a result, the closure of locally owned ethanol plants could have larger economic impacts in rural communities than investor-owned plants.

Alternatively, new technologies could emerge to make ethanol more profitable. Since 2001, the ethanol industry has significantly cut the amount of water used in production from almost five gallons of water per gallon of ethanol to less than four (Keeney and Muller, 2006; Wu, 2008). What innovations will emerge from new technology that will boost ethanol productivity? Over the past few years, ethanol yields per bushel of corn have increased 6.4 percent for dry mills (Wu, 2008), rising to 2.8 gallons of ethanol per bushel of corn in 2008. Scientists are also exploring how enzymes could boost ethanol yields (McGinnis, 2007). If the market stabilizes and mandates hold, ethanol production could support economic activity into the future.

CONCLUSION

An ethanol boom has helped spur economic activity in many rural communities. Ethanol production has added value to U.S. corn production and contributed to higher cropland values, but it has posed some challenges to the livestock sector. New ethanol plants have added jobs in many rural communities, which have supported additional gains in related industry and household spending. However, as more insight into the ethanol industry is gained, expectations regarding the wave of pending activity have declined. Proponents have touted ethanol as fueling the current farm boom and spurring a wave of business activity on rural Main Streets. Opponents have identified ethanol as the root cause of lost profitability in the livestock industry. In both cases, the economic impacts of ethanol are probably not as large as touted.

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Commentary

Seth Meyer

There has undeniably been a reversal of fortunes in the ethanol industry since 2006. With petroleum prices well off their peak of mid-2008, the current economic recession, and an uncertain policy environment, Jason Henderson's examination of the role that ethanol plays in rural economic development is well timed and raises important questions concerning the industry's contribution to stimulating the rural economy.

He lays out the potential direct impacts on the rural economy from biofuel-induced changes in employment and commodity prices, as well as the indirect and induced effects, noting the limited direct employment effect found in several studies. Further, he notes that secondary effects hinge on the assumed multiplier effect, which depends on production response, which itself depends on the induced commodity price change. To this end, he does an admirable job of attempting to determine the contribution of biofuels to the runup in commodity prices in mid-2008—no small task. He concludes that biofuels contributed a noticeable amount to the increase in commodity prices but that direct and indirect employment effects may be limited, and given the role policy plays in the industry, it could be dealt a blow with the stroke of a pen. While this author makes no conclusions about the broader benefits of biofuel production, I hope to complement the discussion about effects on commodity prices and the role that federal policy plays in the market for biofuels.

COMMODITY PRICES IN 2007-08: TRANSIENT OR PERSISTENT FACTORS?

A number of factors came together during the 2007-08 crop year, creating the perfect storm. Short- and long-run issues of commodity supply and demand, as well as policies around the world, combined for a significant spike in commodity prices in a setting of strong and volatile petroleum prices. In examining the factors that led to record commodity prices in the summer of 2008, Dr. Henderson draws on research by Fortenbery and Park (2008) to arrive at a $0.63 per bushel contribution to the corn price from the growth in ethanol production over the 2005-08 period. Although this is significant, the increase in prices during the same period was well in excess of that amount.

It is clear that biofuels have had an effect on commodity prices, but estimates have varied considerably from a negligible impact to attributing most of the rise in prices to increased biofuel production. The varying estimates expose the difficulty in arriving at a precise estimate. In addition, the question remains: Are the other contributing factors transient in nature or persistent and likely to resurface as world economies recover from the current economic crisis?

Poor wheat yields in Canada, Eastern Europe, and Australia helped fuel grain prices over the summer of 2008, but these crop shortages could clearly be considered a transient factor that would disappear with a return to normal yields. However,

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Table 1

Change in World Grain Productivity (percent)

Growth measure	1960-70	1970-80	1980-90	1990-2007
Yield	2.8	1.9	2.4	1.3
Area	0.5	0.9	–0.5	–0.2
Production	3.3	2.8	1.6	1.0

SOURCE: USDA Production, Supply and Distribution database (accessed November 1, 2008).

an analysis of grain area and yield around the world shows a potentially concerning slowdown in growth over the past few decades (Table 1), thereby limiting supply growth at the same time consumers in the developing world became more affluent, demanding more meat and therefore increased use of feed. In addition, world grain stocks levels have been low, by historical standards, for the past several years. Policy changes in the United States in the 1980s reduced domestic grain stock holdings just as Chinese grain stocks began to rise. In 2000-01 the Chinese began to liquidate those stocks, thus limiting the ability to draw on them to moderate short-run price increases (Figure 1). With supplies constrained and demand showing little response, prices continued to rise. Several countries, worried about the effect of rising prices on their domestic consumers, instituted trade restrictions on grains, rice in particular. This drove prices yet higher. Add to this the much discussed effect of demand for grain and vegetable oils to produce biofuels both at home and abroad, and it becomes obvious that a precise estimate of the effects of biofuel production on commodity prices is both difficult to quantify and highly context dependent (Westhoff, Thompson, and Meyer, 2008). Had one or several of these factors not been present, one may have arrived at a different conclusion about the price impact of biofuels.

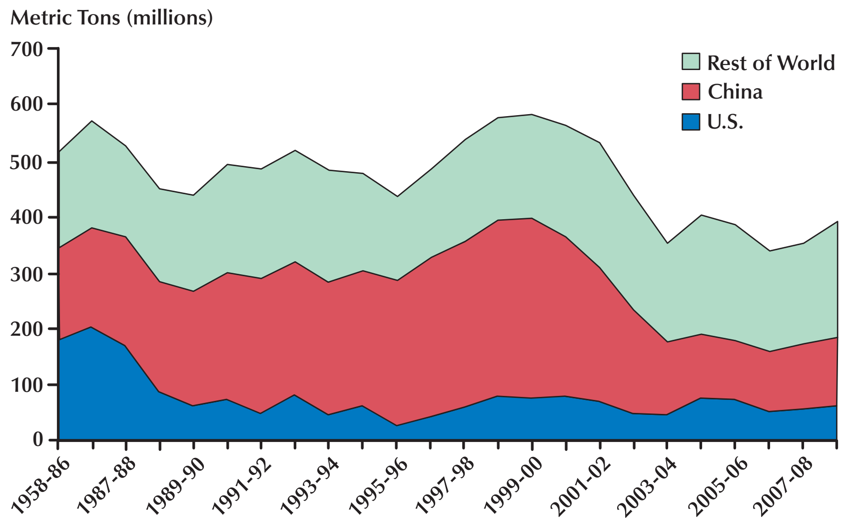
THE IMPORTANCE OF POLICY

The role of current biofuel policy in commodity and biofuel markets is equally context dependent and, as Dr. Henderson clearly outlines, is subject to change with policy priorities. Current policies fall roughly into two categories: (i) tax credits and (ii) quantity mandates established in the Energy Independence and Security Act (EISA) of 2007 (Energy Information Agency, 2008). The credits go to blenders who mix biofuels with traditional petroleum-based motor fuels and are payable at any ethanol price. Mandates require the blenders to blend a specific quantity of biofuel each year subject to a schedule in the EISA legislation. If petroleum prices are at levels similar to those seen in mid-2008, the mandates may be irrelevant as blenders choose to blend quantities in excess of their required amounts, while the blenders' credit will induce further production. In this instance, the blenders' credits influence biofuel production and therefore commodity prices, while mandates have little to no effect. Alternatively, if petroleum prices are at the lower levels seen at year-end 2008, the mandates may be binding, determining demand, and thus removal of blenders' credits may have little to no effect on the quantity of biofuel produced and therefore the demand for grains.

Which policy is the most influential is dependent on the oil price, but the combination of policies boosts biofuel production at all oil prices. A shift in policy, that is, elimination of these policies, would have sizable consequences for the industry (Figure 2). With regard to the construction of new facilities—approximately 13 billion gallons of corn-based ethanol capacity completed or under construction today—this is enough capacity to fulfill corn ethanol's targeted mandate for the next several years. Additional plant construction and the associated jobs will be limited unless petroleum prices return to mid-2008 levels and current policies remain in place. The uncertainty surrounding the

Figure 1

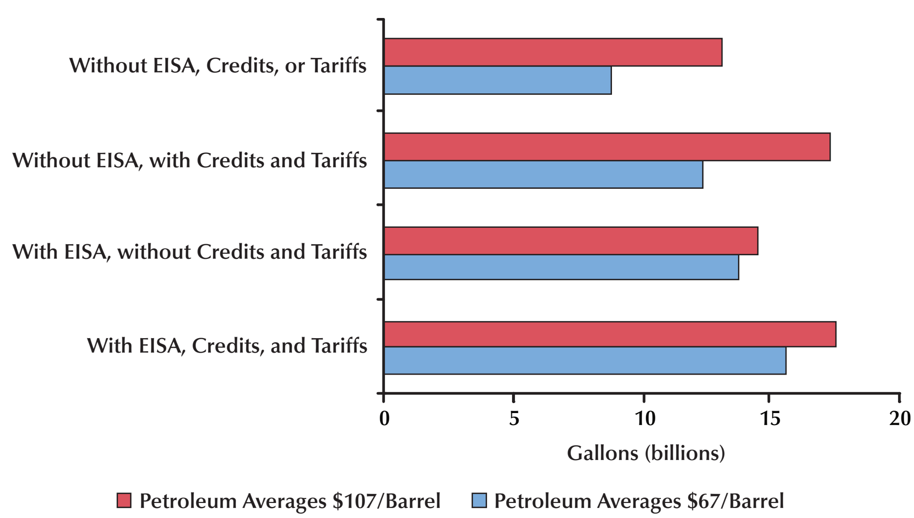
World Grain Stocks



SOURCE: USDA Production, Supply and Distribution database (accessed November 1, 2008).

Figure 2

Petroleum Price Impact on Ethanol Production (2011-17 Average) Under Various Policy Regimes



SOURCE: Westhoff et al. (2008).

continuation of those policies makes for an uninviting investment atmosphere. Other classes of mandates such as cellulosic ethanol hold potential for both increased crop production and profitability and their associated economic activity. The path of these second-generation technologies is unclear and perhaps even more dependent on the continuation of favorable policies.

The current economic crisis and the corresponding decline in petroleum prices have brought new scrutiny to the biofuel industry. High petroleum prices in the spring and summer of 2008 were followed by increased grain production. Although weakness in world income growth has cut demand for feed grains and commodity prices, the decline in petroleum prices has cut biofuel demand, leaving production to be increasingly determined by policy and idling excess capacity. Ethanol producers who locked in grain inputs at higher prices, in fear of yet higher grain prices, have experienced mounting losses, and stock prices for public companies in the industry have fallen precipitously over the past 24 months. When the world economy begins recovery and world grain and petroleum demand strengthens, much in the biofuel sector will depend on how petroleum prices respond. Should the recovery lead to rapidly increasing petroleum prices, we could return to strong commodity prices once again, likely with a response by the biofuel industry that incorporates lessons learned during the past 24 months.

Whereas ethanol advocates cite numerous reasons for supporting domestic production of biofuels, Dr. Henderson raises all the relevant concerns in evaluating the industry as a rural development tool. Biofuel production clearly has some impact on commodity prices and his estimates appear plausible, but the size and persistence of such increases remain uncertain, as do the net effect of those prices given the offsetting livestock producer impacts, increase in land prices, and concerns about consumers in developing countries. The direct effects on employment appear limited with secondary effects largely dependent on the assumed multiplier effect, and a portion of the industry production is also reliant on public policy for continued viability. Dr. Henderson's arguments concerning biofuel production as a limited tool for rural development are convincing, but the broader discussion about the objectives of supporting domestic biofuel production is likely to continue for the foreseeable future.

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Panel Discussion: The Future of Biofuel

An Economic Critique of Corn-Ethanol Subsidies

Jerry Taylor

If corn ethanol is such a wonderful product, why does it require government subsidy?[1] If ethanol is truly economically competitive with gasoline absent government preference—as many of its supporters seem to believe—then private investors will produce ethanol for the market regardless of whether government lends a hand (Tyner and Taheripour, 2008).[2] Subsidies in this case will simply result in more ethanol production than is economically efficient. If ethanol is *not* economically competitive with gasoline, then subsidies distort the market by steering investment away from economically attractive gasoline and toward economically unattractive ethanol. Consumer well-being and overall economic efficiency suffer as a consequence.

Support of ethanol subsidies and consumption mandates offer a mix of arguments to justify government intervention. Those arguments can be neatly sorted into two categories: those that forward wealth distribution claims and those that forward efficiency claims. The former arguments, although interesting, are not addressed in this paper. Ethanol may or may not transfer wealth to rural America, for instance, but preferences with regard to wealth allocation are subjective and not worth much analytic time. The latter arguments, however, are grounded in concrete claims that can be proven or disproven and are, thus, the focus of this paper.

To have any intellectual force, the argument that ethanol subsidies and consumption mandates enhance economic efficiency must begin with a discussion of market failure. Economists broadly agree that, as a general rule, leaving production and consumption decisions to market actors proves more economically efficient than leaving the same to governmental planners. Only if some unique and fundamental failure occurs that prevents gains to trade in a given market is there room for the argu-

1 This paper is exclusively concerned with ethanol made from corn. Unless otherwise indicated, all references to ethanol are in relation to ethanol made from corn. When economists discuss ethanol subsidies, they are almost always referring to four subsidies in particular: a $0.51 per gallon blenders' tax credit afforded to refineries that use ethanol in motor fuel (known in the law as the Volumetric Ethanol Excise Tax Credit, it is scheduled to be reduced to $0.45 per gallon in 2009); a Renewable Fuels Standard that requires U.S. refiners to consume a certain amount of ethanol per year (9 billion gallons, for instance, in 2008, rising to 36 billion gallons by 2022); a 2.5 percent ad valorem tariff on ethanol imports; and a $0.51 per gallon tariff on the same. However, a number of other direct and indirect federal, state, and local subsidies afforded to the ethanol industry in aggregate are quite large but are rarely considered in the peer-reviewed literature (Hahn, 2008). That is largely because such subsidies are difficult to quantify in a satisfactory manner and because they are often afforded to other industries besides ethanol, leading to debate about whether it is appropriate to consider them as ethanol subsidies per se. The Energy Information Administration (EIA; 2008) pegs the cost of ethanol subsidies to the taxpayer at $3 billion in 2007. The best guess of the total federal subsidy afforded to the ethanol industry that year, however, is conservatively estimated at $6.9 to $8.4 billion and $9.2 to $11 billion in 2008, or $1.50 to $1.70 per gallon of gasoline-equivalent ethanol (Koplow, 2007).

2 Tyner and Taheripour (2008) believe that ethanol production in the United States was (barely) profitable without subsidy (defined as operations clearing a 12 percent or better return on equity) for the first time in 2001. From 2002 to 2003 production returned to unprofitability absent subsidies, but from 2004 to 2007 significant profits were realized even without subsidy largely because of the de facto ban on methyl tertiary-butyl ether as a fuel additive and a surge in ethanol demand to provide those blending services. In 2008, however, production again reached the break-even point.

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ment that government intervention improves the functioning of those markets (Cowen, 1988, and Cowen and Crampton, 2003). Hence, the case for ethanol subsidies hinges on whether concrete market failures exist in transportation fuel markets.

This paper examines the claims made about alleged market failures in transportation fuel markets. Two claims in particular warrant examination: that gasoline prices are too low because they do not account for the national security costs associated with gasoline consumption and that the environmental costs associated with gasoline consumption are ignored in the pricing mechanism. Subsidy proponents argue that if gasoline prices included both the national security and environmental costs associated with gasoline consumption, ethanol would be much cheaper than gasoline and demand for the latter would grow dramatically. Alas, those costs ("externalities" in economic parlance) are not embedded in final consumer prices and thus market actors, left to their own devices, will overconsume gasoline and underconsume ethanol. Other market failures have been alleged but they are altogether less compelling than these two. A cursory examination of a few of them follows.

"BIG OIL" MARKET POWER

We occasionally hear that "Big Oil" exercises their market power to the detriment of motorists by restricting ethanol's entry into end-use fuel markets (Cooper, 2005). The oil industry's reluctance to use high blends of ethanol in gasoline absent a government mandate, build ethanol delivery infrastructure to supply service stations, or provide E85 pumps[3] are often marshaled as evidence that oil companies are unfairly strangling an economic competitor in its bed. The existence of this self-serving oil cartel is said to explain why this otherwise commercially attractive transport fuel—ethanol—requires government subsidies and consumption mandates.

Yet, as of 2007, 38 percent of the retail fuels market was composed of independent service stations, not vertically integrated franchises, and another 13 percent of grocers and other hypermarkets. Only 49 percent of retail fuel was sold by stations associated with major oil companies. Likewise, 56 percent of the refining market was composed of independent, vertically deintegrated refining companies (Lowe, 2008). Big Oil is simply incapable of keeping ethanol out of service stations if profits are to be made by selling ethanol to motorists.

Statistical analysis of market data finds no evidence that market power in the oil sector has any impact on national retail motor fuel prices, although mergers and acquisitions have likely increased fuel prices in some regions while decreasing them in others (Chouinard and Perloff, 2007, and Taylor and Van Doren, 2006). Likewise, metrics regarding market concentration in the refining sector (such as the Herfindahl-Hirschman Index) do not suggest much market power in four of the five refining Petroleum Administration Defense District regions of the United States (Du and Hayes, 2008).

The economic and regulatory hurdles to entering the refining or retail sales markets are modest. Refineries change hands frequently—as do service stations. This factor is important because many economists now believe that, if a market is theoretically contestable, market power is functionally modest to nonexistent (Baumol, 1982; and Baumol and Panzer, 1982), although actual entry may still be important in some industries (Borenstein, 1992).[4]

Finally, ethanol is delivered primarily by rail but also by truck and barge. The oil industry is in no position to block the expansion of that infrastructure or to prevent third parties from investing in dedicated ethanol pipelines (ethanol cannot move through pipelines used for oil or gasoline because ethanol is water soluble).

A variation of the above narrative holds that oil refining capacity is so tight that, absent govern-

[3] E85 is motor fuel that is 85 percent ethanol and 15 percent gasoline.

[4] Many states prohibit entry to some extent in retail fuel markets by preventing major retailers like Cosco, Sam's Club, and Wal-Mart from selling motor fuel. Likewise, zoning laws and environmental regulations have been identified as barriers to entry in some markets. Those are government failures, however—not market failures—and should be addressed by deregulation. Given the inclination of many major retailers to project "green" images to consumers, it may well be that deregulating entry would increase the availability of ethanol to consumers.

ment efforts to promote ethanol, American consumers would have suboptimal volumes of motor fuel available to them and, accordingly, higher pump prices. Thus, the argument is that ethanol increases the amount of motor fuel available—effectively adding to capacity—and serves the role that, for instance, Hamburger Helper serves in increasing the volume of food on a plate of ground beef.

The argument is superficially true. Assume, for instance, that all ethanol disappeared tomorrow. In the short run, gasoline refining capacity is relatively fixed and consumers do not respond robustly to price increases in the short term. Hence, the highly inelastic short-term supply-and-demand curves for gasoline suggest that gasoline prices would increase dramatically—14.6 percent according to a 2004 analysis circulated by the Renewable Fuels Association (Urbanchuk, 2004), a figure that would be even higher today given ethanol's larger share of the motor fuels market in 2008. Supply and demand are more elastic in the long run, so ultimately, prices would rise only 3.7 percent in the long term according to that same analysis.

What is the market failure, however, that leads industry to underinvest in refining capacity? Sometimes we are told that industry conspires to restrain refining capacity to maximize profit (Cooper, 2007). This is a variation of the previous argument about monopoly power in the oil sector. It is also an argument that, even if true, does not necessarily provide evidence of market failure. The exercise of market power may have an impact on wealth distribution (refinery owners are wealthier and everyone else is poorer), but it likely has little impact on overall market efficiency (Posner, 1999).

Many analysts believe that the lack of excess refining capacity is largely driven by the limited profits historically made by those who invest in refining. To the extent that ethanol programs significantly reduce refining profits (see Du and Hayes, 2008), the problems ostensibly addressed by ethanol subsidies may actually contribute to the existence of the underlying problem.

Other times we are told that government policies discourage the construction of new refineries and the expansion of capacity at existing facilities. Although it is unclear to what extent this is true, if government policies inhibit optimal capacity expansion it is a government failure, not a market failure, and is best remedied by direct assault on the policies in question.

The strongest study offered as evidence that ethanol subsidies have reduced motor fuel prices is by economists Xiaodong Du and Dermot Hayes at the Center for Agriculture and Rural Development at Iowa State University (Du and Hayes, 2008). Their regression analysis concludes that ethanol production has reduced retail gasoline prices by $0.29 to $0.40 per gallon from 1995 to 2007 because it has "prevented some of the dramatic price increases often associated with an industry operating at close to capacity" (p. 13).

The Du and Hayes study (2008) does not, however, support the contention that, in a hypothetical world in which ethanol production did not exist, motor fuel prices would be higher. That is because the study assumes that, without ethanol production, gasoline refining capacity would not have grown any more than it did with ethanol production. Given that total refining capacity has historically expanded to meet increased demand (Shore and Hackworth, 2004), it is likely that, absent ethanol production, capacity expansion would have occurred and fuel prices in that counterfactual world would have been no higher than they were historically. The authors acknowledge as much: "Because these results are based on capacity, it would be wrong to extrapolate the results to today's markets. Had we not had ethanol, it seems likely that the crude oil refining industry would be slightly larger today than it actually is, and in the absence of this additional crude oil refining capacity the impact of eliminating ethanol would be extreme" (pp. 13-14).

The Du and Hayes (2008) study also implicitly assumes a fixed amount of oil production. Ample anecdotal evidence, however, suggests that oil producers have responded to U.S. ethanol production by reducing investments in upstream production capacity. This seems reasonable given that ethanol consumption displaces oil consumption and projections about the same heavily affect decisions about investment in future oil production capacity. Consequently, ethanol's impact on oil prices is ambiguous.

Even if ethanol subsidies reduced motor fuel prices, it does not follow that motorists are, on balance, better off. For instance, the two Iowa State economists who produced the aforementioned estimate regarding the reduction of motor fuel prices that has followed from ethanol subsidies (Du and Hayes, 2008) also contend (in Du, Hayes, and Baker, 2008) that the total social costs associated with ethanol subsidies are greater than the aggregated benefits. Cornell economists Harry de Gorter and David Just (2007b) argue that the spread between the two is even greater than alleged by Du, Hayes, and Baker.

This should not be surprising. Subsidies for wheat, corn, soybeans, and other crops produce lower commodity prices, but very few economists argue that gains to consumers outweigh the efficiency losses imposed by those subsidies on the economy as a whole. What consumers gain is more than offset by taxes and the loss as a market actor in other sectors of the economy.

FARM SUBSIDIES

Some have argued that ethanol subsidies actually *reduce* the net burden of subsidies on the taxpayer because the higher corn prices yielded by ethanol subsidies reduce other subsidy payments that would have otherwise gone to corn farmers. This appears to be correct, at least for 2007. Reductions in loan deficiency payments to corn farmers exceeded the costs of the ethanol program by $3.45 billion in that year (Du, Hayes, and Baker, 2008).

Yet it does not follow that ethanol subsidies therefore enhance efficiency. First, the taxpayer savings identified by Du, Hayes, and Baker (2008) do not account for all of the deadweight losses associated with ethanol subsidies.[5] Total deadweight losses are, in aggregate, greater than the advertised savings to the taxpayer (de Gorter and Just, 2007b). Second, although that same study finds a net reduction in farm payments from the ethanol program, it also finds that the net total of social cost associated with the refiners' tax credit, the ethanol consumption mandate, and the ethanol tariff (absent any consideration of the alleged national security or environmental benefits of ethanol) was $780 million in 2007.

One further point should be made. The existence of farm subsidies is not a market failure—it is a government failure. In a narrow sense, ethanol subsidies may reduce the cost of farm subsidies to the taxpayer, but a far more direct and less-costly means of doing the same is simply to dismantle the farm subsidies in question.

LEVELING THE PLAYING FIELD

Ethanol proponents frequently note that government provides substantial subsidies to the oil sector. The belief is that those subsidies provide commercial advantages to oil producers and oil prices are lower as a consequence; that is, oil subsidies distort the market by encouraging excessive oil consumption. Thus, ethanol proponents believe that subsidies for ethanol, beyond simply leveling the competitive playing field, make the economy more efficient by reducing oil consumption from the inefficiently high levels promoted by subsidies to the oil sector.

The EIA pegged federal oil and natural gas subsidies at $2.15 billion in 2007 (EIA, 2008). A more ambitious tally suggests that oil subsidies, broadly defined, were $5.2 to $11.9 billion in 1995, or $1.20 to $2.80 per barrel (Koplow and Martin, 1998; the estimate does not include environmental or national security externalities and, unfortunately, has not been updated). Although laws and outlays have changed substantially since Koplow and Martin's publication (although the EIA's tally finds no appreciable change in the sum of federal oil and gas subsidies since 1999), their estimate illustrates the importance of defining subsidy beneficiaries. To wit, are subsidies programs that exclusively benefit the targeted industry (the EIA definition), or do they also include programs that benefit the recipient and other parties outside that sector of the economy (the Koplow and Martin definition)?

[5] Deadweight losses arise from the economic distortions associated with tax avoidance and changes in social and economic behavior in response to regulatory intervention. A textbook exposition of deadweight loss can be found in Rosen and Gayer (2008).

The EIA calculates that federal oil and gas subsidies outside the electricity sector total $30,000 per million British thermal units (BTUs). Biofuel subsidies outside the electricity sector, however, ($3 billion of the $3.2 billion of which are directed at ethanol via the blenders' tax credit), work out to $5.72 million per million BTU (EIA, 2008, Table 36). Using EIA figures for oil and gas subsidies and estimates of the cost of the blender's tax credit from Koplow (2007), economist Douglas Tiffany (2008) calculates that oil subsidies in 2007 were slightly less than $0.15 per gallon of gasoline while ethanol subsidies totaled $0.588 per gallon. Whether we embrace a narrow or broad definition of subsidy, the conclusion is the same; oil subsidies are relatively trivial while ethanol subsidies are relatively substantial.

Although none of the identified oil subsidies is defensible on economic grounds, they have very little if any impact on oil prices because they do not reduce marginal production costs (Metcalf, 2006). Hence, oil subsidies do not distort the market and do not disadvantage ethanol producers. There is no efficiency problem for ethanol subsidies to correct.

Ethanol subsidies, however, are more pernicious. Unlike oil subsidies, ethanol subsidies reduce marginal production costs and, as a consequence, distort price signals and thus capital allocations in the market. The ethanol subsidy "cure" in this case is far worse than the oil subsidy "disease."

NATIONAL SECURITY EXTERNALITIES

Among the most fashionable preoccupations in foreign policy circles is "energy security." Although the precise meaning of energy security is unclear, foreign policy elites have long been concerned about U.S. reliance on foreign energy (an exception is Gholtz and Press, 2007). Fear of embargoes and supply disruptions affects how Western nations deal with oil- and gas-producing states, what sort of policies are pursued in the Middle East, and even fundamental questions of war and peace.

Proponents of ethanol subsidies argue that if the price of oil included the cost of our "oil mission" in the Middle East, the wars that the U.S. military engages there to protect oil supplies, the costs associated with our need to "kiss the ring" of Middle Eastern oil producers, the economic damage by terrorists from the flow of petrodollars into their coffers, and the harm done to U.S. interests by oil-rich states like Iran, Venezuela, and Russia, then oil consumption would be far less than it is now. Alas, it is believed that those national security externalities are not embedded in gasoline prices and, as a result, gasoline consumption is heavily subsidized. Ethanol consumption is thus suboptimal and ethanol subsidies are an appropriate remedy.

Economists, however, are far less worried about the national security costs of America's reliance on oil (foreign or otherwise) (Bohi and Toman, 1996) and with good reason: Economists understand oil markets far better than do foreign policy elites. The alleged national security externalities associated with gasoline consumption are for the most part a figment of an imagination unmoored from a good understanding of market reality.[6]

Blood for Oil

Many believe that reliance on foreign oil requires the United States to militarily defend friendly exporting states and to ensure the safety of oil supply facilities and shipping lanes. Those marching under banners declaring "No Blood for Oil" seem to believe that is the case, as do most mainstream foreign policy analysts. Delucchi and Murphy (2008) offer a rigorous attempt to quantify the public dollars associated with the "oil mission." They suggest that if motor vehicles in the United States did not consume Persian Gulf oil, the U.S. Congress would have likely reduced military expenditures by $13.4 to $47 billion in 2004 (one of the

[6] Greene and Leiby (2006) argue that oil-price volatility imposes significant economic losses and that ethanol is less subject to disruption and thus offers economic advantages. Although empirical claims appear to be untrue, U.S. data from 1960 to 2005 demonstrate that corn harvests are far more variable than oil import volumes (Eaves and Eaves, 2007). Even if that were not the case, price volatility does not suggest a market failure. If ethanol were more commercially attractive because its price were more stable, refiners would take that into account when making decisions about optimal motor fuel blends. The claim that oil price volatility imposes an externality on third parties does not comport with the standard definition of market failure in that the same would hold true for all price changes anywhere in the economy (economists refer to this phenomenon as a "pecuniary externality"; Huntington, 2002).

two years examined in the analysis). If U.S. motor vehicles did not consume any oil at all, military expenditures would have, oddly enough, gone down by far less: by $5.8 to $25.4 billion in 2004. The "best guess" of this analysis is that, if U.S. gasoline consumers were forced to pay for the U.S. oil mission, gasoline prices would increase by $0.03 to $0.15 per gallon.

Simple economics, however, suggests that the oil mission—however large it may be—is unnecessary, regardless of what Congress may think. Oil producers will provide for their own security needs as long as the cost of doing so results in greater profits than equivalent investments could yield. Because Middle Eastern governments typically have little of value to trade except oil—oil revenues, for instance, are 40 to 50 percent of Iranian government revenues and 70 to 80 percent of Saudi government revenues—they must secure and sell oil to remain viable (EIA, 2006). Given that their economies are so heavily dependent on oil revenues, Middle Eastern governments have even *more* incentive than do consuming states to worry about the security of oil production facilities, ports, and shipping lanes (West, 2005).

In short, whatever security our military presence provides (and many analysts think that our presence actually *reduces* security; see Jervis, 2005) would be provided by incumbent producers were the United States to withdraw. That Saudi Arabia and Kuwait paid for 55 percent of the cost of Operation Desert Storm suggests that keeping the Strait of Hormuz free of trouble is certainly within their means.

The same argument applies to al Qaeda threats to oil production facilities. Producer states have such strong incentives to protect their oil infrastructure that additional Western assistance to do the same is probably unnecessary. Although terrorists do indeed plot to disrupt oil production in Saudi Arabia and elsewhere, there is no evidence to suggest that producer-state security investments are insufficient to protect their interests.

The U.S. oil mission is thus best considered a taxpayer-financed gift to oil regimes (and, perhaps, the Israeli government) that has little, if any, effect on the security of oil production facilities or, correspondingly, the price of oil. One may support or oppose such a gift, but our military expenditures in the Middle East are not necessary to remedy a market failure.

Foreign Policy Distortions

Many foreign policy analysts believe that U.S. oil imports are dependent on friendly relationships with oil-producing states. The fear is that unfriendly regimes might not sell us oil—a fear that explains why former Federal Reserve Chairman Alan Greenspan supported the two Gulf Wars against Iraq (Woodward, 2007). Others believe, however, that maintaining good relations with oil producers interferes with other foreign policy objectives—such as the defense of Israel and the pursuit of Islamic terrorists—and increases anti-American sentiment in oil-producing states with unpopular regimes (Scheuer, 2007 and 2008). The problem with this argument, however, is that its fundamental premise is incorrect. Friendly relations with producer states neither enhance access to imported oil nor lower its price (Adelman, 1995).

Selective embargoes by producer nations on some consuming nations are unenforceable unless all other nations on Earth refuse to ship oil to the embargoed state or a naval blockade is used to prevent oil shipments into the ports of the embargoed state. That is because, once oil leaves the territory of a producer, market agents—not agents of the producer—dictate where the oil goes, and anyone willing to pay the prevailing world crude oil price can have all he or she wants. The 1973 Arab oil embargo is a perfect case in point. U.S. crude oil imports actually increased from 1.7 million barrels per day (MBD) in 1971 to 2.2 MBD in 1972, 3.2 MBD in 1973, and 3.5 MBD in 1974 (EIA, 2004). Instead of buying from Arab members of the Organization of the Petroleum Exporting Countries (OPEC), the United States bought from non-Arab oil producers. The customers displaced by the United States bought from Arab members of OPEC. Beyond the modest increase in transportation costs that followed this game of musical chairs, the embargo had no impact on the United States (Fried, 1988, Parra, 2004, and Adelman, 1995). In short, all that matters for the majority of consumers is how much oil is produced for world markets, not from whom the oil was initially purchased.

Do oil-producing nations allow their feelings toward oil-consuming nations to affect their production decisions? Historically, the answer has been "no." The record strongly indicates that oil-producing states, regardless of their feelings toward the industrialized West, are rational economic actors. After a detailed survey of the world oil market since the rise of OPEC, oil economist M.A. Adelman concluded, "We look in vain for an example of a government that deliberately avoids a higher income. The self-serving declaration of an interested party is not evidence" (Adelman, 1995, p. 31). Philip Auerswald of George Mason University agrees, stating "For the past quarter century, the oil output decisions of Islamic Iran have been no more menacing or unpredictable than Canada's or Norway's" (Auerswald, 2007, p. 22).

If energy producers are wealth maximizers, what do we make of countries that are selling oil and natural gas to others at below-market rates? For instance, Russia sold oil to Cuba at below-market prices during the Cold War; Russia has long sold natural gas to Ukraine at below-market prices but has ended its natural gas subsidy to Georgia as relations have soured; and China sells oil to North Korea at low rates and used this as leverage to induce North Korea to bargain over its nuclear weapons program.

Two conclusions seem reasonable. First, sellers have leverage in natural gas markets that is not possible in oil markets because oil can be transported easily, whereas natural gas is shipped through pipelines. Buyers have few near-term alternatives if natural gas sellers reduce shipments. As liquefied natural gas gains market share, however, natural gas markets will look increasingly like world crude oil markets, and the ability of Russia or other states to extract concessions from consumers will dissipate.

Second, the Russia-Cuba and China–North Korea cases involve poor countries receiving foreign aid in the form of low-priced oil. We are unaware of any wealthy Western countries receiving such in-kind aid from oil-producing countries.

What if a radical new actor were to emerge on the global stage? For example, if the House of Saud were to fall and the new government consisted of Islamic extremists friendly to Osama bin Laden, the new regime might reduce production and increase prices. But that scenario is by no means certain given that Iran—despite all its anti-Western rhetoric—has not reduced oil output.[7]

Regardless, the departure of Saudi Arabia from world crude oil markets would probably have about the same effect on domestic oil prices as the departure of Iran from world crude oil markets in 1978. The Iranian revolution reduced oil production by 8.9 percent, whereas Saudi Arabia accounts for about 13 percent of global oil production today. Oil prices increased dramatically after the 1978 revolution, but those higher prices set in motion market supply-and-demand responses that undermined the supply reduction and collapsed world oil prices eight years later (Adelman, 1995). The short-term macroeconomic impacts of such a supply disruption would actually be less today than they were then, given the absence of price controls on the U.S. economy and our reduced reliance on oil as an input for each unit of gross domestic product (Dhawan and Jeske, 2006, Walton, 2006, and Fisher and Marshall, 2006).

So while it is possible that a radical oil-producing regime might play a game of chicken with consuming countries, producing countries are very dependent on oil revenue and have fewer degrees of freedom to maneuver than consuming countries. Catastrophic supply disruptions would harm producers more than consumers, which is why disruptions are extremely unlikely. The best insurance against such a low-probability event is to maintain a relatively free economy where wages and prices are left unregulated by government. That would do more to protect the West against an extreme production disruption than anything else in government's policy arsenal.

Oil Profits for Terrorists

Does Western reliance on oil put money in the pocket of Islamic terrorists? To some degree, yes. Does that harm Western security? Probably not—at least, probably not very much.

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[7] While it is true that oil production in Iran was about twice as high under the Shah than it has been under the Islamic Republic, almost all analysts agree that this reflects the damage to the oil infrastructure during the 1980-88 war with Iraq, the "brain drain" that has occurred in response to the revolution, and poor state management of Iranian oil assets—not the intentional result of state policy.

Before we go on, it is worth noting that only 15.5 percent of the oil in the world market is produced from nation-states accused of funding terrorism (Lundberg Survey, 2006). Hence, the vast majority of the dollars we spend on gasoline do not end up on this purported economic conveyer belt to terrorist bank accounts.

Regardless, terrorism is a relatively low-cost endeavor and oil revenues are unnecessary for terrorist activity. That a few hundred thousand dollars paid for the 9/11 attacks suggests that the limiting factors for terrorism are expertise and manpower, not money.

This observation is strengthened by the fact that there is no correlation between oil profits and Islamic terrorism. In Taylor and Van Doren (2007), we estimated two regressions using annual data from 1983 to 2005: the first between fatalities resulting from Islamic terrorist attacks and Saudi oil prices and the second between the number of Islamic terrorist incidents and Saudi oil prices. In neither regression was the estimated coefficient on oil prices at all close to being significantly different from zero.[8]

During the 1990s, inflation-adjusted oil prices and profits were low. But the 1990s also witnessed the worldwide spread of Wahhabi fundamentalism, the buildup of Hezbollah, and the coming of age of al Qaeda. Note too that al Qaeda terrorists in the 1990s relied on help from state sponsors such as Sudan and Afghanistan—nations that are not particularly known for their oil wealth or robust economies.

Producer states do use oil revenues to fund ideological extremism. Saudi financing of madrassas and Iranian financing of Hezbollah are good examples. But given the importance of those undertakings to the Saudi and Iranian governments, it is unlikely that they would cease and desist these activities simply because oil profits were down. They certainly were not deterred by meager oil profits in the 1990s.[9]

The futility of reducing oil consumption as a means of improving national security and energy independence is illustrated by the fact that states accused of funding terrorism earned $290 billion from oil sales in 2006 (Lundberg Survey, 2006). Even if that sum were cut by 90 percent, that would still leave $29 billion at their disposal—more than enough to fund terrorism given the minimal financial needs of terrorists.

Rents to Bad Actors

When oil prices are high, so too are oil profits for inframarginal (low-cost) producers. Even if those profits do not find their way to international terrorists, they prop up many regimes we find distasteful. Oil producers in the Second and Third worlds often use their robust flow of petrodollars to squelch human rights at home and to menace neighbors abroad. Many foreign policy elites argue that oil consumption thus harms our national security by strengthening these bad international actors (Lugar and Woolsey, 1999, and Council on Foreign Relations, 2006).

It is unclear to what extent oil profits are associated with human rights abuses or militaristic activity. Examples abound: Relatively long-lived regimes with terrible human rights records—such as North Korea—have no oil revenues to speak of, and this is the case even within the same socioeconomic region. Denuding Iran and Libya of oil revenues might produce a government that looks a lot like Syria, and denuding Venezuela of oil revenues might produce a government that looks a lot like Cuba. After all, most of the "bad acting" petrostates that foreign policy elites worry about yielded unsavory regimes even when oil revenues were a small fraction of what they are today.

The claim that oil revenues increase the threat posed by such regimes to their neighbors seems reasonable enough, but again, the extent to which this is true is unclear. Pakistan is a relatively poor country with few oil revenues but it has still managed to build a nuclear arsenal and is constantly on the precipice of war with India. Impoverished, oil-poor Egypt and Syria have at various times been

[8] Unit root tests suggested that fatalities and Saudi oil prices had unit roots but terrorist incidents did not, so the former were first differenced before the regressions. Even after first differencing, autocorrelation existed, so autoregressive terms were added to each regression, which further weakened the insignificant relationships.

[9] Although little is known about funding trends associated with Iranian support for Hezbollah, the Iranian government probably spends no more than $25 to $50 million on Hezbollah a year (Cordesman, 2006). Less is known about Saudi contributions to Islamic extremism (Prados and Blanchard, 2004).

the most aggressive anti-Israeli states in the Middle East. Russia launched its war with Chechnya before oil revenues engorged its treasury.

While I have little doubt that—all other things being equal—a rich bad actor is more dangerous than a poor bad actor, the marginal impact of oil revenues on "bad acting" might well be rather small. That unsavory petrostates have been fully capable of holding on to power, oppressing their people, and menacing their neighbors during a decade associated with the lowest inflation-adjusted oil prices in history (the 1990s) suggests that nothing short of rendering oil nearly valueless will have any real effect on regime behavior.

For the sake of argument, however, let us assume that there is some incremental benefit associated with reducing oil revenues to bad-acting oil producers. Unfortunately, we have only very blunt and imperfect instruments at hand to achieve that end. Policies that might reduce oil consumption would reduce oil demand—and thus, reduce revenues—for *all* oil producers, regardless of whether they are bad actors. Producers in the North Sea, Canada, Mexico, and the United States (which collectively supplied 20.1 million barrels of oil per day in 2006, or 24 percent of the world's crude oil needs that year) would be harmed just as producers in Venezuela, Iran, Russia, and Libya (which collectively supplied 20.3 million barrels per day in 2006) (EIA, 2007).

Given bad acting aplenty in 1998 with the lowest real oil prices in world history, it is unlikely that even the most ambitious policies to reduce oil consumption would have much effect on bad acting. Accordingly, there is good reason to doubt that the foreign policy benefits that might accrue from anti-oil policies would outweigh the very real costs that such policies would impose on both consumers and innocent producers. There are certainly better remedies available to curtail bad behavior abroad.

The Ethanol Remedy

If significant national security externalities *did* exist and were, as a result, significantly affecting gasoline prices, the most direct and efficient remedy would be a tax on oil imports. That would get gasoline prices "right" and lead to optimal motor fuel consumption patterns. Countervailing ethanol subsidies are an extremely inefficient means of remedying the problem given the deadweight losses and inefficiencies associated with most forms of subsidy. They also substitute prospective market judgments regarding appropriate motor fuel consumption with political judgments that are unlikely to prove correct.

Regardless, ethanol production cannot displace significant amounts of gasoline consumption (Akinci et al., 2008). Even if the entire U.S. corn harvest were dedicated to ethanol production, only 3.5 percent of current gasoline consumption would be displaced (Eaves and Eaves, 2007). All available cropland in the United States would have to be dedicated to corn production if all U.S. vehicles were powered by fuel composed of E85 ethanol. By 2036, all rangeland and pastureland would have to be added to that total to maintain adequate production. By 2048, all land outside of urban centers would be required for corn production (Dias de Oliveira, Vaughan, and Rykiel, 2005). Thus, no matter one's opinions about the dangers of oil dependence (foreign or otherwise), corn ethanol cannot displace enough oil to matter.

ENVIRONMENTAL EXTERNALITIES

Many believe that gasoline consumers are being subsidized because they are not required to compensate third parties for the air pollution associated with gasoline consumption. If those environmental externalities were "internalized" via regulation or taxes, gasoline prices would be far higher, gasoline consumption would be consequently lower, and ethanol production would be far greater. Ethanol subsidies are defended as the second-best means of improving market efficiency.

There are three difficulties with this argument. First, it is very unclear how large the externalities are in monetary terms, making it impossible for analysts to know whether interventions to correct those externalities are actually improving or worsening market efficiency. The best available evidence, however, suggests that the air emissions externalities are probably so low that internalizing them via the first-best policy avenue—a pollution tax—would not affect gasoline prices enough to significantly affect the motor fuels market. Second, ethanol's environmental advantages relative to gasoline are greatly overstated. The negative environmental externalities associated with ethanol may well be even greater than those associated with gasoline.[10] Even if they are not, ethanol's environmental advantages are almost certainly not large enough (in monetarized terms) to significantly alter the fuel mix in motor fuels markets. Third, ethanol subsidies are an extremely inefficient means of addressing the environmental externalities of gasoline; far better means of addressing this market failure exist.

Conventional Air Pollutants

It is unclear to what extent there are uninternalized externalities associated with conventional air pollutants from gasoline. A recent review of the peer-reviewed literature suggests that monetized damages from the same might range from $0.016 to $0.184 per mile, which translates into $0.36 to $4.20 per gallon (Parry, Walls, and Harrington, 2006). A frequently cited "best guess" regarding the cost of the conventional air emissions generated by gasoline consumption is $0.16 per gallon (Parry and Small, 2005).

The biggest problem with the above exercises—beyond the uncertainty associated with the human health impacts of exposure to small doses of potentially dangerous air contaminants—is that these studies do not consider the extent to which existing regulation imposes costs on gasoline consumption and the extent to which those costs function as a tax. If, for instance, the conventional air emissions externality were $0.16 per gallon but regulatory policy reduced emissions to where they would have been had a $0.16 per gallon tax been imposed in a world without regulation, then there would be no externality: The consumer would, in a sense, be paying for the pollution costs associated with gasoline consumption (albeit indirectly). Accordingly, the above calculations provide limited guidance to policymakers seeking to promote optimal gasoline prices (Nye, 2008).

Regardless, ethanol is a poor remedy for whatever externalities may exist in this arena. A review of the academic literature finds that, when evaporative emissions are taken into account, ethanol in fuel blends sold on the market today

- increases emissions of total hydrocarbons, nitrogen oxides, nonmethane organic compounds, and air toxics (particularly acetaldehyde, formaldehyde, ethylene, and methanol) relative to conventional gasoline; but
- decreases emissions of carbon monoxide (Niven, 2005; other studies broadly consistent with Niven's findings include von Blottnitz and Curran, 2007, and U.S. Environmental Protection Agency [EPA], 2007).

We pause here to note that carbon monoxide emissions are only a very modest problem in the United States today. Because few areas of the United States violate federal air quality standards for carbon monoxide, ethanol provides little benefit on that front. The other pollutants at issue, however, worsen urban smog and the concentration of dangerous air toxics—far more serious human health matters.

Ethanol proponents often argue that stronger ethanol blends—like E85—are cleaner. Those contentions are not consistent with the reviews of the literature cited above. Nor are they consistent with a recent study concluding that universal use of E85 would increase ozone-related mortality, hospitalization, and asthma by 9 percent in Los Angeles and 4 percent in the United States as a whole relative to a world in which the auto fleet were powered entirely by conventional gasoline (Jacobsen, 2007).

Air Toxics

The above studies explicitly consider toxic air emissions in their analyses, but a recent paper for

[10] Although I only examine conventional air and greenhouse gas emissions in this paper—the main environmental advantages that subsidy proponents allege for ethanol—ethanol has a number of other environmental disadvantages relative to gasoline. The main issues include groundwater contamination (Niven, 2005), water resource use and surface water pollution (National Research Council, 2008; Donner and Kucharik, 2008; and Nassauer, Santelmann, and Scavia, 2007), soil erosion (Patzek, 2004), and habitat destruction (Nassauer, Santelmann, and Scavia, 2007, and Dias de Oliveira, Vaughan, and Rykiel, 2005). Whatever advantages ethanol may have with regard to air emissions (which I believe to be, at best, nonexistent) must outweigh the environmental harms it creates.

the Energy Future Coalition (Gray and Varcoe, 2005) argues that the environmental costs of gasoline-related air toxic emissions total approximately $250 *billion* per year. Although their paper has received little attention in academic circles, it has received modest attention in policy circles, so a brief discussion is in order.

Gray and Varcoe (2005) argue that the direct harms from the various toxic emissions from aromatics in gasoline total about $64 billion a year. But those aromatics also contribute to the formation of particulate matter (PM) in the atmosphere, and the harms from PM that can be traced back to aromatic gasoline emissions are said to equal at least $200 billion a year. Gray and Varcoe round the total sum to $250 billion a year (which was equal to about $1.78 a gallon in 2005) and argue that "leveling the playing field" would justify an equivalent subsidy to the ethanol industry.

The $64 billion estimate for the *benefits* associated with reducing aromatic emissions, however, is derived from the *costs* associated with reducing toxic air emissions in the industrial sector. Yet there is little reason to believe that the costs of emission controls equal the benefits from the same. Gray and Varcoe (2005) justify this leap of faith by citing EPA contentions that the benefits from the regulation of industrial air toxic emissions have in the past exceeded the costs of doing so. But even if the EPA is correct, there is no reason to assume that the cost of reducing toxic air emissions from point sources x years ago has relation to the costs (or benefits) of reducing toxic air emissions from automotive tailpipes today.

Gray and Varcoe's (2005) estimate for the costs associated with PM formation that can be traced back to gasoline aromatics likewise emerges from a problematic set of assumptions. They posit that 40 percent of all $PM_{2.5}$ is carbon based and then assume that half of this mass (when adjusted for population exposures) can be attributed to gasoline emissions.[11] The latter claim appears to be incorrect; their own footnote suggests that only 4 to 33 percent of $PM_{2.5}$ can be traced back to tailpipe emissions.

Using the benefit estimates associated with ambient PM concentration reductions from the recently established off-road diesel fuel regulations, Gray and Varcoe (2005) arrive at about $200 billion in benefits. It is unclear, however, how they trace those costs to aromatic tailpipe emissions from the total universe of motor vehicle tailpipe emissions.

Gray and Varcoe (2005), however, well understand the limitations of their analysis: "We emphasize that these are, necessarily, speculative estimates, based on various heuristic assumptions that cannot easily be proven (or refuted, given basic uncertainties)" (p. 52). Normally, claims that cannot be proven or disproven are called "opinions" or, alternatively, "religious beliefs." Let us posit that we should not use either as the basis for public policy.

If Gray and Varcoe (2005) were familiar with the literature on tailpipe emissions, they would not need such analytic contortions. A review of the literature finds that the environmental costs associated with toxic air emissions from gasoline is likely $0.087 to $1.62 billion annually in 1991 dollars, a tiny fraction of the $64 billion estimate laboriously forwarded by Gray and Varcoe (McCubbin and Delucchi, 1996). While it is unclear to what extent harm from $PM_{2.5}$ can be traced back to gasoline aromatics, the published literature suggests that the environmental costs associated with *all* particulate emissions from motor vehicle tailpipes (not just the aromatics targeted by Gray and Varcoe) is $16.7 to $266.4 billion. The authors who reviewed that literature, however, note that "We are uneasy with this result, even as an upper-bound" (McCubbin and Delucchi, 1996, p. 212) because it is heavily weighted by one study in the literature (Pope et al., 2002) and that study is both anomalous and methodologically problematic (Schwartz, 2006). Likewise, a recent study (Hill et al., 2009) examines the emissions of greenhouse gases (GHGs) and $PM_{2.5}$ from gasoline and corn ethanol. It finds that, for each billion gallons of ethanol-equivalent fuel, gasoline emissions cost $469 million and corn ethanol emissions $472 to $952 million.

There is little reason to accept the $250 billion externality estimate by Gray and Varcoe (2005) and to reject the more careful work in the peer-reviewed literature cited above. Even were we to

[11] $PM_{2.5}$ means particles less than 2.5 micrometers in aerodynamic diameter.

do so, however, it is worth remembering that the toxic air emissions associated with ethanol are even greater than the toxic air emissions associated with conventional gasoline. Hence, even if Gray and Varcoe were correct, it does not justify countervailing subsidies for ethanol.

Greenhouse Gas Emissions

It is difficult to know for certain how ethanol compares with gasoline with regard to GHG emissions because the data required to perform a satisfactory energy life-cycle analysis simply do not exist. Four fundamental problems exist (Delucchi, 2004 and 2006).

First, limited field and facility data are available. Aggregated data are thus required to fill in the holes, and many data points are based on estimates, not observations. Unfortunately, those estimates are frequently only loosely grounded in reality (Liska et al., 2009).

Second, some important disagreements about methodology cannot be easily resolved. For instance, how far back in the production chain should we go in the course of tallying energy inputs? What is the best way to disentangle the energy inputs and GHG outputs associated with ethanol production from the energy inputs and GHG outputs associated with other coproducts (primarily distillers' grains for livestock feed) associated with ethanol production?

Third—and most important—dynamic variables can significantly affect the life-cycle analysis but are generally completely ignored in the literature because they are difficult to model properly. For instance, how and to what extent will the contemplated policy change prices for millions of goods and services (both directly and indirectly), and how will those price changes affect consumption patterns and, thus, GHG emissions?[12] Answering such complex questions requires a rather sophisticated global general equilibrium model, but none have been produced or used in the life-cycle analyses of ethanol that have appeared in the literature.

Fourth, even if done well, the life-cycle models produce findings that are less relevant to policymaking than advertised. For example, what exact policy is being suggested by the life-cycle analysis and is that policy realistic? How does the execution of that policy impact the dynamic economic factors mentioned above? What are the opportunity costs of the contemplated policy? What are emissions at the margin in response to policy-induced change?

Nonetheless, dozens of studies and several computer models exist to partially inform analysis (for instance, Liska et al., 2009; Adler, Del Grosso, and Parton, 2007; Wang, Wu, and Hong, 2007; Groode and Heywood, 2007; Hill et al., 2006; Farrell et al., 2006; Nielsen and Wenzel, 2005; and Patzek, 2004).[13] The best is a recent study from researchers at the University of Nebraska (Liska et al., 2009). That analysis used the most recent data available on individual facility operations and emissions, observed corn yields, nitrogen fertilizer emissions profiles, and coproduct use; all of which prove important because of improved energy efficiencies associated with ethanol production over the past several years. The authors found that the total life-cycle GHG emissions from the most common type of ethanol processing facility in operation today are 48 to 59 percent lower than gasoline, one of the highest savings reported in the literature. Even without subtracting the GHG emissions associated

[12] "Whatever the exact magnitude of these price effects, they are potentially important enough that they ought to be taken seriously in an evaluation of the impact of transportation policies on climate. There is no way to escape this conclusion. We cannot dismiss the effects because they occur outside of the U.S., or outside of the transportation sector, because in an analysis of global warming, we care about all emissions, everywhere. We cannot dismiss price effects on the grounds that a policy will not really affect price, because in principle even the smallest change has a nonzero probability of leading to a nonzero effect on price. (In any event, if the price effects are really so small, then the policy must be so unimportant or ineffective as to have no affect on climate worth worrying about anyway.) And we certainly cannot argue that all such price effects are likely to be substantially 'similar' for all policies, and hence of no importance in *comparison* of alternatives, because this clearly is not the case" (Delucchi, 2004, p. 10).

[13] I am interested only in those studies that attempt to quantify GHG emissions, not in those studies exclusively concerned with the net energy balance of ethanol. The latter issue is theoretically interesting but it asks a question that is not particularly relevant for policy analysis. Even if ethanol has a negative energy balance (more energy inputs were required to produce ethanol than is yielded by ethanol on combustion), if the energy inputs were relatively abundant but the energy displaced by ethanol were relatively scarce, ethanol could have a net negative energy balance but still prove profitable and efficient. Likewise, if the energy inputs have modest GHG emissions but the energy being displaced by ethanol had significantly larger GHG emissions, a negative energy balance might still translate into a net reduction of GHG emissions.

with ethanol coproducts (which accounted for 19 to 38 percent of total system emissions), ethanol would still present GHG advantages relative to gasoline.

Although the study by Liska et al. (2009) appears to offer the best current analysis on this question, many problems remain, rendering policy analysis problematic. First, the study examines only a subset of corn production operations and ethanol processing facilities: dry-mill ethanol processors fired by natural gas in six Corn Belt states. Together, those facilities accounted for 23 percent of U.S. ethanol production in 2006. This approach makes the study stronger because the authors are not forced to rely as heavily on estimates and aggregated analysis, but the downside is that the study ignores a large number of older, less-efficient ethanol processing facilities and thus cannot be used to assess the GHG balance of the ethanol industry as a whole. While the findings may well point to where the industry will be in the future as older, less-efficient facilities lose market share and are upgraded or retired (Groode and Heywood, 2007), the bankruptcies that are shuttering many newer facilities at present caution against certainty on this point.

Second, estimates regarding emissions are still relied on to some degree, and one of those estimates in particular—the estimate pertaining to the release of nitrous oxide (N_2O) from fertilizer use in corn production—is problematic. Although the study comports with convention in that it relies on emission estimates offered by the Intergovernmental Panel on Climate Change (IPCC, 2006), a recent study (Crutzen et al., 2007) finds that the IPCC estimates pertaining to N_2O release from fertilizer does not comport with the observed data. Crutzen et al. (2007) find that N_2O emissions from fertilizers used in biofuel production are three to five times greater than assumed by the IPCC and that, if we use those higher emissions in the ethanol life-cycle models (as Crutzin et al. did using the openly accessible EBAMM model constructed by Farrell et al., 2006), "the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), can contribute as much or more to global warming by N_2O emissions than cooling by fossil fuel savings" (p. 389). Given that the lead author of the study—Paul Crutzen—is a Nobel laureate chemist who has specialized in fields related to atmospheric science, his findings cannot be lightly dismissed.

Third, Liska et al. (2009) acknowledge the importance of the impact of ethanol production on crop prices and, thus, on global land-use patterns, but they do not account for the GHG emissions associated with those changes. Those emissions are substantial, and no life-cycle analysis of ethanol can credibly ignore them.

A worldwide agricultural model constructed by Searchinger et al. (2008) finds that the increases in crop prices that follow the increased demand for ethanol will induce a global change in the pattern of land use. Those land-use changes produce a surge in GHG emissions that is dissipated only by conventional life-cycle emissions savings many decades hence. Although the study modeled ethanol production increases that were beyond those mandated in existing law, "the emissions from land-use change per unit of ethanol would be similar regardless of the ethanol increase analyzed" (p. 1239).

While critics of Searchinger et al. (2008) rightly point out that (i) the agricultural model employed in the study was crude, (ii) much is unknown about the factors that influence global land-use decisions, (iii) improved yields are reducing the amount of land necessary to meet global crop demands, and (iv) any land additions to crop production do not need to come from forests or other robust carbon sequestration sinks (Renewable Fuels Association, 2008), none of those observations is sufficient to reject the basic insight forwarded in Searchinger et al. (2008). If ethanol demand increases corn and other crop prices beyond where they otherwise would have been, profit incentives will induce investors to increase crop production beyond where production would otherwise have been. If that increased production comes in part from land-use changes relative to the baseline, then significant volumes of GHG will likely be released and those emissions will threaten to swamp the GHG savings found elsewhere in the life-cycle analysis. Even if the upward pressure on crop prices as a consequence of ethanol consumption is more than offset by downward price pressures following from other factors, crop acreage retirement will not be as large as might otherwise have been the case and terrestrial sequestration will be lower as a consequence. Every link in that chain of logic is unassailable.

Changing global land use is but one of the many impacts that ethanol might have on hundreds of industrial sectors worldwide. The work of Searchinger et al. (2008) is ultimately unsatisfying because it is only a crude and partial consideration of those impacts, many of which might indirectly affect global land-use patterns. For instance, if ethanol consumption reduces the demand for—and thus the price of—crude oil in global markets, how much of those "booked" reductions in oil consumption will be offset by increased demand induced elsewhere by the lower global crude oil prices that follow (known as a "rebound effect" in economics)? How might that rebound effect influence all sorts of GHG emissions vectors? None of these types of questions are asked in ethanol GHG life-cycle analyses, but they are clearly crucial to the analysis.

To summarize, a narrow, conventional consideration of the GHG emissions associated with ethanol suggests that ethanol reduces climate change harms relative to gasoline. If the IPCC has underestimated N_2O emissions from fertilizer—as appears to be the case—then ethanol probably is *at best* a "wash" with regard to GHG emissions. Even if that is not the case, consideration of secondary and tertiary emissions impacts strongly suggests that most, if not all, advertised GHG gains are lost in the changes in land-use patterns that follow increases in ethanol production relative to the baseline. Other changes in anthropogenic emissions—positive and negative—would almost certainly follow as well, but existing models do not bother to search for them and thus we do not know enough to say much beyond this with confidence.

First versus Second-Best Remedies

If there are in fact uninternalized environmental externalities associated with gasoline consumption, the most direct and efficient remedy is to impose a tax on emissions (or a cap-and-trade program that functions like a tax) to correct prices accordingly. Countervailing ethanol subsidies are a much less-efficient remedy because they create deadweight losses, do not correct gasoline prices or ethanol prices for environmental externalities, and impose a market share for ethanol that might not have arisen in equilibrium.

One might argue that emissions taxes on conventional pollutants in motor fuel markets are impractical and/or unlikely and that ethanol is a necessary second-best alternative. But even if so, tighter regulation of motor fuel emissions is almost certainly more efficient than ethanol subsidies *if* government intervention is warranted. This is particularly true given that ethanol has substantial air emissions of its own. Nondiscriminatory emission regulations that apply regardless of fuel source are a far more defensible intervention.

Price internalization exercises to address GHG emissions, however, are not only conceivable, they are probable in the near term given the current political makeup of Washington and voter sentiment. Once a federal cap-and-trade program is in place, ethanol proponents will lose the argument that gasoline prices are suboptimal because they do not consider the cost of GHG emissions. Of course, one might always argue that the permit prices yielded from such a regime are too low to adequately reflect the damages, but a recent "best guess" about those damages based on the literature suggests that the uninternalized GHG externalities associated with gasoline amount to only about $0.05 per gallon (Parry and Small, 2005).

If the displacement of gasoline with ethanol is in fact among the most cost-effective means of reducing GHG emissions, ethanol producers should be able to prove that fact in a carbon-constrained, cap-and-trade market without government subsidy. But even if we posit the lowest-bound estimate for total ethanol subsidies and divide that figure by the GHG savings reported in Wang, Wu, and Hong (2007; a 19 percent reduction of total life-cycle GHG emissions relative to gasoline), we find that $300 of subsidy is necessary to displace a metric ton of GHG emissions from gasoline. "Based on historical prices for carbon offsets, this same investment could have purchased 90-120 times as much displacement on the CCX [Chicago Climate Exchange], the most appropriate benchmark for the U.S. carbon market. Even on the more expensive ECX [European Climate Exchange], the subsidies could have purchased 11 metric tonnes of offsets" (Koplow, 2007,

p. 35). If we instead use the high end of the GHG savings reported in Liska et al. (2009) those figures could be cut by two-thirds—still yielding costs that could not be sustained if market actors, rather than political actors, were deciding how best to respond to a carbon-constrained world.

THE POLITICAL ECONOMY OF SUBSIDY

Although there has long been a debate about the merits of ethanol subsidies, most parties in the discussion accepted without question the idea that subsidizing ethanol reduces oil consumption. How much, of course, was open to debate. Yet a rigorous examination of the existing subsidies in place by Cornell economists Harry de Gorter and David Just (2007a) finds that one of those subsidies—the blenders' tax credit—actually *subsidizes* gasoline consumption within the context of the current regulatory regime.

The conclusion is counterintuitive but the analysis is sound. The explanation is as follows. By itself, the blenders' tax credit ensures that ethanol is often cheaper than gasoline from the refiners' perspective. Refiners will thus compete to secure that ethanol, which results in the price of ethanol being "bid up" until it is above the market price of gasoline by at least $0.51 per gallon (the size of the tax credit). In a world with the blenders' tax credit at the 2006 level, retail fuel prices are lower by 1.9 percent ($2.32 per gallon rather than $2.36 per gallon). Ethanol production increases from 653 million gallons to 6.67 billion gallons while gasoline production declines from 141.2 billion gallons to 135.7 billion gallons. The credit serves as an ethanol consumption subsidy with most of the benefits going to ethanol producers and the remainder to motorists.

By itself, the Renewable Fuel Standard (which mandates specified levels of ethanol consumption) produces motor fuel costs that are a weighted average of the cost of ethanol and the cost of gasoline. In a world with the consumption mandate at the 2006 level, retail fuel prices are 0.48 percent lower ($2.31 per gallon rather than $2.32 per gallon). Ethanol production increases from 6.67 billion gallons (assuming a nonbinding mandate in the form of the ban on methyl tertiary-butyl ether as a fuel additive) to 10 billion gallons while gasoline production falls from 135.7 billion gallons to 132.5 billion gallons. The mandate, like the credit, serves as an ethanol production subsidy with almost all of the benefits captured by ethanol producers.

When a tax credit is added to a consumption mandate, however, there is no incentive for refiners to bid up the price of ethanol; the mandated demand for ethanol ensures that ethanol (even with the tax credit) is more costly than gasoline. Because competition in the refining sector is relatively intense, refiners cannot capture the full benefit of the tax credit. Instead, it is passed on to consumers. Using the 2006 blenders' tax credit, this produced retail fuel prices 1.42 percent lower than they would have been without the tax credit but with the mandate: $2.31 per gallon rather than $2.34 per gallon. Ethanol production increases a wee bit—from 9.99 billion gallons to 10 billion gallons—but gasoline production *increases* even more—from 132.1 billion gallons to 132.5 billion gallons. The combined policies are, in effect, a direct gasoline consumption subsidy with all of the benefits captured by motorists.

Such analyses highlight the difficulty of accepting claims about the impact of ethanol production on foreign oil imports or GHG emissions without careful consideration of the indirect impact that subsidies have on the market. Unfortunately, this is an exercise rarely performed in the literature pertaining to the advertised benefits of ethanol (and, implicitly, government preferences for the same).

CONCLUSION

Why should taxpayers subsidize ethanol? The most commonly offered rationales—that ethanol reduces harm caused by our reliance on foreign oil and a host of air pollution problems—do not hold up to scrutiny. Foreign oil dependence is not a substantial foreign policy or economic problem, and ethanol offers little remedy for any problems that might exist. Environmental gains are likewise unclear. The balance of the evidence suggests that ethanol worsens conventional air pollution and offers no net reductions in GHG emissions. In fact, there is good reason to believe that GHG emissions might well go up as we displace gasoline in favor of ethanol.

Even if we were to accept the national security and environmental benefits claimed most frequently for ethanol in the literature, in 2012 ethanol subsidies would still cost $3 billion more than the monetized benefits delivered (Hahn, 2008).

Other justifications for subsidy have even less merit. There is little evidence to suggest that "Big Oil" is strangling ethanol for competitive advantage or that ethanol on balance reduces motor fuel prices by any consequential amount. Ethanol subsidies may in some periods reduce net federal subsidies to corn producers, but the deadweight losses associated with ethanol subsidies more than offset this savings to the taxpayer. Finally, they do not "level the playing field." In fact, they distort the playing field and produce inaccurate price signals which, in turn, lead to less economic efficiency and, by force, less overall wealth creation.

Whatever problems exist in motor fuel markets are better remedied by direct interventions to address identified problems. Ethanol subsidies are extremely poor remedies for those alleged problems.

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The Future of Biofuels

Rick Tolman

CORN SUPPLY AND DEMAND

According to the U.S. Department of Agriculture (USDA), U.S. corn growers produced 12.1 billion bushels of corn in 2008, the second-largest crop ever. This harvest reflects the increasing ability of growers to produce higher yields, measured in bushels per acre (bu/acre), due to improvements in agronomic practices and biotechnology that improve the corn seed itself. The 2008 national average yield, 153.9 bu/acre, is the second-largest on record.

As high as this yield is (by comparison, the 1988 yield was only 84.6 bu/acre), many in the corn industry expect it to nearly double well before mid-century. In fact, many growers who take part in the National Corn Growers Association (NCGA) National Corn Yield Contest routinely score yields much higher than the national average.

Since 1994, corn productivity per acre has accelerated as a result of advances in marker-assisted breeding, biotechnology, and improved farming practices. Growers are harvesting considerably more corn without significantly increasing acreage. Based on past performance, average production per acre is projected (following a 15-year trend) to hit 180 bu/acre by 2015. Some seed

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researchers foresee corn production near 300 bu/acre by 2030.

Modern farm management practices play an important role in increased productivity, along with new and improved production tools, such as global positioning systems, yield mapping, and precision nutrient-application methods. Nationwide, corn growers are harvesting more corn per acre while making great strides in efficient input use. This is resulting in a more sustainable environmental footprint.

Although corn production is expanding, some uses for it are not expanding at the same rate. Other corn demand categories, such as livestock production and exports, have shown limited future growth—meaning that increased corn supplies will result in more corn available for biofuel production. Demand for corn in the livestock and poultry sectors has been relatively flat in the past 10 marketing years. The amount of raw field corn fed to livestock is expected to decline slightly as more corn is displaced by distillers' grains, a co-product of ethanol production. Furthermore, the amount of corn used for human food has been flat, and corn exports have trended up only slightly.

Even as corn use for ethanol has risen dramatically over the past 10 years, American farmers have continued to be the world's top exporter of corn—satisfying the demands of foreign customers. Corn exports have remained steady or expanded slightly and, through exports of distillers' grains, the ethanol sector is helping satisfy foreign demand for high-protein, high-energy livestock feed. The United States exported about 2.4 million metric tons of distillers' grains in 2007.

The Food and Agricultural Policy Research Institute's (FAPRI) *2008 U.S. and World Agriculture Outlook* (Carriquiry et al., 2008) provides projections for agricultural commodity production and disappearance. It considers average weather patterns, existing farm policy, current trade agreements, and customs unions.

FAPRI projects that the nation's corn growers will harvest 15.2 billion bushels in 2015. This is congruent with NCGA's vision of corn growers being able to harvest 15 billion bushels by 2015. FAPRI projects corn volume to produce ethanol to reach 5.2 billion bushels in 2017. This increase will result in 10 billion bushels of corn for all non-ethanol use categories. And this is projected to be accomplished with only a limited increase in planted acres over the 93.6 million acres used in 2007.

The growing demand for ethanol is projected to keep pace with the projected increases in total corn production into 2017. FAPRI projects that most of the historic non-ethanol uses of corn will provide little growth. Given the rising cost of production, absent a market for ethanol the nation's corn producers would once again face marginal profits from high production and insufficient demand.

THE VALUE OF ETHANOL

Ethanol is a significant market for U.S. corn, but its value goes far beyond its role as a major use of corn. Developing this new value-added industry not only creates a new market for our corn producers, it lessens our dependence on foreign oil and helps revitalize rural America.

Ethanol plants are helping rejuvenate rural communities across the country by creating high-paying jobs, boosting local tax revenues, and creating partnership opportunities for local businesses. Rural communities across America face an increasing challenge (brain drain) as they strive to create opportunities for their youth to remain in their local communities. The ethanol industry is the single most important industry created by the agricultural sector in decades allowing rural American communities to continue to remain economically viable.

The demand for corn ethanol production was originally created in response to the oil crisis of the 1970s. After the crisis was resolved, oil prices dropped to a level that challenged the economic viability of biofuels. This situation has now changed, however, as oil prices have moved erratically and the viability of biofuels has strengthened. In conjunction with positive economics, public policy initiatives have helped break oil companies' control of the liquid transportation distribution systems.

Even with the Renewable Fuel Standard passed by the U.S. government and the subsequent rise in the demand for corn, the long-term economic health for corn producers is far from secure. With the production efficiency increases stated above combined with the steady acreage dedicated to corn production, supply will either continue to match demand or problematically outpace demand.

According to the USDA's pricing models based on more than 30 years of data, corn prices over the next 10 to 15 years will reach a new plateau, but farm profitability will remain tight mainly because of increases in input costs driven by the price of oil. Raw material costs for inputs like nitrogen fertilizer are reaching record gains and do not move through the distribution system as quickly as, say, conventional gasoline, while other inputs like diesel fuel are already affecting producers. Thus, the rise in corn prices had a positive impact on corn growers in 2007-08, but the long-term reality in the current environment is that producers will see very tight to negative margins.

Continued strong growth in the ethanol sector will keep corn producers viable, which can keep oil consumption in check while continuing to provide a substantial amount of feed to the livestock industry through distillers' grains. This will be a challenge in the current economic environment, where the subprime mortgage crisis had increased the cost of capital. Farming is a capital-rich proposition and producers now require two to three times more capital just to produce a crop.

Ethanol has revitalized the rural landscape, provided a new market for domestically produced grain, and dented our need for imported oil, but it has not done so irresponsibly. Corn to ethanol is—and will remain—a healthy economic growth tool, not a get-rich-quick scheme for producers, and the ripples from this positive market will reach those beyond the farm gate to benefit anyone who uses energy and eats food.

RESPONDING TO THE MYTHMAKERS

Food versus Fuel

Diverting agriculture crops from the table to the fuel tank has been the focal point of critics stirring the so-called food-versus-fuel controversy. Any discussion of corn ethanol, however, must consider two factors: the shifting nature of our country's crops and the price of corn (specifically, its impact on overall food prices).

Farming acreage has been trending downward during the past few decades. In 1932, when corn reached its highest acreage count, 320.4 million acres of farmland were under cultivation countrywide; in 2007 total acreage under cultivation was an estimated 278.1 million. The development of suburban communities in the second half of the twentieth century was a major contributor to the decrease of both farmland and parkland acreage.

Crop production, however, is an even more significant issue regarding demand for certain crops and how it is met: Corn yield increased more than fivefold between 1932 and 2007. The average yield, represented as bu/acre, grew from 26.5 bu/acre in 1932 to an estimated 151.1 bu/acre in 2007, and experts believe average yield can increase to 180 bu/acre or more over the next decade, as noted above.

As consumers, we all understand the pinch to our pocketbooks when food prices increase. Grocery shoppers and restaurant diners need to understand that the cost of food ingredients in products they buy represents less than one-fifth of the price at checkout. So how much of an impact do rising corn prices have on overall food prices? Food prices are largely determined by costs and profits after commodities leave the farm. On average, only about 19 percent of the price of food can be attributed to ingredients. Marketing and transportation costs comprise a much higher portion of total costs. For example, consider the impact of rising corn prices on a box of corn flakes as outlined in Table 1 and the following significant facts about food production.

About 50 percent of the corn crop is used for animal feed. Corn makes up a relatively large share of the product prices of eggs, pork, and poultry. Beef and dairy products also contain significant costs for corn, but the prices of processed foods are largely determined by the cost of other components:

- International demand for dairy products has outstripped international supply. Moreover, the world demand for dairy products has put U.S. products onto world markets, thereby raising prices.
- Agriculture is playing a large role in the supply of U.S. fuel. Agriculture's involvement will help offset any increase in food

prices, with lower fuel costs and cleaner, less-polluting renewable fuels. Moreover, government payments to farmers will be reduced as a result of higher crop prices, for example, they were $6 billion less in 2007.

- Combining the efficiencies at the farm with increased ethanol yields from grain, an acre of corn can produce more than 400 gallons of ethanol, compared with 320 gallons only 10 years ago. With the implementation of biomass conversion and increased grain yields, the grain ethanol industry is expected to reach 600 gallons of ethanol per acre in the next decade.

Net Energy/Liquid Petroleum Displacement

A key metric for judging the success of alternative fuels is whether the product supplies more energy than is needed to produce it. This may seem like a straightforward calculation, but it has been hotly debated because of different methods of quantifying energy value. Another layer of complexity is that today's accounting for energy inputs versus outputs is no longer satisfactory. One must also look at the quality of that energy in terms of nonrenewable carbon dioxide (CO_2) and CO_2 equivalents generated in fuel production and use. The common terms used for these analyses are "net energy" and "liquid petroleum displacement."

First, a few clarifying points will aid the discussion of ethanol and liquid petroleum displacement. The common metric of British thermal units (BTUs) per gallon is used when measuring the total energy content of a liquid fuel. Analysis of current transportation fuels—mainly conventional gasoline—yields a value of approximately 110,000 BTUs per gallon.

Ethanol, by comparison, yields only 84,000 BTUs per gallon. This fact is interpreted by many to imply that ethanol is a lesser energy product than gasoline. In reality, all this shows is that ethanol has a lower energy density than gasoline. Depending on the engine using the ethanol and ethanol-blended fuels, efficiencies in converting the liquid potential energy into kinetic energy can be almost on par with each other. Today the engines in the North American fleet capable of burning the higher-blend ethanol fuel, E85, are not yet optimized for ethanol. They run more efficiently on conventional fuel. As flexible-fuel vehicle (FFV) adoption increases and ethanol availability becomes more widespread, this performance discrepancy will be addressed.

Understanding the energy density discrepancy between the two fuels is necessary to better understand the second part of this issue, net energy balance. The core of net energy balance is this: How much energy do you get out compared with how much energy you put in? Since the late 1980s, more than 25 studies have examined the energy balance of ethanol. Only six have shown ethanol to have a negative energy balance (more energy used in production than is delivered to the vehicle). The most recent study (Liska et al., 2009) reviewed several different ethanol production examples, and found that eight corn-ethanol scenarios had net energy ratios from 1.29 to 2.23. For the most common biorefinery types, the net energy ratio ranged from 1.50 to 1.79.

Nevertheless, media outlets have consistently cited both sides of this argument in an attempt to be "balanced"—while not informing the public of the discrepancy in study results. It frustrates the ethanol industry that media outlets continue to focus on studies that cite a negative energy balance for ethanol even though these studies are few in number. Beyond the net energy argument, it becomes exceedingly clear that the net CO_2 emissions for biofuels such as ethanol are significantly lower than petrochemicals, which are nonrenewable CO_2 sources in and of themselves.

It does take energy to produce ethanol: Natural gas and electricity are used to power ethanol plants, and fertilizer and diesel engines are needed to grow and harvest corn. Studies repeatedly have shown the energy required to produce ethanol is less than the energy ethanol delivers for personal vehicle use. Moreover, most critics of ethanol on net energy grounds fail to perform similar analyses of petroleum-based gasoline's net energy. In fact, petroleum performs worse than ethanol under this direct comparison. Ethanol's biggest advantage is that it can continue to use less and less fossil energy for production through greater efficiencies, as well

Table 1

The Impact of Rising Corn Prices on a Box of Corn Flakes

	Corn costs				Estimated retail price	
Item	$2/bu = $0.035/lb	$4/bu = $0.07/lb	$6/bu = $0.107/lb	As of April 2008	Increase (%) in the past 17 months	Increase (%) due to corn costs
Corn Flakes cereal, 18-oz box: 12.9 oz of milled corn produces one 18-oz box (USDA)	$0.028	$0.056	$0.086	$3.69	$1.06 (40%)	$0.06 (6%)

as the use of other renewable sources of energy to power ethanol plants.

POLITICAL ISSUES

Two salient political issues will have a tangible impact on the future of ethanol: higher blends and FFVs.

Higher Blends

With the passage of the 2007 energy bill, the Renewable Fuel Standard will require the United States to use 36 billion gallons of biofuels by 2022. With this schedule now law as of January 1, 2009, major infrastructure changes must take place to facilitate implementation of the standard.

Moving to higher blends of ethanol will be critical to the industry. The United States uses roughly 145 billion gallons of gasoline each year. By 2015, ethanol will comprise at least 15 billion gallons, or roughly 10 percent of the fuel market. Because the highest level of ethanol certified for conventional automobiles is currently 10 percent (E10), the industry must move rapidly to secure certification for higher blends (such as E20) for the market to readily absorb the increasing volumes of ethanol available beyond a nationwide 10 percent blend. Otherwise, the ethanol industry will likely hit a "blend wall" at 10 percent.

Flexible-Fuel Vehicles

Currently, most American, Japanese, and European auto manufacturers allow only 10 percent ethanol to be blended into gasoline because of the composition of rubber sealing joints in fuel systems. These joints can become compromised with higher ethanol blends, leading to engine damage. Engine manufactures will void engine warranties if higher blends are used. However, technology now exists to use up to 100 percent ethanol in automobiles—as has been implemented in Brazil for several decades.

In the United States, auto manufacturers produce FFVs that can use E85 (a gasoline blend that is 85 percent ethanol). The incremental cost of building a FFV versus a non-FFV is estimated at approximately $150. Once a conventional vehicle has been manufactured, however, the conversion to flexible-fuel can cost much more.

The reality is that FFV technology is readily available at a low cost and has been implemented in Brazil by the same auto manufacturers that produce cars in the United States. The issue of fuel flexibility is not technological—rather, it is political. The current U.S. fuel infrastructure (which is owned by oil producers and refiners) widely resists energy products not manufactured from within the petroleum system. It also is clear that in the current economic environment, the oil network is well funded to keep allies aligned with its interests.

Because of the political barriers to expanded use of ethanol, the NCGA supports the open fuel standard. Enabling biofuels to break the current oil monopoly may require even more than that effort. It may, for example, require "legislation requiring all major oil companies to convert pumps for E85 at 50 percent of their owned or branded stations" (Sandalow, 2007, p. 93) or "legislation prohibiting franchise agreements that limit pumps for biofuels at service stations" (p. 94)—as Brookings Institution energy and environment scholar David Sandalow recommends in his important book, *Freedom from Oil*.

Biofuels are already ready to play an important role in freeing us from our dependence on foreign oil, and the relevant technologies are only going to improve. But political action is clearly needed to allow them to reach their potential.

The future for corn ethanol in the United States is bright. The trends in the cost of production, productivity, and sustainability are all moving in a positive direction. Corn ethanol is the bridge to second- and third-generation biofuels, but it will continue to play a key role for the foreseeable future as we develop alternative sources to petrochemical feedstocks.

CONCLUSION

Ethanol sourced from corn has become the primary and most successful biofuel to date. As such, it has generated the most focus, criticism, and scrutiny. It is important to realize that corn ethanol is still a formative and nascent industry that is undergoing rapid transformation and technological change.

Critics tend to focus on old metrics and unequal comparisons. The future of ethanol sourced from cellulosics[1] is bright and necessary, but it is theoretical at this point. Cellulosics will evolve from the success of corn ethanol, not as a revolution displacing it. Cellulosic ethanol will not occur without the technological advances developed in current plants that are producing corn ethanol.

The biofuels market is broad and wide, requiring both corn ethanol and sugar-based ethanol as well as other sources of cellulosics. Sources are complementary and should not be cast as competitors, particularly in an unequal fashion.

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[1] Cellusosic ethanol is produced from a wide range of biomass, such as agricultural plan waste (e.g., corn stover—the leaves and stalks of corn plants left in the field after harvest) or "energy crops" (e.g., switchgrass).

Long-Term Sustainability in the U.S. Corn Ethanol Industry: Some Key Determinants

Nicholas Kalaitzandonakes, James Kaufman, Wyatt Thompson, and Seth Meyer

The U.S. ethanol industry has changed dramatically in the past five years. Driven by the need for national energy independence, concerns over air quality, and an interest in rural development, a number of government policies were introduced within the span of a few years and had significant impact. The 2004 ethanol tax credits, the Energy Policy Act of 2005, the 2006 ban of methyl tertiary-butyl ether (MTBE), and later the Energy Independence and Security Act of 2007 all significantly expanded the opportunity for ethanol use in the United States.

A positive macroeconomic environment also played a role. Robust global economic expansion led to strong and sustained growth in the demand for oil and gasoline for the better part of this decade. Gasoline prices grew steadily in the United States from 2002 on and along with them ethanol prices. The fast-expanding market for ethanol and strong prices led to large investments in new productive capacity. From the beginning of 2002 to the end of 2008, the ethanol industry grew from 61 plants with a combined capacity of 2.3 billion gallons per year to 170 plants with 12 billion gallons of capacity (Renewable Fuels Association [RFA], 2009a).

The decline of gasoline and ethanol prices from their meteoric rise in the summer of 2008 and the softening demand for fuels amid the worst recession in decades have raised concerns about overcapacity and the long-term sustainability of the ethanol industry. Government policies and macroeconomic conditions will continue to influence the future profitability of the corn ethanol industry in the United States, but so will the strategies that firms pursue in the coming years.

This article examines the recent cyclical movements in the revenues and capital outlays of the U.S. corn ethanol industry and evaluates their likely trends and impacts on the industry's sustainability. It also examines the potential contribution of factors under the control of ethanol firms: the pursuit of efficiencies and technical innovation.

DRIVERS OF PROFITABILITY IN THE ETHANOL INDUSTRY

Industry sustainability starts the drive for profitability at the ethanol plant. For any dry grind ethanol plant, the bulk of the revenues comes from two products: ethanol (85 percent) and coproduct dried distillers' grains with solubles (DDGS; 15 percent). Similarly, a single input—corn—accounts for 65 percent of a plant's variable costs (Hofstrand, 2008). Because DDGS are used as feed for livestock, they can substitute for corn in animal rations. For this reason, corn and DDGS prices tend to move together. This correlation simplifies the calculation of plant profitability.

Plant managers and analysts alike can approximate plant profitability with the simple calculation shown in Table 1. For example, if corn were $3.25 per bushel and ethanol $1.80 per gallon, then a dry mill's return over operating costs would be $0.35 per gallon. A combination of corn at $3.25 and ethanol at $1.60 would cut the per gallon return by more than half, to $0.15. Assuming that the average payment to capital invested is equal to $0.20 per gallon, this net return would not attract investment. Corn at $3.25 and ethanol at $1.40 or less would result in outright losses per gallon of ethanol produced, likely leading to plant closures if such prices and losses persisted.

A higher ethanol price or lower corn price would tend to increase profitability. In 2006, for instance, when ethanol was around $2.50 per gallon

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Table 1

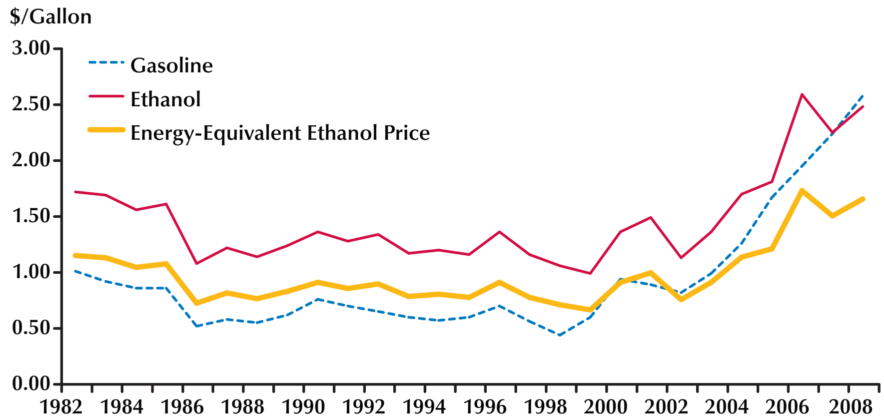
Dry Mill Ethanol Plant Returns Over Operating Costs, 2008-09

Corn ($/bushel)	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
DDGS ($/ton)	73.54	81.83	90.12	98.41	106.69	114.98	123.27	131.56	139.85	148.13	156.42	164.71	173.00	181.28
Ethanol($/gallon)						Net returns over operating costs								
1.25	**0.13**	**0.06**	0.00	–0.07	–0.13	–0.20	–0.26	–0.33	–0.39	–0.46	–0.52	–0.59	–0.66	–0.72
1.30	**0.18**	**0.11**	**0.05**	–0.02	–0.08	–0.15	–0.21	–0.28	–0.34	–0.41	–0.47	–0.54	–0.61	–0.67
1.35	**0.23**	**0.16**	**0.10**	**0.03**	–0.03	–0.10	–0.16	–0.23	–0.29	–0.36	–0.42	–0.49	–0.56	–0.62
1.40	0.28	**0.21**	**0.15**	**0.08**	**0.02**	–0.05	–0.11	–0.18	–0.24	–0.31	–0.37	–0.44	–0.51	–0.57
1.45	0.33	0.26	**0.20**	**0.13**	**0.07**	**0.00**	–0.06	–0.13	–0.19	–0.26	–0.32	–0.39	–0.46	–0.52
1.50	0.38	0.31	**0.25**	**0.18**	**0.12**	**0.05**	–0.01	–0.08	–0.14	–0.21	–0.27	–0.34	–0.41	–0.47
1.55	0.43	0.36	0.30	**0.23**	**0.17**	**0.10**	**0.04**	–0.03	–0.09	–0.16	–0.22	–0.29	–0.36	–0.42
1.60	0.48	0.41	0.35	0.28	**0.22**	**0.15**	**0.09**	**0.02**	–0.04	–0.11	–0.17	–0.24	–0.31	–0.37
1.65	0.53	0.46	0.40	0.33	0.27	**0.20**	**0.14**	**0.07**	**0.01**	–0.06	–0.12	–0.19	–0.26	–0.32
1.70	0.58	0.51	0.45	0.38	0.32	0.25	**0.19**	**0.12**	**0.06**	–0.01	–0.07	–0.14	–0.21	–0.27
1.75	0.63	0.56	0.50	0.43	0.37	0.30	**0.24**	**0.17**	**0.11**	**0.04**	–0.02	–0.09	–0.16	–0.22
1.80	0.68	0.61	0.55	0.48	0.42	0.35	0.29	**0.22**	**0.16**	**0.09**	**0.03**	–0.04	–0.11	–0.17
1.85	0.73	0.66	0.60	0.53	0.47	0.40	0.34	0.27	**0.21**	**0.14**	**0.08**	**0.01**	–0.06	–0.12
1.90	0.78	0.71	0.65	0.58	0.52	0.45	0.39	0.32	0.26	**0.19**	**0.13**	**0.06**	–0.01	–0.07
1.95	0.83	0.76	0.70	0.63	0.57	0.50	0.44	0.37	0.31	**0.24**	**0.18**	**0.11**	**0.04**	–0.02
2.00	0.88	0.81	0.75	0.68	0.62	0.55	0.49	0.42	0.36	0.29	**0.23**	**0.16**	**0.09**	**0.03**
2.05	0.93	0.86	0.80	0.73	0.67	0.60	0.54	0.47	0.41	0.34	0.28	**0.21**	**0.14**	**0.08**
2.10	0.98	0.91	0.85	0.78	0.72	0.65	0.59	0.52	0.46	0.39	0.33	0.26	**0.19**	**0.13**
2.15	1.03	0.96	0.90	0.83	0.77	0.70	0.64	0.57	0.51	0.44	0.38	0.31	**0.24**	**0.18**
2.20	1.08	1.01	0.95	0.88	0.82	0.75	0.69	0.62	0.56	0.49	0.43	0.36	0.29	**0.23**
2.25	1.13	1.06	1.00	0.93	0.87	0.80	0.74	0.67	0.61	0.54	0.48	0.41	0.34	0.28
2.30	1.18	1.11	1.05	0.98	0.92	0.85	0.79	0.72	0.66	0.59	0.53	0.46	0.39	0.33
2.35	1.23	1.16	1.10	1.03	0.97	0.90	0.84	0.77	0.71	0.64	0.58	0.51	0.44	0.38
2.40	1.28	1.21	1.15	1.08	1.02	0.95	0.89	0.82	0.76	0.69	0.63	0.56	0.49	0.43
2.45	1.33	1.26	1.20	1.13	1.07	1.00	0.94	0.87	0.81	0.74	0.68	0.61	0.54	0.48
2.50	1.38	1.31	1.25	1.18	1.12	1.05	0.99	0.92	0.86	0.79	0.73	0.66	0.59	0.53

NOTE: The table shows net returns over variable operating costs for various combinations of ethanol and corn prices. To calculate plant profits, capital and other fixed costs would also need to be subtracted from these figures. In the area above the bold type, negative numbers indicate the average plant is not able to cover operating costs. In the area with bold type, net returns over operating costs are less than $0.25 per gallon, which may be less than required to cover fixed costs. In the area below the bold type, net returns over operating costs are more than $0.25 per gallon, thus likely exceed fixed costs. The matrix assumes DDGS prices change as a function of corn prices. Other operating costs (fuel, electricity, labor, etc.) are included in the calculations. The matrix assumes a constant DDGS yield of 17 pounds per bushel of corn converted to ethanol and a linear relationship between DDGS and corn prices.

Figure 1

Ethanol and Gasoline Prices



NOTE: Prices are Omaha prices to fuel blenders; the energy-equivalent ethanol price is two-thirds the price of gasoline. Prices are not adjusted for the ethanol tax credit.

SOURCE: Nebraska state government (www.neo.ne.gov/statshtml/66.html), with 2008 preliminary data from the Food and Agriculture Policy Research Institute (FAPRI) at the University of Missouri–Columbia (MU).

and corn around $3.00 per bushel, average returns over operating costs for a dry mill were $1.12 per gallon—a rather hefty return to capital.

These calculations of operational profitability illustrate a simple reality in the corn ethanol industry: Understanding the long-term sustainability of ethanol requires knowledge of the factors that shape the price of ethanol and its relationship to the price of corn. Recent history provides some guidance.

The Price of Ethanol and the Factors That Shape It

The ethanol market evolved quickly over only a few years, often clouding the exact relationship between ethanol prices and the market forces that shape them. Historically, ethanol has been more expensive than gasoline on a per-gallon basis (Figure 1). However, an energy-equivalent price reflecting ethanol's energy content offers a better comparison of value.[1] The energy-equivalent price of ethanol was also higher than the price of gasoline during the 1980s and 1990s. Ethanol and gasoline burn differently and as a result ethanol-blended fuel improves the performance of some cars. Accordingly, consumer demand for ethanol as a fuel supplement resulted in price premiums over the 1980-2000 period (Tyner, 2007).

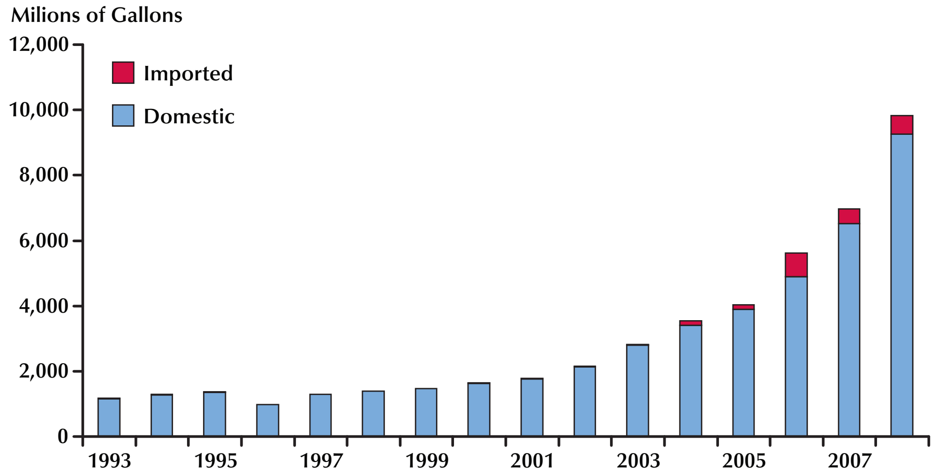
As ethanol production capacity rose from less than one billion gallons in the mid-1990s to almost double that by 2000, ethanol price premiums eroded, suggesting the fuel-supplement market segment was more than saturated (see Figure 1). As ethanol supplies mounted, with production and imports growing to about four billion gallons by 2005 (Figure 2), the energy-equivalent price of ethanol began to lag gasoline prices. The price of ethanol, however, did not fall during the early part of the decade. Rather, it rose by more than 80 percent between 1999 and 2005—but it did not keep pace with the price of gasoline, which nearly tripled over the same period.

Then in 2006, regulatory changes led fuel blenders to discontinue the use of MTBE in some markets and replace it with ethanol (Westhoff et al., 2007). Previously, MTBE had been required as a

[1] Ethanol is not exactly the same as gasoline. One difference is energy content. A gallon of ethanol has about two-thirds the amount of energy as a gallon of gasoline, which implies that ethanol usually propels a car only two-thirds of the distance of an equivalent volume of gasoline.

Figure 2

U.S. Domestic and Imported Ethanol



SOURCE: Data for 1993-2007 are from the Department of Energy (DOE), Energy Information Association (EIA); tonto.eia.doe.gov/dnav/pet/pet_pnp_oxy_dc_nus_mbbl_m.htm). Data for 2008 are from FAPRI-MU baseline projections.

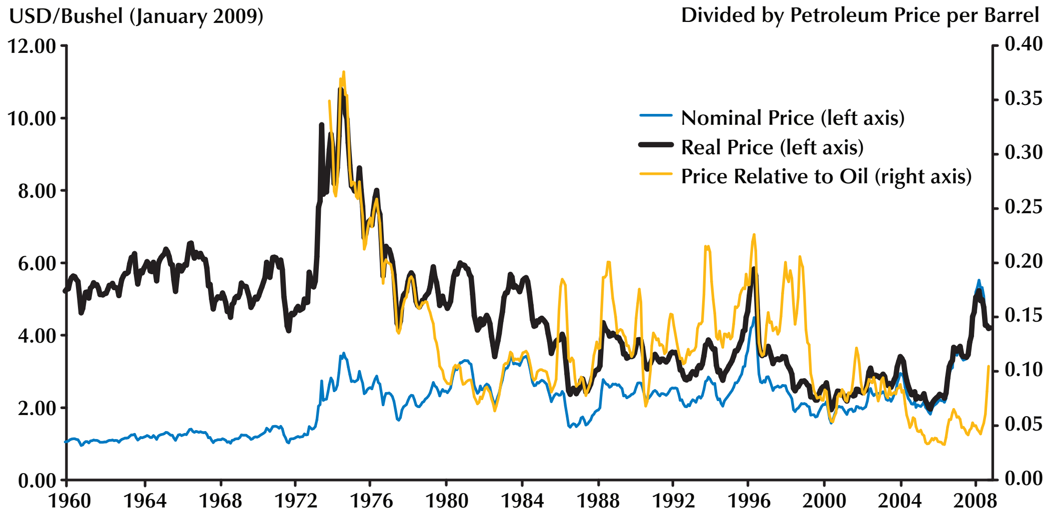
fuel additive to reduce certain pollutants emitted by gasoline. Its use was concentrated in urban areas and periods when air pollution levels were high. MTBE replacement led to a sudden expansion in the demand for ethanol that pushed the limits of domestic production capacity. Ethanol prices spiked in 2006 as blenders outbid one another for ethanol to use as an additive (see Figure 1). Increased profitability in 2006 helped spur increases in production. Additive use was met and quickly exceeded, so the premiums associated with additive use once again eroded, and analysts do not expect them to return (de Gorter and Just, 2007; and Thompson, Meyer, and Westhoff, 2008). The energy-equivalent price of ethanol has since continued to lag the price of gasoline as an increasing amount of ethanol-blended fuel has been purchased simply as a substitute for gasoline.

A number of federal and state policies have facilitated the expansion of corn ethanol from the supplement, to the additive, and, more recently, the fuel replacement market segment. Significant policies include tax credits for fuel blenders ($0.45 per gallon of ethanol used), an import tariff ($0.54 per gallon of imported ethanol), and, more recently, via the Renewable Fuel Standard (RFS) legislation, a mandated volume of renewable fuel that must be blended with gasoline (10.5 billion gallons of corn ethanol for 2009). Both the tax credits and the RFS mandate have expanded the demand for corn ethanol, and the import tariff has maintained ethanol prices at slightly higher levels.

Because of such structural shifts in the demand and supply of ethanol, the exact ethanol price mechanism remains somewhat uncertain. For instance, analysts disagree about how ethanol in E10 (fuel that is 10 percent ethanol by volume) is effectively priced. It could be reasonable to assume that the price of ethanol is determined by the price of E10 relative to the price of gasoline and the energy content of E10 relative to that of gasoline. However, two points may indicate otherwise. First, in areas where air-quality regulations require that local fuels contain an additive, consumers have no choice but to buy fuel with ethanol. Second, consumers might not realize the lower energy content of E10 because it is still 90 percent gasoline, so the negative effect on miles per gallon may be 3 percent or so. If this reasoning holds, then ethanol is priced according to the volume of gasoline it displaces (Tyner, 2007).

Figure 3

Corn Prices in Nominal and Real Terms and Relative to Petroleum Prices



SOURCE: Average corn prices are from the USDA Economic Research Service; www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx. Petroleum prices are from the DOE EIA; tonto.eia.doe.gov/merquery/mer_data.asp?table=T09.01. The producer price index for finished goods is from the Federal Reserve Bank of St. Louis; research.stlouisfed.org/fred2/series/PPIFGS/downloaddata?cid=31.

The opposing view addresses both these points. First, the ethanol market has expanded well beyond the additive segment and the price of ethanol must be low enough to induce demand in markets where ethanol-blended fuels must compete with gasoline. Second, because enough buyers are both informed and discriminating, the price of E10 at retail should be lower than the price of gasoline. This opposing view, then, suggests that the price of ethanol is increasingly set according to its energy content (de Gorter and Just, 2007; and Thompson, Meyer, and Westhoff, 2008).

Looking ahead and barring major changes in the current policy environment, further expansion in ethanol use beyond the E10 market is likely to occur only by increasing sales of E85.[2] This fuel, which has as much as 85 percent ethanol, causes a clear reduction in mileage, so it is likely to sell in large volumes only if competitively priced on an energy-equivalent basis with gasoline. Regardless of their position on E10, analysts tend to agree that a large expansion of the E85 market would drive the price of ethanol to compete with the price of gasoline on an energy-equivalent basis (Tyner, 2007; and Thompson, Meyer, and Westhoff, 2008).

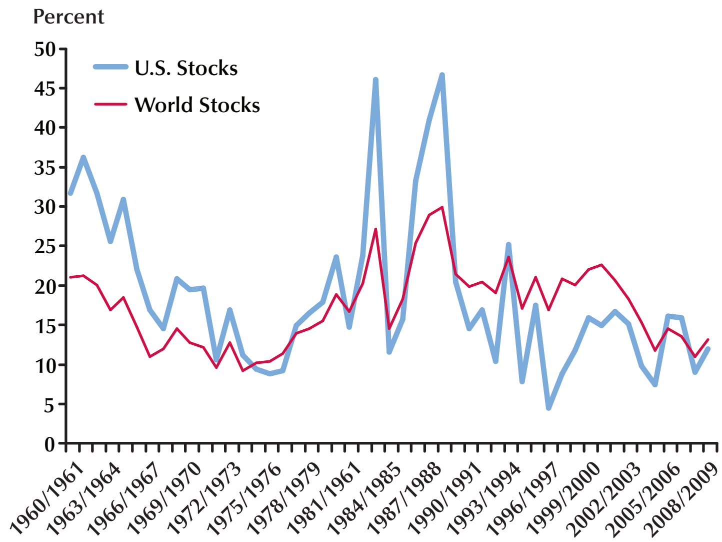
The Relationship of Ethanol and Corn Prices

The price of ethanol is an important determinant for the long-term profitability of the U.S. corn ethanol industry, and its relationship to the price of corn is as essential. For the most part, manufacturing industries that add value to agricultural commodities price their products based on processing and marketing margins, which are added to the price of the commodity feedstock. Accordingly, their revenues and costs are closely linked. In the case of ethanol production, such a link does not exist because the bulk of revenue is determined in the petroleum (gasoline) market, while most of its cost is determined in the corn market—two markets that have historically exhibited little association (Figure 3). Wide fluctuations in corn and petroleum

[2] It is estimated that the current E10 market could be saturated by approximately 15 billion gallons of ethanol a year.

Figure 4

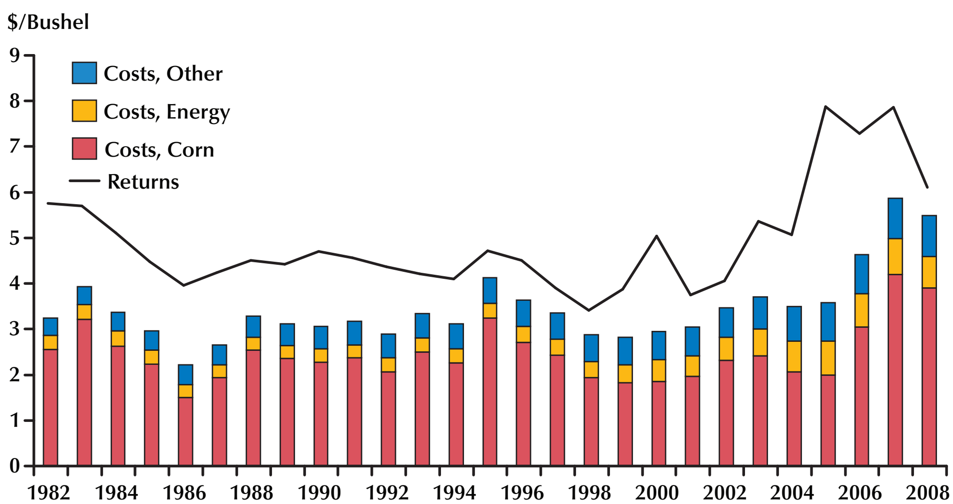
Corn Stocks-to-Use Ratio



SOURCE: USDA Foreign Agricultural Service *Production, Supply, and Distribution* database.

Figure 5

Ethanol Dry Mill Costs and Returns per Bushel of Corn Processed



NOTE: Returns include the value of ethanol and DDGS sold per bushel of corn.

SOURCE: Authors' calculations using various sources, including Nebraska state government ethanol plant price and USDA cost data.

prices in recent months have put this lack of association in sharp focus.

Petroleum price variability is not new, but it may have been largely forgotten when the cost of a barrel was $20 or less in the early part of this decade. The runup to over $140 per barrel in 2008 ended any complacency. And the subsequent drop to $40 per barrel shocked perhaps the ethanol industry as much as anyone because ethanol prices quickly followed suit.

Price swings in the corn market are similarly not new (see Figure 3). Both demand and supply factors influence corn prices over time. Changes in the demand for corn are generally incremental and anticipated; however, shifts in the supply due to weather, pest infestations, and other shocks are more abrupt and can have significant short-term effects on corn prices. Demand and supply factors and even speculators have been viewed as key drivers of the recent volatility in corn markets (e.g., Sanders, Erwin, and Merrin, 2008; and Trostle, 2008). Moreover, the current environment of low buffer stocks might also be playing a role because demand and supply shocks are magnified under such conditions (Figure 4).

If the prices of petroleum and corn moved in concert, their variability would have limited effects on the ethanol industry. Yet, historical movements in corn and petroleum prices have been largely unrelated (see Figure 3), leaving revenues and costs in ethanol production unlinked and causing large swings in the profitability of ethanol plants (Figure 5). The magnitude of this problem is not easily overstated. When the price of corn relative to the price of petroleum has increased, ethanol profitability has suffered. Further, this inverse relationship has become progressively stronger as ethanol has progressed from a supplement to an additive to a fuel replacement. As price premiums for the more inelastic supplement and additive segments eroded and corn prices increased relative to gasoline, profitability declined more abruptly (e.g., first in the early 1990s and more recently in 2008; see Figures 3 and 5).

The inverse relationship of corn and petroleum prices suggests that sustained high petroleum (ethanol) and low corn prices could yield windfall profits for the ethanol industry. At the same time, any random sustained confluence of high corn prices and low petroleum (ethanol) prices could be quite damaging to the U.S. corn ethanol industry. Hedging could guard against some undesirable corn-to-ethanol (or petroleum) price spreads, albeit at some cost. Nevertheless, such strategies can provide only short-term relief because futures contracts for certain commodities (e.g., corn and ethanol) may not extend long enough to cover the sustained trends in relative corn/petroleum prices that have been observed in the past (see Figure 3); and if they did, they could be quite costly.[3]

Probably the most significant "hedge" against the possibility of unprofitably high relative corn prices is currently provided by the renewable fuels mandates. They indirectly link ethanol and corn prices because blenders must use the required corn ethanol irrespective of price.[4] However, such a hedge is generally most effective when the mandate is greater than the productive capacity of the industry. Because the productive capacity of the U.S. corn ethanol industry has exceeded the mandated limits up to now, the level of protection afforded by the RFS remains uncertain.

THE PURSUIT OF EFFICIENCIES

As the U.S. corn ethanol industry has grown to its current capacity and increasingly competes with gasoline as a replacement fuel, the pursuit of efficiency and cost effectiveness has become central to its success and long-term sustainability. The potential for efficiency gains can be evaluated only through a careful assessment of the current state of the industry and of the areas where gains

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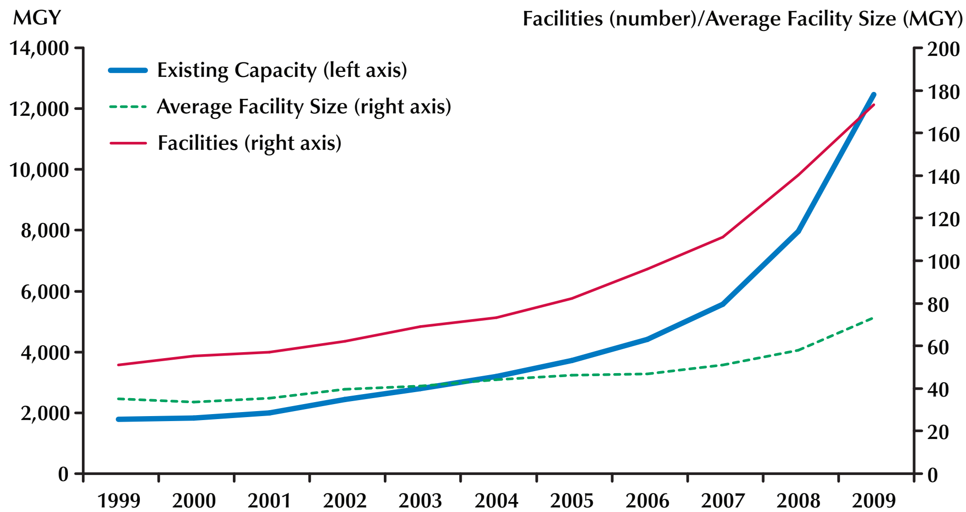
[3] There are also some natural hedges in ethanol production that reduce the industry's risk exposure and are worth noting. DDGS and corn are substitutes and as such their prices are closely correlated. Another natural hedge, albeit a less pronounced one, is the link between petroleum and ethanol prices, which helps to drive ethanol prices, and the cost of natural gas and other fuels that fire ethanol plants. While such prices tend to move together, the correlation between petroleum and natural gas prices is not very strong, particularly for short-term shocks.

[4] Several factors may diminish the effective hedge provided by the RFS against high relative corn prices in any given year. First, fuel blenders can use renewable identification number credits from previous years to meet up to 20 percent of the mandated quantities in subsequent years and may be permitted briefly to fall short. Second, the legislation allows mandates to be waived if broad conditions are met.

Figure 6

Industry Growth and Average Firm Size in the U.S. Corn Ethanol Industry



SOURCE: RFA, "Industry Statistics"; www.ethanolrfa.org/industry.statistics/.

might be possible. Nevertheless, some initial useful observations can be made.

With the swift growth of the U.S. ethanol industry in the past decade, the average ethanol plant size grew rapidly. Facilities built just 10 years ago were comparatively small in size: The average facility produced just over 30 million gallons per year (MGY). A few large ethanol facilities, mostly wet mills, pushed the average firm size upward. The average facility size gradually increased until the mid-2000s and then dramatically accelerated (Figure 6). By early 2009, the average facility produced 72 MGY (RFA, 2009b), with at least 37 facilities topping 100 MGY (*Ethanol Producer Magazine*, 2009).

These newer and larger facilities were built to take advantage of scale economies. Capital costs per gallon of capacity for a 100 MGY facility are 20 percent lower than those for a 50 MGY facility (Eidman, 2007). Larger facilities also have lower operating costs. When corn was priced at $4 per bushel, a 100 MGY facility had 3.5 percent lower variable costs than a plant half that size—with the variable cost savings increasing as corn prices decreased (Eidman, 2007).

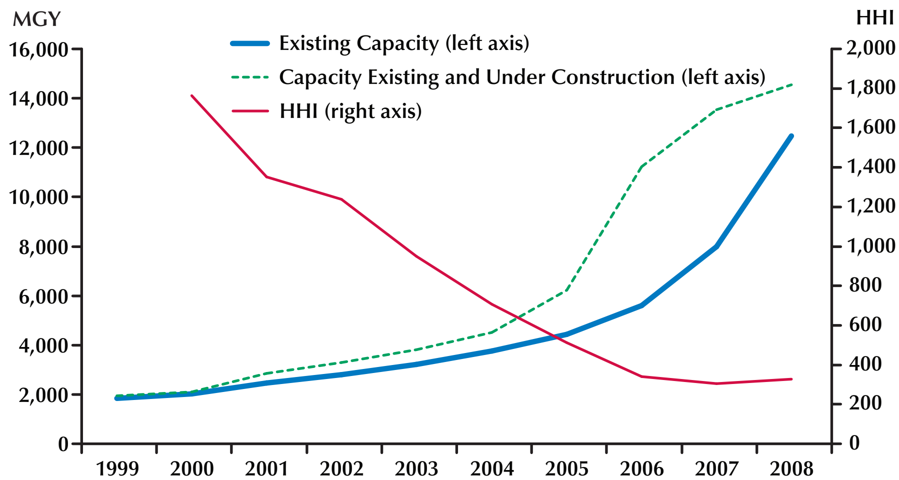
The continued entry of new ethanol firms during this period of fast growth also produced a dispersed and increasingly competitive industry, as evidenced by a fast declining Herfindahl-Hirschman Index (HHI; Figure 7). Much of the pre-2000 ethanol production capacity was at large wet mills owned by major agribusinesses. In this environment, the industry was relatively concentrated, with an HHI above 1,800 (U.S. Federal Trade Commission, 2008). As new dry mills were built, the HHI fell rapidly, ultimately bottoming out in 2007 at 292—indicating minimal levels of industry concentration and disperse ownership of assets.

Not all ethanol firms have responded well to the recent economic downturn. Many have experienced financial problems from eroding and even negative margins and several have filed for bankruptcy, including a few large firms such as VeraSun (filed in October 2008), Renew Energy (filed in January 2009), and Panda Ethanol (filed in January 2009). As a result, by the end of 2008 roughly 1.8 billion gallons, or 16 percent, of total U.S. ethanol production capacity had been idled (RFA, 2009a).

The need to improve the performance of existing capital assets under the pressure of overcapacity,

Figure 7

Entry and Industry Concentration in the U.S. Corn Ethanol Industry, 1999-2008



SOURCE: Authors' calculations and the U.S. Federal Trade Commission (2008).

uncertain demand, and weak processing margins has fomented an environment ripe for industry restructuring and consolidation that will ration existing assets and capitalize on scale and scope economies. Given the low level of industry concentration and the dispersed location and ownership of capital assets, the potential efficiency gains are large. Sources of such scale and scope economies include (i) superior management and other human capital; (ii) improved sourcing of inputs (e.g., yeast, chemicals, and credit); (iii) centralized grain origination; (iv) advanced supply-chain management through multiple plant locations; (v) improved ability to market and price ethanol; (vi) enhanced potential for development and commercialization of coproduct value streams; (vii) centralized and more sophisticated hedging of inputs, outputs, and spreads; and (viii) increased capacity to manage research and development and regulatory compliance.

Each of these factors can improve the operational effectiveness and profitability of ethanol firms. For instance, optimal plant size and location must account for distance to urban markets where most ethanol is consumed and rural locations where corn is sourced and DGGS are used. Consolidation of multiple plants in selected locations under common ownership could therefore yield sizeable economic gains through improved market access and supply-chain optimization. Similarly, larger firms are generally better positioned to fund and perform research and development, which involves large up-front fixed costs. Already, many of the larger U.S. ethanol firms have active research programs, some cofunded by the U.S. government, to develop and implement new technologies such as cellulosics (which uses the non-starch, typically fibrous, structural parts of plants to make ethanol) and fractionation (a process that removes nonfermentable components from fermentable ones). Consolidation into larger firms could therefore accelerate innovation, improve efficiency, and make the industry more competitive.

Industry consolidation has already started, but at a slow pace. As tight credit markets continue in the wake of the recent economic crisis, financing for mergers and acquisitions remains constricted. As credit markets begin to thaw, consolidation in the industry could accelerate. The restructuring of the corn ethanol industry could therefore occur quite quickly. Efficiency gains from restructuring and consolidation, however, would likely be more gradual and ongoing and therefore take longer to contribute to the competitiveness and sustainability of the industry.

THE IMPACT OF INNOVATION

Another key source of sustained productivity gains in the corn ethanol industry is technical innovation. Some of the innovations have been developed by the ethanol industry while others by allied industries. Indeed, corn has been an attractive ethanol feedstock due, in large part, to an advanced and efficient system of breeding, production, and handling. Between 1980 and 2008, the average U.S. corn yield rose from 104 bushels per acre to 153 bushels per acre (United States Department of Agriculture [USDA], 2008a). Over the same period, processing improvements at ethanol facilities produced steady efficiency gains, raising ethanol yields from 2.5 gallons a bushel in 1980 to 2.8 gallons a bushel in 2007 (Wu, 2008). These two improvements alone increased the amount of ethanol derived from an acre of corn by 62 percent.

The pipeline of future technical innovations that could improve the cost competitiveness of corn ethanol production is even more promising. Historically, farm-level improvements have come from improved hybrids, precision agriculture, improved machinery, integrated pest management, reduced tillage, and other innovations. One recent addition is biotechnology, which has already demonstrated its ability to lower production costs, increase yields, and reduce the environmental footprint of corn production (Fernandez-Cornejo and Caswell, 2006; and Kalaitzandonakes, 2003). Because of such advances, in 2008 four of five corn acres in the United States were planted with biotech hybrids (USDA, 2008b). Continuing research and development promises a burgeoning pipeline of novel corn traits. While the pipeline builds on the efficacy of first-generation offerings such as insect and herbicide resistance, it also promises new traits such as drought resistance, increased nitrogen utilization, and improved yields. Ultimately these technologies promise to accelerate the growth in corn yields and productivity.

Innovative technologies that offer significant productivity gains are also expected at ethanol facilities and include the following:

- **Corn Oil Extraction.** With this technology, a conventional dry mill will be able to remove corn oil after the ethanol distillation process. This will not only produce a second coproduct and revenue stream but also decrease the costs associated with drying DDGS.
- **Raw Starch Hydrolysis.** With this technology, increased/improved enzymes eliminate the need for liquefaction and saccharification; biotechnology facilitates the hydrolysis process through corn engineered to produce amylase enzymes in the seed. High-amylase corn eliminates the need for additional enzymes in raw starch hydrolysis.
- **Dry Mill Corn Fractionation.** This technology separates the starch from nonfermentable portions of the corn. High-starch slurry allows for increased ethanol yield and capacity utilization. Corn oil and fiber can also be separated with this technology.
- **Corn Kernel Fiber to Ethanol.** In combination with fractionation this technology could convert fiber to ethanol, further increasing the ethanol yield.
- **Highly Fermentable Corn.** This biotechnology produces corn hybrids with improved fermentation characteristics that allow ethanol to be produced more efficiently. Existing highly fermentable corn hybrids derived from traditional breeding have, on average, a 5 percent higher starch content, which can result in a 2.7 percent increase in ethanol yield (Haefel et al., 2004).

The potential effects of these and other technologies on the efficiency and profitability of ethanol production is sizeable.

We now measure the potential effects of new biotech corn traits and certain process engineering innovations on ethanol production while accounting for all relevant market effects. We use two scenarios to evaluate the potential aggregate yield effects of new biotech corn traits; however, we ignore other potential efficiency gains from lower input use (e.g., pesticides), changes in agronomic practices (e.g., tillage), and the like.

Table 2

Potential Impacts of Innovations in Ethanol Production and Operating Returns

Variable	Percent change with 1.8% corn and 1% ethanol yield growth	Percent change with 3.0% corn and 1% ethanol yield growth
Corn yield (bushels/acre)	2.5	10.2
Dry mill yield (gallons/bushel)	2.8	2.8
Corn market		
Planted area	–0.1	–0.6
Production	0.0	9.5
Total domestic use	1.7	6.7
Fuel	1.9	8.2
Feed	1.9	7.2
Food	0.3	1.0
High-fructose corn syrup	0.0	0.2
Exports	4.7	17.4
Corn farm price	–2.9	–11.7
Ethanol Market		
Production	4.4	10.8
Ethanol price	–1.0	–2.5
Ethanol dry milling returns (per gallon)		
Ethanol revenue	–1.0	–2.5
DDGS revenue	–7.2	–17.5
Corn cost	–5.4	–13.9
Net operating returns	7.7	30.1

Prevailing long-term trends show that U.S. corn yields have grown 1.35 percent per year for the past 40 years (USDA, 2008a). Specific biotechnology innovations and experimental field data indicate that 1.8 to 3.0 percent growth in yields might be possible in the near future (e.g., Korves, 2008; and Edgerton, 2008). We use these figures as the lower and upper bounds for our analysis. To account for the efficiency gains from process engineering and other innovations that improve the efficiency of the ethanol plant, we analyze the additional effect of 1.0 percent annual growth in the ethanol yield per bushel of corn.

As corn innovations are introduced in the market place, they change the relative productivity of the crop, and farmers respond through their planting decisions. These in turn shift the aggregate supplies of corn and other crops, change their relative prices, and shift their demand. Similar, though more limited, changes occur in response to process innovations at the ethanol plant. To account for such complex market changes, we use the FAPRI-MU model of crops and biofuel markets (Thompson, Meyer, and Westhoff, 2008). This partial-equilibrium model covers supply and demand quantities, including acreage planted, production, other domestic uses, trade, stocks, prices, and policies. In this context we evaluate the economic implications of the innovation scenarios discussed above for the 2009-18 period. This empirical analysis allows us to examine the potential effects of innovation on the supply of ethanol and the average profitability of the U.S. ethanol industry. The results are presented in Table 2 and are expressed as changes relative to a baseline where corn and ethanol yields grow at their historical averages—1.35 percent and 0.5 percent per year, respectively.

The empirical results from the partial-equilibrium analysis suggest that accelerating corn and ethanol yield growth rates shift corn and ethanol supplies upward. Given that aggregate corn demand is somewhat inelastic, when corn prices decline, demand increases. In domestic markets, the use of corn for food, feed, and fuel all increases. Exports of corn increase even faster as export markets respond to movements in U.S. corn prices. The reduction in corn prices also reduces the cost of ethanol production, lowering the price of ethanol and increasing demand for the biofuel. The magnitude of the change is influenced by the responsiveness of demand in the ethanol market. Given that the industry now supplies the supplement, additive, and the more responsive E10 markets, the outward shift is absorbed by an elastic demand and the resulting effect on the price of ethanol is small. The reduced input costs and relatively small decline in output prices lead to a 7.7 to 30 percent increase in net operating returns per gallon. It is worth emphasizing that these effects are over and above the improvements in operating returns that are expected with the continued growth of corn and ethanol yields at their historical rates.

The results of the partial-equilibrium model illustrate the potentially significant impact of new technologies on the level of efficiency and profitability of the U.S. ethanol industry. As firms continue to develop and adopt such new technologies, the industry will become more competitive and its sustainability will significantly improve.

SUMMARY AND CONCLUSION

Fueled by government policies and a positive macroeconomic environment, the U.S. ethanol industry has experienced strong and ongoing growth since the turn to this century. Over this nine-year period, the industry transformed itself from a niche player to a significant supplier of fuel to compete with gasoline in the U.S. market. As the macroeconomic environment worsened in the later part of 2008, the industry's growth stalled and the viability of some of the newly installed capacity became uncertain as petroleum, ethanol, and corn prices declined and ethanol processing margins with them.

This last stage of the industry cycle has created an environment where consolidation could follow. Industry consolidation could yield sizeable efficiency gains from scale and scope economies, as well as technical improvements and better allocation of resources. A full pipeline of innovations could bring large productivity gains to the U.S. ethanol industry—some targeting the operations of the mill and some its key feedstock—corn. Together, efficiency gains from industry consolidation and productivity growth from innovation could strongly improve the competitiveness and sustainability of the industry.

A possible threat to the stability and sustainability of the industry, however, is its unlinked revenue-cost structure, which is increasingly driven by changes in the relative prices of petroleum and corn. A random and sustained low-corn, high-petroleum price combination results in windfall profits for the industry. A similarly random and sustained high-corn, low-petroleum price combination results in lasting losses. Given the wide variation in the petroleum and corn markets, this characteristic could make the industry prone to boom-bust cycles. This issue has attracted little attention so far, possibly due to the implicit "hedge" currently offered by the RFS mandates. As the industry continues to improve its competitive edge and grow, effective means for linking costs and revenues might become necessary to prevent this subtle industry feature from becoming its Achilles' heel.

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