Ethanol

Ethanol, also known as ethyl alcohol and grain alcohol, is a colorless, flammable liquid with a chemical formula that is written as either \( \text{C}_2\text{H}_6\text{O} \) or \( \text{C}_2\text{H}_5\text{OH} \). The latter formula is used to emphasize the presence of the OH complex of atoms called hydroxyl. (Notice that both formulas indicate the same numbers of carbon, hydrogen, and oxygen atoms.) Ethanol has a boiling point of 172°F (77.8°C) and a lower heating value of 76,330 Btu per gallon at 60°F (21.28 MJ/l at 16°C). As a biofuel, it is used mainly in the transportation sector. Its most important contribution is as a fuel additive. It is also available at some service stations in richer gasoline-ethanol blends, such as E10, E85, and E100, which consist of 10 percent, 85 percent, and 100 percent ethanol, respectively. (E100 is something of a misnomer since ethanol is never sold pure; a toxin is always added to make the ethanol unfit for human consumption.)
Ethanol is the alcohol in alcoholic beverages, and methods of producing ethanol-containing beverages date back to antiquity. What is different with respect to the production of ethanol for use in the transportation fuels market is that huge volumes of almost pure ethanol are now manufactured solely to be burned. Production at this scale has required new ideas and new technologies to convert various ethanol feedstocks into fuel. But current technologies are not adequate to the task, and new and important changes in production methods are on the horizon, methods that may have far-reaching effects on the price and quantity of ethanol available.
This chapter begins by describing some characteristics of current large-scale ethanol production. It then describes an ongoing debate over ethanol’s value as a transportation fuel. It concludes with a discussion of some characteristics of the ethanol market.

THE MECHANICS OF ETHANOL PRODUCTION
Ethanol can be produced from a variety of feedstocks, including corn, sugarcane, wheat, barley, potatoes, sorghum, sweet potatoes, and sugar beets. More broadly, ethanol can be made from any commodity that contains either starch or sugar. (In theory, grasses, trees, and the agricultural residue left on the fields after the crop has been harvested can also be used to produce ethanol, but the conversion process required for these feedstocks is not ready to be implemented commercially.) Today, only two feedstocks are in large-scale use: corn, the main feedstock in use in the United States, and sugarcane, the main feedstock in use in Brazil. Sugarcane is used to produce

Ethanol plant in Iowa (Jim Parkin)
ethanol in Brazil because in Brazil sugarcane is the least costly way to produce large amounts of sugar. Corn is used to produce ethanol in the United States because in the United States corn is the least costly way to produce large quantities of starch. These two nations produce approximately 70 percent of all the ethanol manufactured in the world today.

The idea behind ethanol production is simple enough. A feedstock is prepared—corn requires more preparation than sugarcane—and then yeast cells are added. The yeast converts some of the prepared feedstock into ethanol. The result of the process is a liquid-solid mixture, the liquid component of which contains water and ethanol. Finally, the ethanol is separated from the mixture in a multistep process to produce a liquid that is almost pure \( \text{C}_2\text{H}_6\text{O} \). The challenge of the production process is to control the purity of the ethanol while producing billions of gallons of fuel each year at a cost that consumers can afford—or at least at a cost that governments can afford to subsidize. (In what follows, most of the emphasis is on the production of ethanol from corn. The United States produces 97 percent of its ethanol from corn. For more information on Brazil and the ethanol markets there, see the sidebar “Ethanol in Brazil,” as well as the Further Resources section at the end of this volume.)

There have long been two main approaches to manufacturing ethanol fuel from corn. The technologies are called dry milling and wet milling. The distinction remains useful, although recent innovations in the dry milling process have begun to blur the differences in the methods. In 2007, in the United States, roughly 82 percent of all ethanol was produced in dry mills; the remaining 18 percent was produced in wet mills. Dry mills are often preferred to wet mills, because they are cheaper to build and so reduce investor risk. Their lower prices also enable small farmer cooperatives to construct their own plants.

The basic dry mill process begins by washing the corn, grinding it, and mixing it with water to form a mash to which enzymes
are added to convert the starch present in the corn into glucose molecules. The mixture is then heated. Next, yeast is added, and it converts the glucose into roughly equal amounts of ethanol and carbon dioxide in a process called fermentation. The process stops when the ethanol has risen to about 12 to 18 percent of the mixture when measured by volume. At this point, the plant operators have a mixture of ethanol, water, and solids. The ethanol is separated in a two-step process. First, the mixture is heated in a process called distillation. Because the boiling point of ethanol at atmospheric pressure is roughly 40°F (20°C) lower than the boiling point of water, the ethanol evaporates first. The resulting ethanol vapor is recondensed apart from the mixture. The ethanol recovered during distillation still contains approximately 4 percent water, too much for it to be used as fuel. So the ethanol is then separated from the remaining water by a molecular sieve, a material that allows water molecules to pass through but not the larger ethanol molecules.

What is left behind after the ethanol has been separated is the water-soaked corn residue. The water is removed, and the result is a material called distillers dried grains and solubles (DDGS). DDGS is a valuable animal feed. Sometimes only some of the water is removed, producing a material called wet distiller’s grains that can also be used as feed, but it must be consumed within a few days or it will spoil.

On average, the dry mill process produces 2.75 gallons (10.4 l) of ethanol and 17 pounds (7.7 kg) of DDGS for each bushel of corn produced. (A bushel of corn weighs 56 pounds [25 kg].) Sometimes ethanol mills are located near a feedlot so that the distiller’s grains can be fed to cattle without drying. It is to the producer’s advantage to avoid the evaporation process for DDGS, because drying requires energy, and energy costs money.

The wet mill process is more involved. The crucial step that distinguishes the two processes occurs near the beginning of the wet mill process, shortly after the corn has been washed. The corn is soaked in a special solution that allows the plant operator to
BIOFUELS

Most ethanol is produced in dry mills, which, in addition to ethanol, produce large amounts of distiller’s grains and carbon dioxide.

separate the starch, from which the ethanol is produced, from the rest of the corn kernel. By processing the corn more carefully, the plant operators are able to extract more coproducts, including corn oil, corn gluten meal, a poultry feed, and corn gluten feed, most of which is exported. The starch is then converted to glucose, which is fermented, and the ethanol, recovered. This part of the process is similar to that used in a dry mill and has already been described. The result of the wet mill process is (on average) 1.8 pounds (0.82 kg) of corn oil, 2.65 pounds (1.2 kg) of corn gluten meal, 13.5 pounds (6.13 kg) of corn gluten feed, and 2.65 gallons (10.3 l) of ethanol for each bushel of corn.

The amount and quality of coproducts obtained during the ethanol production process is crucial since their sale can mean the difference between profit and loss for plant operators. More recent
innovations in the dry mill process now enable plant operators to begin to extract other coproducts such as corn oil, and so the distinction between the two processes is not as clear as it once was. Further refinements in the ethanol production process have also meant that the amount of energy expended in producing a gallon of ethanol has also continued to decrease from about 70,000 Btu per gallon (19 MJ/l) in 1970 to about 41,000 Btu per gallon (11 MJ/l) at today’s most efficient dry mills. (Some ethanol producers have begun to switch from natural gas, the fuel most frequently used, to coal in order to save more on fuel costs.)

When the price of oil rises, the price of ethanol becomes more competitive relative to the price of gasoline. But even if gasoline becomes more expensive than ethanol, ethanol cannot replace gasoline. In the United States, the volumes of ethanol being produced are tiny compared to the amount of gasoline consumed each year. And because of ethanol’s lower heating value—it is only two-thirds that of gasoline—cars can only drive two-thirds as far on a tank of ethanol as on a tank of gasoline. Consequently, it takes about 1.5 gallons of ethanol to replace a gallon of gasoline. If ethanol is to replace a significant amount of gasoline, it must be produced on an enormous scale. This is a big challenge, especially since efficient ethanol plants already convert more than 90 percent of the cornstarch into ethanol, so there is not much room for additional efficiencies in this area.

The simplest way to increase ethanol production is to plant more corn, but there are limits—limits on the amount of land that can be devoted to the production of transportation fuels instead of food and animal feed, and even tighter limits on the amount of land that should be devoted to transportation fuels. In any case, given the size of the gasoline market, no amount of U.S. farmland will be sufficient to satisfy even one-third of the nation’s current demand for gasoline since current ethanol yields are in the range of 370 to 430 gallons of ethanol per acre of corn per growing season, and the
United States consumes almost 400 million gallons of gasoline per day—that is, in metric units, 3,460 to 4,020 liters per hectare per season versus 1.5 billion liters per day. If ethanol becomes competitive with gasoline on price, overproduction of ethanol will be impossible. How, then, can more ethanol be produced? What else can be done?

The first strategy is to increase the yield of corn per acre. United States farmers have been increasing their per-acre yields for many decades. By way of example, average yields during the early 1970s were, for the most part, well below 100 bushels per acre (6,200 kg/ha) and although there are always year-to-year fluctuations, yields exceeding 150 bushels per acre have become commonplace in recent years, a more than 50 percent increase over 1970s production levels. Continuing improvements in the per-acre yield of corn are expected into the foreseeable future as farmers continue to refine the methods by which they raise their crops and biotechnology companies continue to refine the genetics of corn. (Approximately 50 percent of the corn produced in the United States comes from genetically modified seeds, which were created to increase the hardiness of the plants and improve the yields obtained by the farmer.)

The biggest change in ethanol production will come if engineers are able to commercialize the production of ethanol from cellulosic biomass, a term that includes trees, leaves, grasses, and corn stover, the term used to denote the stalks and leaves of the corn plant, as well as many other sources of biomass. The process by which this is accomplished is called cellulosic biomass-to-ethanol or, sometimes lignocellulosic biomass-to-ethanol. (“Cellulosic biomass-to-ethanol,” or cellulosic ethanol for short, is just the name of the process by which the ethanol is produced. The ethanol that results from the cellulosic ethanol process is chemically identical with the ethanol produced by more conventional means.)

From the point of view of the ethanol producer, there are two big differences between using corn and cellulosic biomass. First,
corn kernels contain starch, which is easily converted into ethanol. There is little starch in cellulosic biomass. Instead, cellulose and certain related materials must be converted into ethanol. Cellulose is a material that contributes to the rigidity of plants, and cellulosic ethanol involves breaking down cellulose and related materials into simple sugars so that microorganisms can convert the sugars so obtained into ethanol.

The conversion of cellulosic biomass is significantly more difficult than the conventional process in which ethanol is produced from starch (or sugar), and despite a great deal of research some difficulties remain to be solved before the cellulosic ethanol process becomes commercially viable. Using present technology, the cost of producing cellulosic ethanol is about 50 percent higher than the cost of producing corn ethanol.

The second major difference between using corn kernels and, for example, corn stover as feedstock in an ethanol production process is that the conversion of stover yields little in the way of useful coproducts. Recall that in a corn kernel-to-ethanol production process, the production of coproducts can mean the difference between profit and loss. The production of ethanol from stover yields only plant residue and some methane. These can be used as fuel to provide process heat, but they are low-value products. It seems likely, therefore, that ethanol produced from stover will be priced higher than ethanol produced from corn kernels for the foreseeable future. The goal is to make the difference small enough to make cellulosic ethanol profitable.

The potential importance of stover arises from the fact that, when measured by weight, for every unit of corn harvested, one unit of stover is left in the field. Converting a substantial fraction of this stover into ethanol would greatly increase the per-acre yield of ethanol. But not all stover is available for use as a feedstock. In order to prevent erosion, about two-thirds of the stover would still have to be left in the field. This leaves one-third available for collection.
At 150 bushels of corn per acre, farmers achieve a yield of about 4.2 short tons of corn per acre (9.4 t/ha). This translates into about 1.4 oven-dry short tons of recoverable stover per acre (3.1 t/ha). With a maximum theoretical yield of about 107 gallons of pure ethanol

The countries with the largest ethanol industries are the United States and Brazil. They produce ethanol at roughly the same rate per year, but when measured as a percentage of the national transportation fuels market or as a percentage of the national agricultural sector, the ethanol industry is many times bigger in Brazil than it is in the United States.

In Brazil, ethanol is produced from sugarcane. (Brazil has been a major sugar producer for much of its history and presently accounts for almost one-third of global sugarcane production.) The sugar-ethanol industry in Brazil accounts for 17 percent of agricultural output and two percent of the nation’s gross domestic product. Somewhat more than half of all sugarcane grown in Brazil is used to produce ethanol. This represents an enormous commitment of agricultural resources. In 2007, roughly 15 million acres (6 million ha) were devoted to sugarcane production, and current plans involve expanding the amount of land devoted to sugarcane by 50 percent by the year 2012, at which point 3.6 percent of all arable Brazilian land would be used to grow sugarcane.

Brazil is also the world’s pioneer in ethanol use, having developed a major internal market for ethanol in the 1970s. But it has encountered significant difficulties in creating a stable ethanol market. In the early 1980s, following the oil crises of the 1970s, approximately three-fourths of all new cars sold in Brazil ran on pure ethanol. When the price of oil collapsed in the 1980s so did sales of ethanol-powered cars. In 2000, sales of ethanol began to increase in step with the price of oil, but in 2003, there was an ethanol shortage. Flex-fueled vehicles, cars and light trucks that can run on pure ethanol or on any ethanol-gasoline blend, proved to be the solution to this type of instability. Today, close to 90 percent of new cars sold in Brazil are flex-fuel vehicles.
for each oven-dry ton of stover (446 l/t), farmers could, at current rates of production, increase ethanol production by as much as 150 gallons per acre (1,400 l/ha), an enormous jump in productivity. A more realistic ethanol yield of 75 percent of the maximum would

In 2007, almost all of the filling stations in Brazil offered motorists a choice between pure ethanol—what in the United States is called E100—and an ethanol-gasoline blend. Until 2006, this blend contained 25 percent ethanol, but ethanol shortages during that year led to price spikes, and the government responded by reducing the ethanol component of the ethanol-gasoline blend to 20 percent. In the spring of 2008, Brazil used a 24 percent ethanol-gasoline blend. Brazil hopes to increase ethanol production by approximately 62 percent by 2012 and is expanding sugarcane production and improving its energy infrastructure accordingly, including the construction of ethanol pipelines. Much of this additional ethanol will be for the export market. The United States market is seen as especially promising despite that nation’s 54-cent-per-gallon tariff. (Brazil’s ethanol industry is remarkably efficient. Brazilian sugarcane production costs are, for example, about two-thirds that of Mexico and less than half that of the United States, and it produces about 660 gallons of ethanol per acre (6,200 l/ha) so the high tariffs imposed by the government do not necessarily make exports to the U.S. market impossible, although a reduction in the tariff would lead to a surge in exports.)

Historically, the pattern of ethanol consumption in Brazil is complex, which serves to illustrate just how hard it is to replace petroleum in the transportation sector. But energy analysts now predict steady increases in Brazilian domestic ethanol consumption and Brazilian ethanol exports during the next ten years. Taken together, the high price of oil, flex-fuel technology, and increases in ethanol productivity mean that ethanol may soon become the principal transportation fuel for light cars and trucks in Brazil. This would be a historic change in energy consumption patterns.
still mean an extra 112 gallons per acre (1,050 l/ha), which would increase the ethanol yield by almost one-third. As strains of corn are developed that can be grown at higher densities, the yields from stover will increase as well. The barriers that prevent companies from producing cellulosic ethanol are economic and technical, but they are not insurmountable. Cellulosic ethanol is probably only a matter of time.

**THE NET ENERGY BALANCE**

One of the most controversial aspects of corn-based ethanol production involves the so-called *net energy balance*, a measure of the energy value of ethanol as a fuel. Arithmetically, the net energy balance is a fraction in which the numerator is the amount of energy obtained by burning a unit of ethanol, and the denominator is the amount of energy expended in producing the same unit of ethanol:

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\text{net energy balance} = \frac{\text{energy output}}{\text{energy input}}
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Unlike the energy output, which is determined by burning a sample of ethanol in a laboratory and measuring the amount of thermal energy produced, there is less agreement about the best way to compute the amount of energy expended in manufacturing a sample of ethanol—that is, the numerator in the net energy balance is well understood, but there is substantial disagreement about the definition of the denominator. (In what follows, only corn-based ethanol will be considered, because many of these ideas were first developed to understand the corn-based ethanol process. But the same ideas—although not the same numbers—would apply to other ethanol feedstocks and, more generally, other biofuels.)

Some aspects of what should be included in calculating the energy input are noncontroversial: For example, there is general agreement that one should count the amount of electricity used by the ethanol plant to produce its ethanol, and one should also count the gasoline, diesel fuel, or ethanol consumed by the farm machin-
ery used to plant, harvest, and transport the corn that was used as ethanol feedstock. Another energy expenditure about which there is general agreement is the amount of natural gas burned during an ethanol production run. (Substantial amounts of natural gas are consumed making a batch of ethanol because distillation is an energy-intensive process.) There are also other energy losses that are less obvious but still significant and not especially controversial. Fertilizer for the corn, for example, is a necessary input when producing corn-based ethanol, and fertilizer production, although it occurs far from the farm, requires substantial amounts of energy, especially natural gas. Other input costs are less clear. Should one also count the energy used by the employees at the fertilizer factory to drive back and forth to work while they were producing the fertilizer? How far up the chain of production should one go in calculating the energy input?
Finding a reasonable measure of the total energy input required for the production of one unit of ethanol is important because one argument for producing ethanol, an argument that many find persuasive, is that the production of ethanol contributes to the energy supply. But if the net energy balance of corn-based ethanol is less than one—that is, if more energy is required to produce the ethanol than is recovered by burning it—then the production of ethanol represents an energy loss. To put it another way: If the net energy balance is less than one, the more ethanol that is manufactured, the greater the drain on the nation’s energy supplies. Alternatively, if the net energy balance is approximately one, then the ethanol industry is “robbing Peter to pay Paul”—that is, it is expending valuable energy resources only to recover them in the form of ethanol, but not increasing the amount of available energy. A net balance that is significantly greater than one would mean that the production of ethanol contributes to the nation’s energy supply. From a practical point of view, this is the most desirable of the three possibilities.

Much of the controversy about the value of corn-based ethanol was generated when a researcher named David Pimentel claimed that the net energy balance for ethanol is less than one. His analysis was criticized on two fronts.

➢ First, critics claimed that he used outdated information about ethanol production practices.
➢ Second, Pimentel’s analysis included some of the energy used to manufacture the farm machinery and other less obvious “costs.” The critics countered that if one is to include some of the energy used to manufacture the machinery, why not also include some of the energy required to manufacture the materials that were used to build the factories that were used to manufacture the farm machinery . . . and so on?
One step leads to the next with no end in sight, and is it not clear how much this type of analysis reveals about the value of ethanol as a transportation fuel. This second objection to Pimentel’s analysis is less easily resolved, because what should be included depends on one’s perceptions. There is no one right answer.

Several later analyses of the net energy balance—ones that used better data and different assumptions about what should be counted—yielded a range of values, all of which were somewhat greater than one. A more representative net energy value for these later studies is 1.34—that is, 34 percent more energy is obtained from burning ethanol than was used to produce it. Some studies that calculated significantly higher energy balances took into account the energy value of the coproducts, a practice that tends to obscure ethanol’s contribution to the nation’s energy supply.

None of these analyses indicate that the production of corn-based ethanol is an especially efficient use of valuable energy resources, but production continues. There are several reasons that resources continue to be devoted to the production of ethanol. Three of the more important are the following:

1. previous studies are not the final word on the subject of ethanol’s net energy balance
2. production technology continues to improve (making the denominator in the energy balance smaller)
3. sufficiently large government subsidies can make ethanol production economically attractive even if the net energy balance is much less than one

Finally, it is important to keep in mind that the purpose of the net energy balance is to provide insight into what can be expected from the production of ethanol, but energy policy cannot be based on the value of a single fraction, informative as that fraction may be. There are other considerations besides the net energy balance in...
determining ethanol’s value as a fuel, the most important of which is that ethanol is a transportation fuel. Much of ethanol’s value lies in the fact that it is a partial alternative to oil, which is the essential transportation fuel. Most oil is consumed by the transportation sector, and the world’s entire transportation sector—planes, cars, ships, trucks, trains, virtually everything that moves—depends on oil. In this sense, the transportation and oil sectors are mutually and completely dependent on one another. But the price and the supply of oil are volatile, which explains why all nations that are dependent on oil imports continually search for alternative transportation fuels. So far, alternatives have not been easy to find.

The other widely used primary energy sources—coal, natural gas, and uranium—are poorly suited for direct use in the transpor-
Ethanol is a method of storing some of the energy of coal, natural gas, and uranium for use in automobiles and light trucks. It stores part of the energy of these other energy sources in a form that can be conveniently used in the transportation sector.

THE UNITED STATES ETHANOL MARKET

According to a 2007 study carried out at the University of Minnesota, if all of the corn grown in the United States were used to produce ethanol, it would replace only about 12 percent of the gasoline supply. The report concludes that “neither [ethanol nor biodiesel] can replace much petroleum without impacting food supplies.” But the United States could never afford to convert its entire corn crop into ethanol. Corn is too important. Corn-based ethanol will, therefore, never really compete with gasoline as a national transportation fuel, because there will never be enough of it. This much is certain. But despite the tiny (compared to oil) ethanol market, ethanol has become an important component of the nation’s fuel supply. To understand why, it helps to know more about gasoline, a complex fuel manufactured to satisfy a number of conflicting performance requirements.

One of the problems that early chemical engineers encountered in manufacturing gasoline was that once inside the engine’s cylinders, gasoline would ignite at unpredictable times. The result was a phenomenon called engine knock, which occurred when gasoline ignited before the spark plug fired. Engine knock led to diminished automotive performance and premature engine wear. Lead was
added to gasoline beginning in the early 1920s in order to better control the conditions under which the fuel would ignite. But the lead found its way out of the engine and into the atmosphere when the fuel was burned. As gasoline consumption grew, so did the levels of lead in the environment and in the blood of those exposed to auto exhaust. Lead is a poison, and elevated levels of lead in the body can cause nerve damage and learning disorders—especially among children. During the 1970s, lead levels in gasoline averaged 2–3 grams per gallon (0.5–0.8 g/l), resulting in the emission into the atmosphere of 200,000 short tons (180,000 metric tons) of lead by U.S. cars and light trucks each year.

During the late 1970s, the federal government began a program of reducing lead levels in gasoline with the goal of eventually eliminating lead altogether. Refiners responded to the mandate to reduce lead levels by substituting methyl tertiary-butyl ether (MTBE) for lead. The additive MTBE worked as intended: It prevented engine knock.

In 1990, Congress passed the Clean Air Act Amendments. In response the U.S. Environmental Protection Agency (EPA) began to study the problem of reducing levels of carbon monoxide, a poisonous gas, in auto exhaust, and in 1992, the EPA initiated the Winter Oxyfuel Program with that goal in mind. The cheapest and easiest way to accomplish the reduction of carbon monoxide was by adjusting levels of MTBE in gasoline. In 1995, the EPA initiated the Year-Round Reformulated Gasoline Program to reduce smog, which can also be accomplished by adjusting levels of MTBE to the gasoline. (By way of example, the optimal formulation for reducing carbon monoxide with MTBE is at a concentration of 15 percent by volume. For reducing smog formation, the optimal concentration of MTBE in gasoline is 11 percent by volume.)

But MTBE is not the only option for any of these applications. Ethanol blended with gasoline diminishes the possibility of engine knock. It can also be blended with gasoline to diminish carbon monoxide emissions and smog. For a long time, ethanol ran a dis-
Ethanol is second to MTBE in these applications, because in many ways ethanol is inferior to MTBE as an additive. MTBE could be mixed with gasoline at the refinery and distributed through the nation’s enormous pipeline distribution system, but ethanol had to be mixed at the distribution terminal. It is ill-suited for distribution through the gasoline pipeline system. Moreover, MTBE-gasoline mixtures have a lower vapor pressure than an ethanol-gasoline mix. In practice, this means that the MTBE-gasoline mixtures evaporate more slowly and thereby contribute less to air pollution. Ethanol also has a lower energy content than MTBE (93,540 Btu/gal versus 76,330 Btu/gal [26 MJ/l versus 21 MJ/l] LHV). Finally, MTBE is cheaper than ethanol. There would have been little interest in ethanol except for the generous government subsidies paid for ethanol production. (By way of comparison, ethanol mixed at a concentration of 7.3 percent by volume reduces the emission of carbon monoxide to that obtained by using MTBE, and mixed at a level of 5.4 percent by volume, ethanol reduces smog formation in a way that is similar to that of MTBE.)

Today, there is little demand for MTBE. The problem is that MTBE, which has been identified as a potential carcinogen, diffuses easily through water—more easily than gasoline. When underground gasoline tanks leaked, MTBE quickly diffused through the groundwater—and the water became undrinkable. States began to ban the use of MTBE. This created an opportunity for ethanol producers, and so ethanol became important—not so much as a transportation fuel but as a fuel additive, a replacement for the fuel additive MTBE. (The term fuel additive implies that the volume of ethanol used is small relative to the volume of gasoline in which it is mixed, and that it is added for reasons other than its energy value, which was, initially, certainly the case with ethanol.) But because the volume of gasoline consumed in the United States is huge, the ethanol industry has been kept busy supplying what is, for it, a large amount of product.
What of using ethanol as fuel instead of as fuel additive? The Energy Policy Act of 2005 contains a provision that mandates increases in the amount of “renewable” transportation fuel used each year beginning in 2006. This mandate has contributed to the growth of the ethanol market, although ethanol’s contribution as a transportation fuel, rather than as a fuel additive, remains small. This is not to say that the production of ethanol is negligible in the agricultural sector. It is not. If, as projected by the U.S. Department of Agriculture, ethanol replaces 7.5 percent of the gasoline used in the United States in 2017, almost one-third of the nation’s corn crop will be required for ethanol production.

The big change, if any, in ethanol’s status as a transportation fuel will occur when cellulosic ethanol becomes commercially feasible, at which time producers will be able to convert almost any plant feedstock into ethanol. Provided the price of oil is high enough (or government subsidies are large enough), volumes of ethanol can then be expected to rise sharply.