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# Current Issues in Ethanol Production

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## Current Issues in Ethanol Production

In his 2007 State of the Union speech, President George W. Bush called for a significant increase in ethanol production subsidies that are paid to those companies that blend the fuel with gasoline. The Energy Policy Act of 2005 provided generous subsidies for ethanol production. As a result, ethanol production has increased. Over 100 ethanol refineries produced more than 5.4 billion gallons in 2006. The 2005 bill had set targets of 4.0 billion gallons for 2006 and 7.5 billion gallon by 2012. With many more ethanol plants coming online in the next few years, those targets look comfortably attainable. President Bush has announced plans to increase this target to 35 billion gallons per year by 2017. This would displace about 15 percent of U.S. gasoline consumption.

### History of Ethanol

In the 1850s, ethanol was a major fuel for lighting homes and businesses. During the Civil War, a liquor tax was placed on ethanol to raise money for the war. The tax increased the price of ethanol such that it could no longer compete with other fuels, such as kerosene, in lighting devices. Ethanol production declined sharply because of this tax and production levels did not begin to recover until the tax was abolished in 1906.

In 1908, Henry Ford designed the Model T to run on a mixture of gasoline and alcohol, calling it the fuel of the future. When Prohibition began in 1919, ethanol was banned because it was considered liquor. It could only be sold when it was mixed with petroleum. With the end of Prohibition in 1933, ethanol was used as a fuel again. Ethanol use increased temporarily during World War II when oil and other resources were scarce.

In the 1970s, interest in ethanol as a transportation fuel was revived when embargoes by major oil producing countries cut gasoline supplies. Since then, ethanol use has been encouraged by offering tax benefits for producing ethanol and for blending ethanol into gasoline. In 1988, ethanol began to be added to gasoline for the purpose of reducing carbon monoxide emissions.

As a transportation fuel, ethanol can be used as a total or partial replacement of gasoline. All vehicles that run on gasoline can use a blend of 10 percent ethanol and 90 percent gasoline (i.e., E10) without making modifications to their engines. Over 90 percent of the ethanol produced in the United States is mixed with gasoline to make E10. E85 is an alternative fuel that is 85 percent ethanol and 15 percent gasoline. Vehicles are not modified to run on E85; they are specially manufactured as flexible fuel vehicles. A number of flex fuel vehicles are on the road today, including vehicles from Ford, General Motors, DaimlerChrysler, Mercedes, Mercury, Nissan, Mazda and Isuzu.

Flexible fuel vehicles can use any mixture of ethanol and gasoline up to E85. In the United States there are no 100 percent ethanol vehicles. In Brazil there are vehicles that run on 100 percent ethanol, but in the United States no vehicles are made to run on 100 percent ethanol and there are no places that sell 100 percent ethanol.

The engine must be modified to use any fuel with more than 10 percent ethanol. Since ethanol is corrosive, all fuel hoses need to be replaced to prevent corrosion. Ethanol has poor lubricating properties; therefore, the valve seats in the cylinder head are hardened to handle ethanol fuel. Remapping of the engine for the higher octane fuel is also needed because E85 has an octane number of approximately 106, almost 10 higher than petroleum. Finally, changes must be made to the ignition timing and fueling of the engine (Warwick Innovative Manufacturing Research Centre 2007).

Three of the biggest ethanol companies today are: Aventine Renewable Energy, Inc., Archer Daniels Midland Co. and U.S. BioEnergy. Aventine Renewable Energy, Inc. is a leading producer and marketer of ethanol and related by-products. Last year Aventine Renewable Energy supplied 696 million gallons. Archer Daniels Midland Co. (ADM) is the largest producer of fuel ethanol in the United States. ADM currently produces 1,070 million gallons per year, representing 22 percent of total US fuel ethanol production. U.S. BioEnergy is headquartered in St Paul, Minnesota; Brookings, South Dakota; and Wichita, Kansas. U.S. BioEnergy currently operates four ethanol plants and has two plants under construction. When these plants are completed, they will own and operate seven plants with a combined expected ethanol production of 600 million gallons per year. They announced a merger with VeraSun in late 2007, which would create the largest ethanol company in the United States.

Along with these companies, there are three big ethanol technology providers: POET, Fagen, Inc. and Briohn Building Corporation. POET has a network of 20 plants in five states, producing over one billion gallons of ethanol annually. More important than volume, though, is their efficiency. POET delivers a turn-key development, design, engineering, construction, management and marketing services for all of their plants. They have also perfected the leading brand of premium dried distillers grains soluble on the market, Dakota Gold. Fagen, Inc. is a design-build contractor specializing in heavy industrial engineering and construction. President and CEO, Ron Fagen, has been involved in industrial construction since 1974. Briohn Building Corporation has been providing design/build construction services throughout the Midwest since 1979.

**Ethanol made from Corn Starch**

The most common way to make ethanol is to use the corn kernel. Figure 1 displays the anatomy of the corn kernel. Figure 2 shows the nutrient composition of a typical corn kernel. To be more exact, the starch in the corn kernel is the main source of energy. As of now, there are two processes that are in production: dry milling and wet milling. In these two main processes, there have been many advances in technology that have made these processes faster and cheaper than in the past. As of January 2007, dry mill plants accounted for 82 percent and wet mills had 18 percent of ethanol production (Renewable Fuels Association 2005). The main difference between the two plants is the first phase of the process.

*Dry Milling Technology and Process*

In dry milling, the entire corn kernel or starchy grain is first ground into flour, which is referred to in the ethanol industry as “meal,” and processed without separating out the various component parts of the grain. Figure 3 shows the process of dry milling. According to Figure 3, the meal is slurried with water to form a mash. Enzymes are then added to the mash to convert the starch to dextrose, a simple sugar. Ammonia is added for pH control and as a nutrient to the yeast.

The mash is processed in a high temperature cooker to reduce bacteria levels ahead of fermentation. The mash is cooled and transferred to fermenters, where yeast is added and the conversion of sugar to ethanol and carbon dioxide begins. The fermentation process generally takes about 40 to 50 hours. During this part of the process, the mash is agitated and kept cool to facilitate the activity of the yeast. After fermentation, the resulting "beer" is transferred to distillation columns where the ethanol is separated from the remaining "stillage." The ethanol is concentrated to 190 proof using conventional distillation and then is dehydrated to approximately 200 proof in a molecular sieve system (Renewable Fuels Association 2005**)**.

The anhydrous ethanol is then blended with about 5 percent gasoline in a denaturing process to render it undrinkable, and thus not subject to beverage alcohol tax. It is then ready for shipment to gasoline terminals or retailers.

The stillage is sent through a centrifuge that separates the coarse material from the solubles. The solubles are then concentrated to about 30 percent solids by evaporation, resulting in Condensed Distillers Solubles, or syrup. Next, the coarse grain and the syrup are dried together to produce dried distillers grains with solubles, a nutritious livestock feed. Whether wet or dry, corn gluten feed is a moderately high source of protein, low in starch, high in digestible fiber and low in oil. It accounts for about 20 to 25 percent of protein and 20 percent of starch. Because of these characteristics, cattle can be fed relatively large amounts.

Figure 4 lists the typical nutrient composition in corn gluten feed, which is a product of wet milling. Despite its high portion of fiber, it can still be regarded as an energy source. Corn gluten feed has a high ruminally degradable protein fraction. The level of protein degradation is slightly lower for dry at 70 percent, than for wet, which is about 75 percent, and is an important factor when considering protein levels in the diet. Fiber in wet form is somewhat more digestible than in the dry form, permitting greater intakes of wet versus dry corn gluten feed. Roe (2006) used central Illinois prices and found that the price of corn has increased from around $2 to $3.55 (up 76%) while dried distiller's grain (DDG) only increased from $79 to $109 (up 38%). Both wet and dry corn gluten feed vary in color from yellow-light brown to dark brown, depending on the amount of steep liquor, drying temperature and drying time. The carbon dioxide released during fermentation can be captured and sold for use in other products.

*Wet Milling Technology and Process*

The other way of making ethanol from the corn kernel is using a wet milling process. This process of making ethanol is not as popular as dry milling, mostly because this process requires additional capital investment. The equipment to make ethanol this way is more expensive and that is what keeps the number of these plants lower in numbers. Figure 5 describes the wet milling process. In wet milling, the grain is soaked, or "steeped," in water and dilute sulfurous acid for 24 to 48 hours. This steeping facilitates the separation of the grain into its many components parts.

After steeping, the corn slurry is processed though a series of grinders to separate the corn germ. The corn oil from the germ is either extracted on site or sold to crushers who extract the corn oil. The remaining fiber, gluten and starch components are further segregated using centrifugal, screen and hydroclonic separators.

The steeping liquor is concentrated in an evaporator. This concentrated product, heavy steep water, is co-dried with the fiber component and is then sold as corn gluten feed to the livestock industry. Heavy steep water is also sold by itself as a feed ingredient and use in other products. The gluten component protein is filtered and dried to produce the corn gluten meal co-product.

According to Figure 5, the starch and any remaining water from the mash can then be processed in one of three ways: fermented into ethanol, dried and sold as dried or modified corn starch, or processed into corn syrup. The fermentation process for ethanol is very similar to the dry milling process described below. Figures 4 and 5 compare the two processes (Renewable Fuels Association 2005**).**

*Advantages and Disadvantages*
One of the biggest problems with using the corn starch alone is that it uses a lot of corn in the making of ethanol. The amount of ethanol produced in the United States has been increasing dramatically, as shown in Figure 6. Ethanol production is using large amounts of the United States corn supply that was going to other industries. In 2001, 35 percent of the corn harvested in the United States was used to make ethanol. In 2007, this amount is projected to increase to 71 percent (United States Department of Agriculture 2007). Further increases in the amount of ethanol are needed to stay on the target set by the President.

The reason that producing ethanol from corn starch was the first and earliest adopted for making ethanol is because the infrastructure was already in place. The corn was being grown, harvested and sold on the open market. The elevators were already available to handle the corn and to store the corn until it was needed. The corn was also inexpensive to buy and no new equipment or change in the way of raising corn was needed. Another big advantage of using the corn kernel was that no new technology was needed.

One way the United States plans to keep up with the amount of corn needed is to use hybrids of corn that make more ethanol per bushel of corn. In June 2007 in St Louis, DuPont and FOSS North America announced an agreement that will help farmers and ethanol producers better understand ethanol yield potential of grain corn being delivered to ethanol plants (Pioneer 2007). The agreement provides FOSS rights to technology developed by DuPont. Under terms of the agreement, Pioneer Hi-Bred is providing FOSS with proprietary Ethanol Yield Potential calibration technology for use in FOSS grain analyzers. The technology provides estimated ethanol yield in terms of gallons per bushel.

Pioneer has already evaluated all of its hybrids for ethanol yields and has identified over 180 hybrids that can be used to produce higher than average amounts of ethanol. These high total fermentable ethanol hybrids are being positioned with farmers near ethanol plants. Other corn seed companies are working to come up with their top ethanol producing corn varieties. Figure 7 shows a rapid increase of U.S. corn used for ethanol from the years 1980 to 2006.

In March 2007, Monsanto announced the possibilities of high fermentable corn. Monsanto has more than 90 different corn seed hybrids that are considered high fermentable corn. These hybrids have high yield potential and can provide up to 2 to 4 percent more ethanol per bushel than average corn (Monsanto 2007).

A new technology, dry fractionation, separates the corn kernel into its components without a soaking step. Depending on the process, several companies currently offer similar technologies in which the feedstock may be misted with water before being separated into bran, germ, and the high starch endosperm portion of the kernel (BioFuels Journal 2005).

The advantage of dry fractionation over processes that require a soak step are threefold: lower costs because less energy is required for drying the feed co-product, lower emissions, and greater co-product output because the mash is more highly concentrated. The germ can be sold or pressed for corn oil, and the bran also has potential for food or energy use.

For many years, researchers have been trying to improve characteristics of yeast, which is a highly effective converter of sugars to ethanol. The desired end product is yeast that would be more heat tolerant and better able to withstand high alcohol concentrations, which would produce fewer undesirable byproducts, and might even be able to convert more types of sugar to ethanol. Developers have already made progress in some of these areas. For example, the ethanol tolerance of yeast is at least one-third higher today than in the 1970s (Rendleman 2007).

Sucrose from starch is not the only type of sugar in the corn kernel. Some of the sugars are pentose, or five carbon sugars not normally utilized by common yeast. Any organism that could ferment pentose into ethanol would be a valuable contribution to corn ethanol conversion efficiency. This conversion has been achieved in the laboratory, but not in large scale production (Rendleman 2007).

*Summary*
There have been a lot of improvements in the dry and wet milling processes in the making of ethanol. New construction today is mostly of dry mills, and most new technology is designed for them. A new technique that separate corn kernel components before processing makes wet and dry milling processes more distinct from each other by allowing the dry mill to recover the co-products from the germ. Process improvements are also being made that reduce the cost of wet milling, generally by shortening the soaking step. Modifications of the dry grind facility have made the recovery of corn germ possible in dry milling. Normally, neither corn germ nor any other corn fraction is separated out before becoming part of the mash. All components go through fermentation and become part of the feed co-product.

### Ethanol made from Corn Starch and Gluten

An "in between" product that is between using the starch alone in the corn kernel and using the whole corn plant, is using the fiber hull of the corn kernel and breaking it down into sugars and making it into ethanol. This process of breaking down the fibrous part of the corn kernel into sugar is called the cellulosic process, which is the same process with some slight differences as breaking down cob, leaves and other cellulose products. The fiber part of the kernel had been a byproduct of the ethanol industry and had been used as a feed source for livestock. If this cellulosic ethanol is used, it means utilizing the hull from the corn kernel to produce additional gallons and revenue. The cellulosic ethanol plants would most likely be set up within existing corn ethanol plants to use the energy and infrastructure such as the grain-handling equipment and grain storage.

ADM is conducting research to discover how to convert more of the corn kernel into ethanol. While much of the kernel is readily convertible to sugar, the hull contains fiber which is not being used. Figuring out how to convert the fiber into more sugar could increase the output of an existing corn-ethanol plant by 15 percent (POET 2007).

*Advantages and Disadvantages*
There are many reasons to start making ethanol out of the fiber part of the corn kernel. For one thing the corn is already at the plant. Being able to make more ethanol from the same amount of corn is a plus for the ethanol industry. POET recently announced they are setting up a cellulosic plant next to an existing corn ethanol plant in Emmetsburg, Iowa, which is expected to be operational by 2009. They believe that 40 percent of the cellulosic material will come from the corn ethanol plant as the fiber part of the corn kernel and the rest will come in the form of corn cobs.

*Summary*
Making ethanol out of the fibrous part of the corn kernel at plants that already make ethanol out of the corn starch seems to be the next logical step for large ethanol producers. One reason that this is happening is that the feedstock is already at the plants. Instead of having to sell the byproduct, the plant can break it down into sugars that can be made into ethanol, which increases the amount of ethanol the plant produces. This also increases the amount of ethanol that is produced per bushel of corn.

**Ethanol Made from Corn Cobs**
Corn cobs are becoming one of the first residues to be used commercially as a way to produce ethanol from part of the corn plant other than the kernel. The breaking down of corn cobs uses the cellulose process which is also the same as breaking down the fibrous part of the corn kernel. At the 2007 Fuel Ethanol Workshop in St Louis, POET announced the successful production of cellulose ethanol from corn cobs. The corn fiber and corn cob is the primary feedstock used to make cellulose ethanol at their production facility in Iowa. The fiber that comes from their fractionation process will provide 40 percent of the cellulose feedstock from the corn kernels that they already process in their production facility. That means that nearly half of their cellulose feedstock comes with no additional planting, harvesting, storage or transportation need (Bernick 2007).

*Advantages and Disadvantages*
The use of corn cobs for ethanol production will result in an estimated 11 percent increase in the amount of ethanol per bushel of corn. On an average basis, that will result in about 27 percent more ethanol per acre (Stowers 2007). One major reason POET chose to use the corn cob is because the cob has higher bulk density than the other parts of the corn stalk. Therefore, it is easier to transport from the field to the facility. POET has not determined an exact amount, but believes the price paid to farmers will be $30 to $60 dollars per ton of corn cobs. There is no major market for cobs, so they will be producing cellulosic ethanol from an agricultural residue, and because the cob is only 18 percent of the above ground stover, it will not adversely impact

soil quality. These will also almost completely eliminate fuel consumption by burning lignin to provide energy and decrease water usage by 24 percent for the ethanol plant if implemented (Bernick 2007).

One problem with using corn cobs to make ethanol is that the corn cobs are not normally collected and are usually run though the chopper on the back of the combine and scattered on the ground. Therefore, equipment makers need to change the combine to make it collect corn cobs just like it collects the grain.

*Summary*
Converting corn cobs to ethanol involves two fundamental steps: breaking the long chains of cellulose molecules into glucose and other sugars, and fermenting those sugars into ethanol. In nature, these processes are performed by different organisms: fungi and bacteria that use enzymes to free the sugar in cellulose, and other microbes, primarily yeasts, that ferment sugars into alcohol.

This means that in the future, collecting corn cobs as an additional commodity might be a way for corn farmers to obtain more income from their corn acres. As of now, corn cobs are also the easiest to transport to an ethanol plant since they are denser than corn stover, which is mentioned later in this paper. Making ethanol out of corn cobs is a way of making ethanol out of a feedstock that has had little or no market until now.

**Ethanol made from Corn Stover**
Another way of using corn to make ethanol is to use the entire residue left after normal harvest of grain is completed. After a combine harvests the corn in the fall and removes the kernels, the stalks, cobs, husks and leaves of the corn plants are left. Figure 8 shows the anatomy of the entire corn plant. Some of this is used for feed and bedding of livestock, while the rest of this is leftover material. This material, called corn stover, provides nutrients for the soil and prevents erosion. It also has the potential for making ethanol. Figure 9 describes the process of using corn stover to make ethanol. This corn stover can be collected in a couple of different ways. The most likely way is for the stover to leave the chopper on the combine, shut it off and leave the residue in a wind row-like straw to be baled. The other way would be to modify a combine to collect the residue into a module similar to the method used to collect cotton and deliver it to a wagon or truck.

*Advantages and Disadvantages*
The United States Department of Energy’s National Renewable Energy Laboratory (NREL) in Golden, Colorado, estimates that converting one third of the nation’s corn stover to ethanol could produce an additional five billion to eight billion gallons of ethanol, enough to have a significant effect on the amount of petroleum used in this country. Nationally, about 244 million tons of corn stover is produced each year. Finding a market for corn stover could mean 10 dollars more per acre for farmers, according to the NREL.

Corn stover is the most abundant agricultural residue in the United States. The challenge is separating the sugars from the lignocellulose. Many technologies have been developed to convert lignocellulose to sugars, but the costs are still high and sugar yields are low. Ethanol is made from corn residue in a process similar to making ethanol from corn grain. After fermenting the corn residue, a byproduct remains that is lignin rich. Lignin is a complex compound found in plant cell walls, which is difficult for microbes to breakdown (Bohlmann 2003).

Zhang's cost effective pretreatment process integrates three technologies: cellulose solvent pretreatment, concentrated acid saccharification, and organosoly; and overcomes the limitations of existing processes (Flanigan 2004). Instead of a high pressure system that operates at between 150 and 250 degrees Celsius, Zhang's "modest reaction" operates at atmospheric pressure and 50 Celsius to pre-treat corn residue to free the solid polymeric sugars. In a several step pretreatment system, Zhang uses a strong cellulose solvent instead of highly corrosive chemicals, high pressure, and high temperature to break up the linkages among lignin, hemicellulose, and cellulose.

During Dr. Zhang's gentler process, there is no sugar degradation and inhibitor formation. In the following step, a highly volatile organic solvent is used to precipitate dissolved cellulose, extract lignin, and enable effective chemical recycling. After pretreatment and reagent recycling, lignocellulose can be fractionated into four products: lignin, hemicellulose sugars, amorphous cellulose, and acetic acid. "Co-products can generate more income, making biorefinery more profitable, and enables satellite biorefineries that fully utilize scattered lignocellulose resources," said Dr. Zang. "For instance, lignin has many industrial uses, from glue to polymer substitutes and carbon fiber, and xylose can be converted to a healthy sweetening additive xylitol, or to the precursors for nylon six."

Amorphous cellulose, which is converted from crystalline cellulose, is another advantageous product from this process because in this form the cellulose material is more accessible for further hydrolysis, resulting in a higher sugar yield, higher hydrolysis rate, and less enzyme use. Dr. Zang tested amorphous cellulose hydrolysis by adding special enzymes trichoderma cellulases from Genercor International. The result is that about 97 percent of the cellulose is digested after 24 hours of the hydrolysis process (Flanigan 2004).

*Summary*

While there are potential benefits from producing ethanol from corn residue, environmental risks, such as increased erosion due to removing corn residue, must be evaluated before corn residue removal becomes wide spread. Soil specific removal rates should be determined for profitable residue use with minimal erosion, nutrient and soil organic matter losses. This information is important to the United States Department of Energy in determining the feasibility of using corn residue for ethanol production. The use of corn residue as a fuel potentially provides an additional income source for farmers and aids in reducing dependence on non renewable energy sources.

In the July/August 2007 issue of *Feed Management* magazine, Lori Weaver's feature article found that it did not make economic sense to produce ethanol from corn stover. The article, titled "Controversy Continues Over Ethanol's Impact on Feed and Food," explains that the only way for corn stover to be economically viable is if the federal government was willing to finance approximately $270 per acre. Weaver also found that this would increase corn and soybean prices to roughly $4.75 and $8.50 per bushel (Tokgoz 2007).

## Butanol

Butanol is a four carbon alcohol. It has been used primarily as an industrial solvent. The worldwide market is about 350 million gallons per year, with the United States market accounting for about 220 million gallons per year. Butanol currently sells for about 3.70 dollars per gallon in bulk. Butanol can also be a replacement for gasoline as a fuel without major engine modifications and can be shipped through existing fuel pipelines. Butanol has high energy content of 110,000 Btu per gallon for butanol vs. 84,000 Btu per gallon for ethanol. Gasoline contains about 115,000 Btu's per gallon. Butanol is six times less evaporative than ethanol and 13.5 times less evaporative than gasoline, making it safer (Sklar 2006).

### *Advantages and Disadvantages*

There has been little to no effort to promote butanol as an alternate fuel because of historically low yields and low concentrations of butanol compared to those of ethanol. Each bushel of corn, results in 1.3 gallons of butanol, 0.7 gallons of acetone and 0.13 gallons of ethanol with concentrations of 1 to 2 percent. Butanol is presently manufactured from petroleum (Sklar 2006).

In the 1900 to 1950 time period, butanol was manufactured from corn and molasses in a fermentation process that also produced acetone and ethanol known as an ABE (acetone, butanol and ethanol) fermentation. However, as demand for butanol increased, production by fermentation declined mainly because the price of petroleum dropped below that of sugar when the United States lost its low-cost supply of sugar from Cuba in 1954. If one compares ABE yield to that of the yeast ethanol fermentation process, the yeast process yields 2.5 gallons of ethanol and is considered a better alternative fuel source over butanol. This result is shown in Figure 10.

One company, Environmental Energy Inc., has developed and patented technology that it believes overcomes the limitations that have to date kept the cost of butanol production from corn and other forms of biomass high. Environmental Energy Inc. claims it can produce 2.5 gallons of butanol from corn with no acetone or ethanol, while most other processes have not been able to achieve better than 1.3 to 1.9 gallon of butanol per bushel and still utilize an ABE process.

According to Figure 11, the worst case scenario is that a 10 million gallon per year butanol bio-refinery will still gross approximately $2 million more than an average 40 million gallons per year ethanol plant. This ability to obtain a higher income is due to the difference in current spot market value of butanol and ethanol, which is $3.38 to $1.54 respectively (Environmental Energy Inc 2004).

### *Summary*

The butanol economy overcomes many problems that are associated with ethanol. Butanol does not have to be stored in high-pressure vessels like natural gas. Butanol can be transported through existing pipelines for distribution. The filling station of the future could service regular automobiles, hybrids and fuel cell vehicles all at one stop, all with one renewable fuel made locally. The application of fuel cell technology is held up by the safety issues associated with hydrogen distribution, since butanol solves another problem. Since butanol can be blended with gasoline or diesel, it can be slowly introduced into the fuel grid as more and more biorefineries are built or converted from ethanol plants throughout the Corn Belt.

**Ranking**

To measure the popularity of these technologies throughout the United States a ranking system is used where 1= widespread commercial use; 2 = used in limited plants; 3 = done in laboratory only; 4 = worked on, but not actually done yet; and 5 = idea being discussed on paper. Figure 12 shows the technologies, the description of the technologies and the ranking. A “1” means the process is in widespread commercial use. A “2” denotes that the process is being used in a limited number of plants. A “3” signifies that the process is widely known about and has been done in a laboratory setting. A “4” means there is information being worked on about this process but not being actually implemented yet. A “5” indicates that this idea is still in the “thinking” or “futuristic” stage.

The first process is the dry milling and wet milling. These two processes are ranked as a number 1 because they both have been in widespread commercial use for many years. The improved yeast and the higher ethanol tolerance of yeast are also ranked as a 1.

The dry fractionation process that separates the germ of the corn kernel without the soaking stage is ranked a 2 because it is being tested and has not been implemented everywhere yet. The last new idea discussed was the fermenting of pentose into ethanol. This is ranked as a 3 since it has only been done in a laboratory.

Ethanol from the fiber part of the corn kernel is ranked as a 2 because there are many plants that are starting to do this, but for the most part the fiber part of the corn kernel is being sold as a byproduct of feed for livestock. The making of ethanol from corn cobs is ranked as a 2 because there are new plants that are setting up to make ethanol out of corn cobs right next to the existing corn ethanol plants. This is a new technology that is starting, but has not been done on a large scale yet.

Ethanol made from the corn stover is ranked as a 3 because there is at least one plant that did open and use corn stover on a pilot project in Harlan, Iowa. There are no other operational plants at this time. It does not appear to be profitable to make ethanol this way right now. Butanol is a biofuel like ethanol that is more powerful and can make more fuel per bushel of corn. Butanol itself would be ranked a 1, as it has been produced commercially for a long time as a solvent. Ranking butanol as a fuel would be a 4. A discussion is happening on whether to change all the ethanol plants over to butanol. This could possibly solve some of the problems that have arisen with using ethanol.

**Economic Outlook of Ethanol made from Corn and Milo in 2007**

The total cost per gallon to make ethanol from corn/milo at September 2007 prices was calculated to better understand breakeven. In Figures 14 and 15, the calculations are shown assuming that the ethanol plants are running at 100 percent capacity. To see the profitability of making ethanol, it is first necessary to find the cost of making ethanol from corn and milo. To accomplish this, the following equation was used:

***Total Cost per gallon = (Corn/Milo Cost per gallon) + (Input cost per gallon) + (Cost of Plant per gallon)***

To find the cost of corn/milo, bushels of corn/milo was used. The bushel weighs 56 pounds and the conversion of one bushel of corn/milo to ethanol is 2.8 gallons. The Manhattan Coop elevator delivery prices for the per bushel cost of corn and milo on September 20, 2007 were corn was 3.11 and milo was 3.23.
***Corn Cost per gallon = (3.11/2.8) = 1.11***
***Milo Cost per gallon = (3.23/2.8) = 1.15***

The input cost per gallon of ethanol was a conservative value and $0.862 per gallon was used. This value was found at Hurt (2006). The cost per gallon takes into account the cost of natural gas at $9.00/millon BTU, electricity at $1.20/ gallon, cost of chemical and enzyme $0.182/gallon and the processing cost $0.297/gallon. Not all ethanol plants are the same. Some plants input costs are a lot lower than others and that makes them more profitable than plants with higher input cost.

To find the fixed cost of the ethanol plants, a life expectancy of 25 years was assumed for the plant. This is difficult to determine since the ethanol industry has just began in the past couple of years. An interest rate of 6 percent was used when paying off the plant or the opportunity cost of using the money elsewhere was assumed. To find the fixed cost per gallon, the PMT equation in Excel, divided by gallons produced yearly, was used.

> (***(=PMT (annual interest rate cost, 25 year life,-cost of plant,0,0) )/ (gallons produced yearly))***

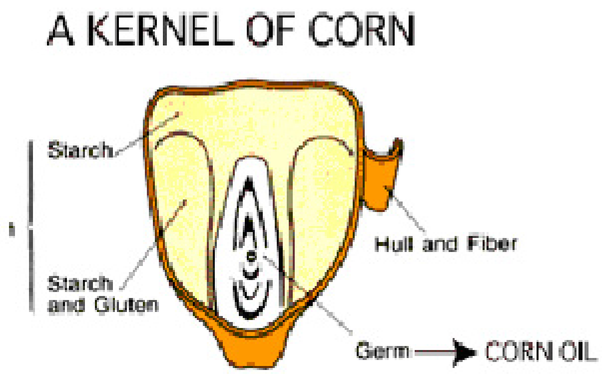
After finding all of the costs, the $1.59 price of ethanol was assumed according to the CBOT. So with this assumption, it costs $2.10 per gallon to produce ethanol. The producers were receiving $1.59 back, thus losing $0.51 for every gallon produced that day. This does not mean every ethanol producer was losing $0.51 per gallon. Depending on the input cost of each individual plant, ethanol could still be making a profit. The break even input cost would be $0.352 per gallon to make ethanol from corn, and $0.315 per gallon to make ethanol from milo if corn and milo prices stayed unchanged. If we used the input cost as our constraint, milo price would need to be $1.72 per bushel, and corn would need to be $1.72 per bushel to make producing ethanol break even with this input cost.

As you can see in both cases in Figure 16 and Figure 17, the cost curves are flat. This is because there is no way of finding out the input cost of each size of ethanol plant. Some small ethanol plants might even be getting their inputs cheaper than a large plant, but basic intuition would tell you that the larger ethanol plants would be able to buy their inputs in bigger quantities and use economies of scale to make their input cost cheaper, making a typical cost curve which is downward sloping.

## Conclusion

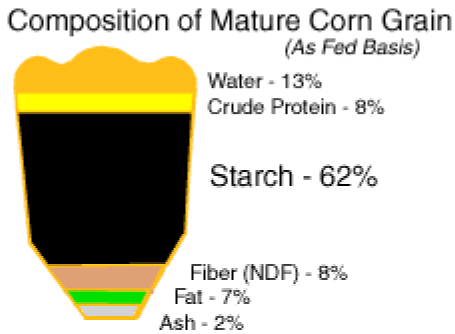
Although ethanol has been around a long time, there are a lot of new technologies and ways to produce it. We have highlighted most of the ways to make ethanol from corn and have shown some of the advantages and disadvantages of each technology. After ranking the technologies, the profitability of producing ethanol from corn and milo was determined based on some assumptions. The ethanol industry is helping to make the United States more independent from foreign oil.

As shown in Figure 18, there is a lot of ethanol production taking place in Kansas and even more planned in the future. This figure is a list of the plants and their present status. In Kansas, most of the ethanol plants use corn as the main feedstock, but some use grain sorghum and wheat. In Kansas, a Spanish company named Abengoa Bioenergy has chosen the town of Hugoton, Kansas, as the site of the first U.S. plant to turn crop residue and other vegetation into ethanol. Abengoa Bioenergy formally announced the $300 million project, which will also include a traditional corn-to-ethanol plant, in August 2007. The regular ethanol plant is expected to produce 85 million gallons a year. The other plant will produce about 30 million gallons from cellulose. The Hugoton project will be funded in part by a $76 million grant from the U.S. Department of Energy (International Herald Tribune 2007).



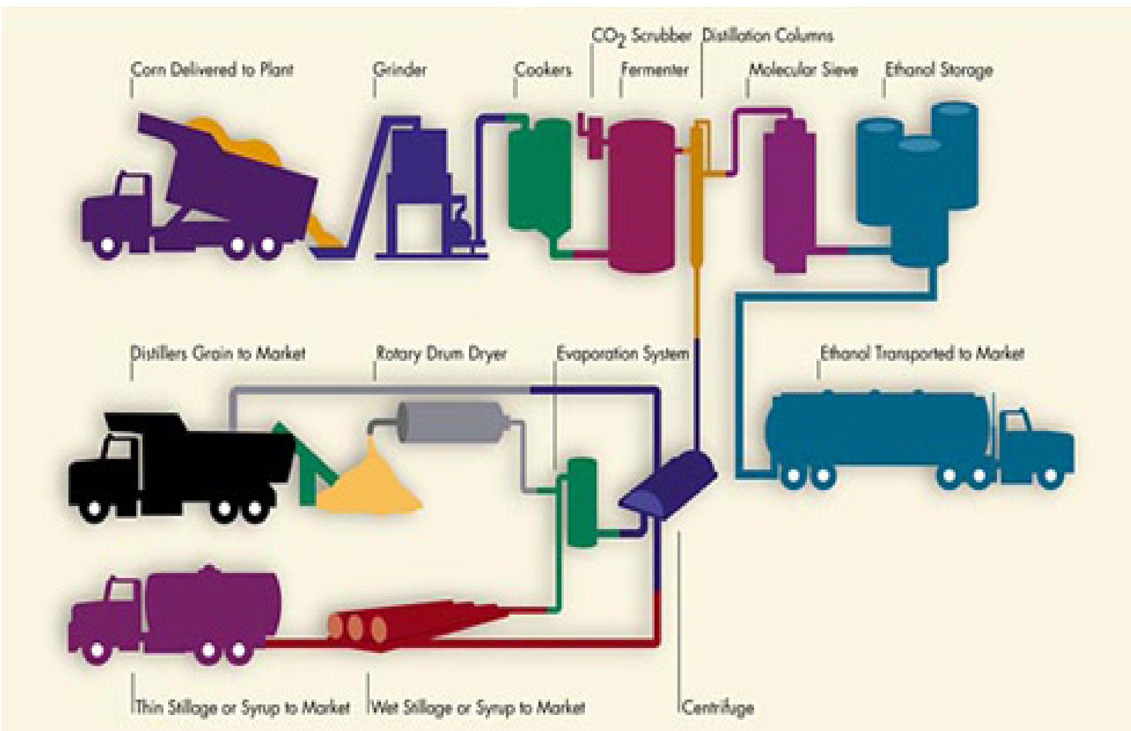

Source: Mayabb 2007.

Figure 1. Anatomy of the Corn Kernel.




Source: Schroeder 1999.

Figure 2. Nutrient Concentration of the Mature Corn Kernel.



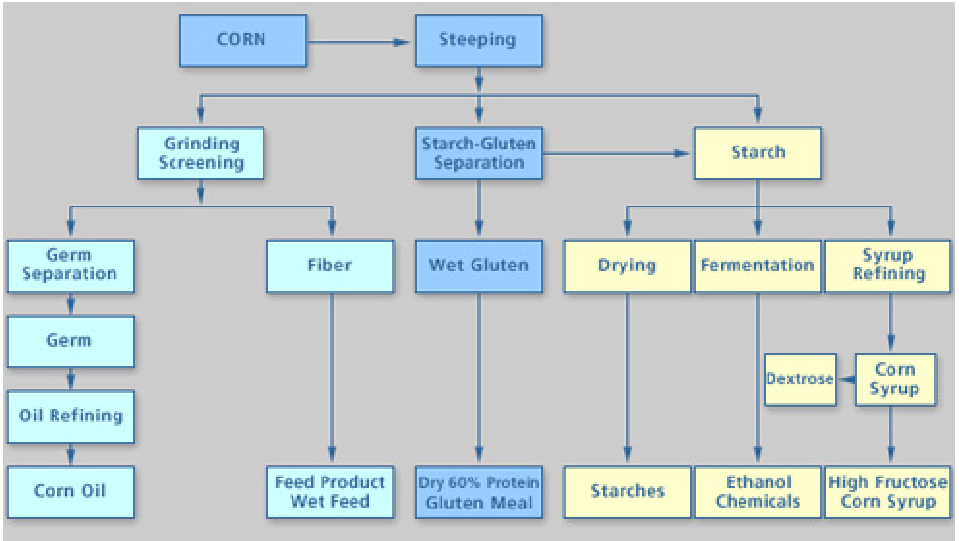

Source: Renewable Fuels Association 2005.

Figure 3. Entire Dry Milling Process from Delivery of Corn to Ethanol Exiting the Plant.

| | Wet Corn Gluten Feed | | Dry Corn Gluten Feed | |
|---|---|---|---|---|
| Type of Nutrient | DM Basis | As Fed | DM Basis | As Fed |
| | percent | | | |
| Dry Matter | 43.0 | -- | 90.0 | -- |
| Crude Protein | 21.5 | 9.0 | 21.5 | 18.0 |
| ADF | 14.0 | 6.0 | 8.4 | 7.6 |
| NDF | 37.9 | 16.3 | 8.4 | 7.6 |
| TDN (average) | 88 | -- | 78 | -- |
| Crude Fat | 1.2 | .5 | 1.2 | .5 |
| Ash | 8.2 | 3.5 | 8.2 | 3.5 |
| Calcium | .1 | .04 | .1 | .04 |
| Phosphorus | 1.2 | .52 | 1.2 | .52 |
| Magnesium | .28 | .12 | .28 | .12 |
| Potassium | 1.8 | .78 | 1.8 | .78 |
| Sulfur | .4 | .17 | .3 | .17 |
| Lysine | .24 | .1 | .6 | .1 |
| Tryptophan | .09 | .04 | .2 | .04 |
| Methionine | .14 | .6 | .5 | .06 |
| Cystine | .4 | .2 | .4 | .2 |
| | parts per million | | | |
| Iron | 165.0 | -- | 165.0 | -- |
| Zinc | 114.4 | -- | 114.4 | -- |
| Copper | 6.0 | -- | 6.0 | -- |
| Manganese | 26.4 | -- | 26.4 | -- |
| Net Energy -- Maintenance, Mcal/lb | .99 | -- | .87 | -- |
| Net Energy -- Gain, Mcal/lb | .65 | -- | .57 | -- |
| Net Energy -- Lactation, Mcal/lb | .86 | -- | .82 | -- |

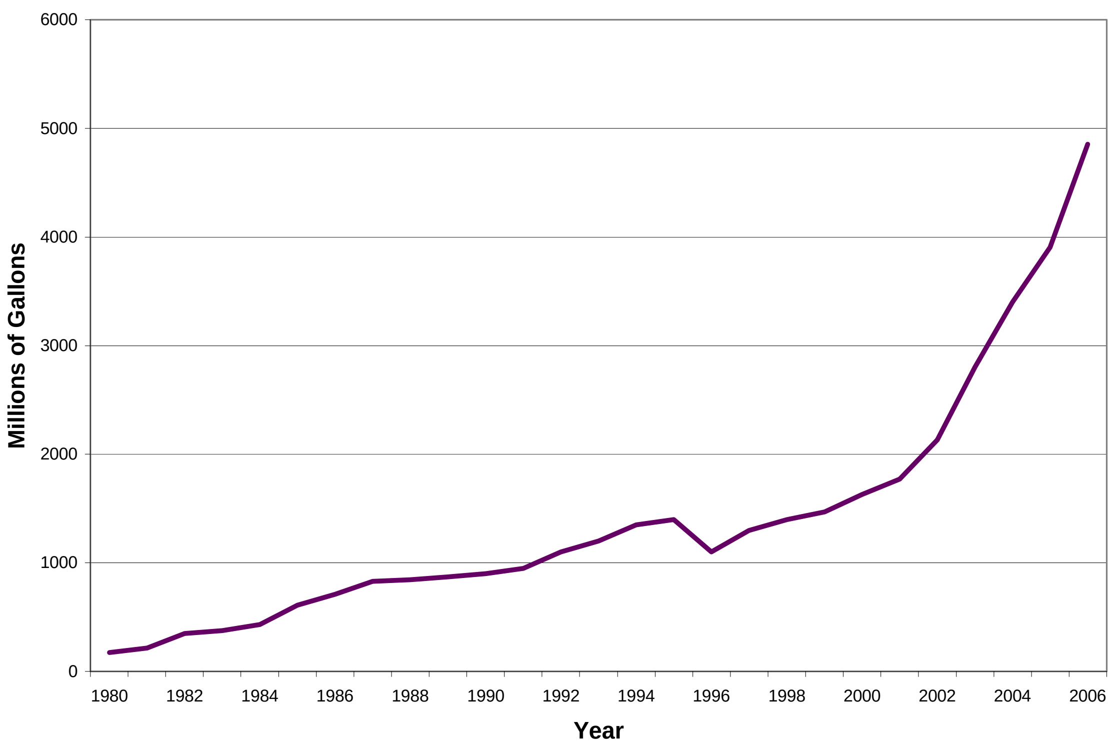
Source: Schroeder 1999.

Figure 4. Nutrient composition of corn gluten feed in terms of wet corn gluten vs. dry corn gluten.



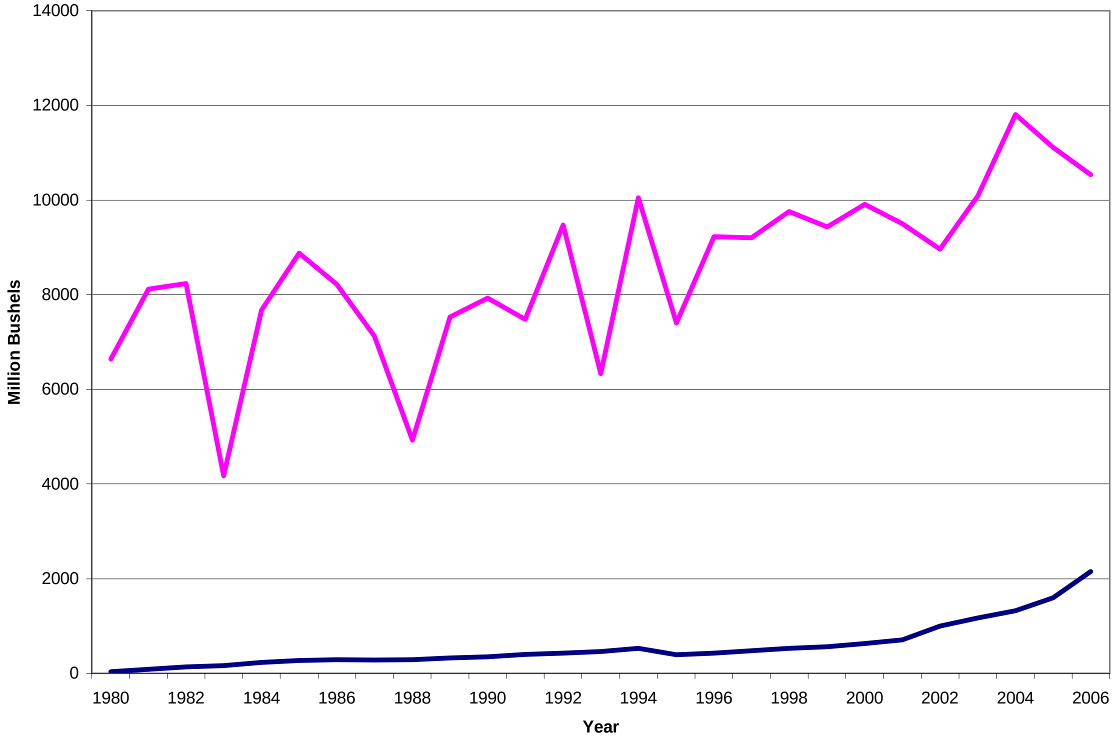

Source: Renewable Fuels Association 2005.

Figure 5. Entire Wet Milling Process from the Corn to the Finished Product.



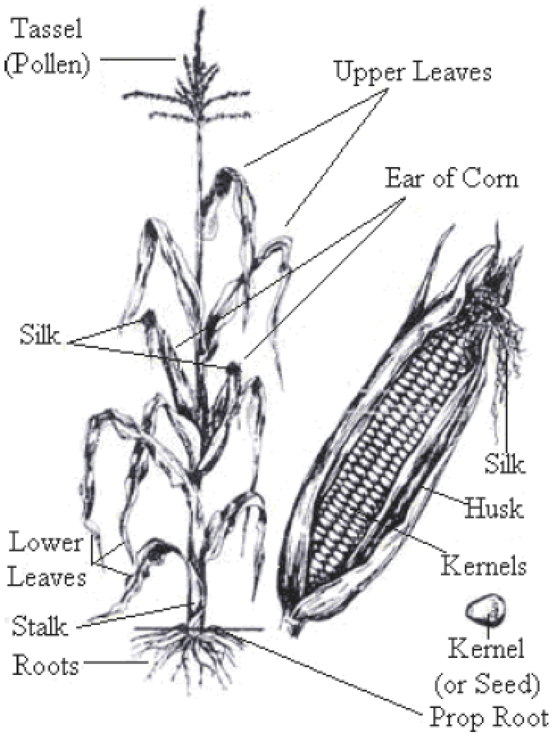

Source: Renewable Fuels Association 2007.

Figure 6. United States Ethanol Production from 1980 to 2007 in Millions of Gallons.



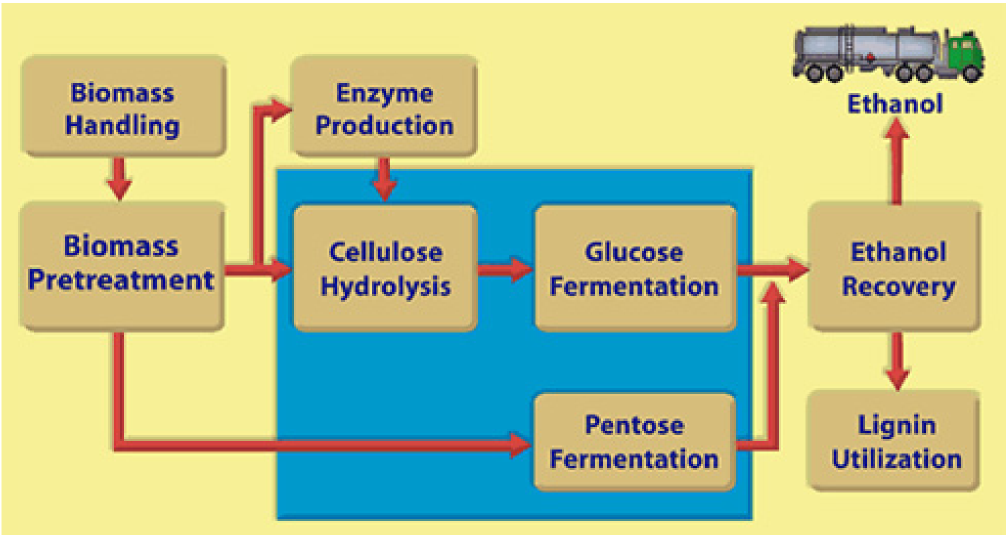

Source: United States Department of Agriculture 2007.

Figure 7. Amount of Corn Used in the United States in the Production of Ethanol along with Total United States Corn Production from 1980 to 2007 in Millions of Bushels.



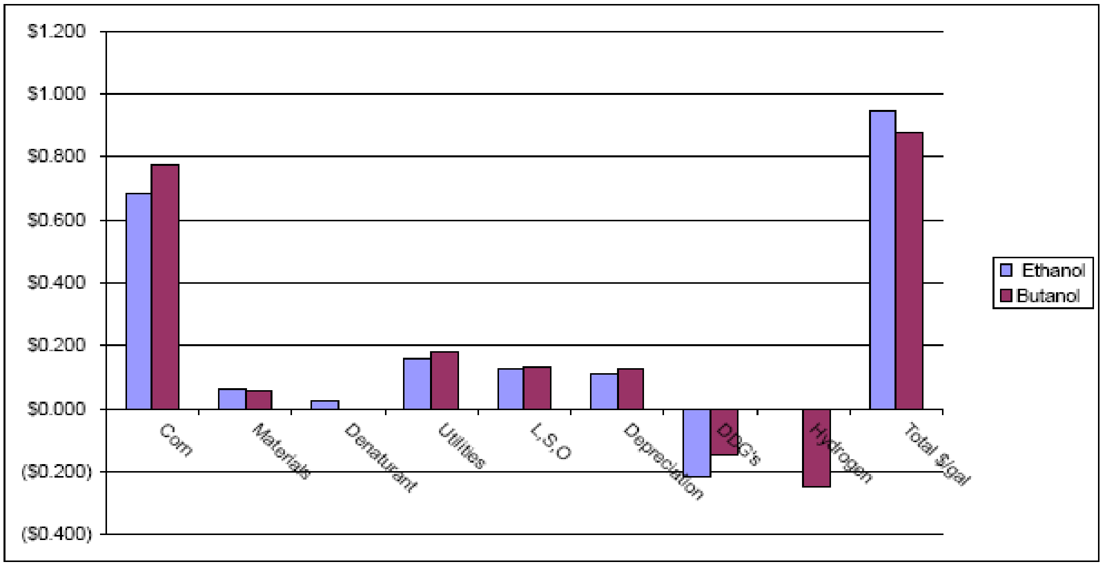

Source: Kansas Corn Growers Association 2004.

Figure 8.Anatomy of the Corn Plant Showing All the Main Parts of a Mature Corn Plant and Corn Ear.



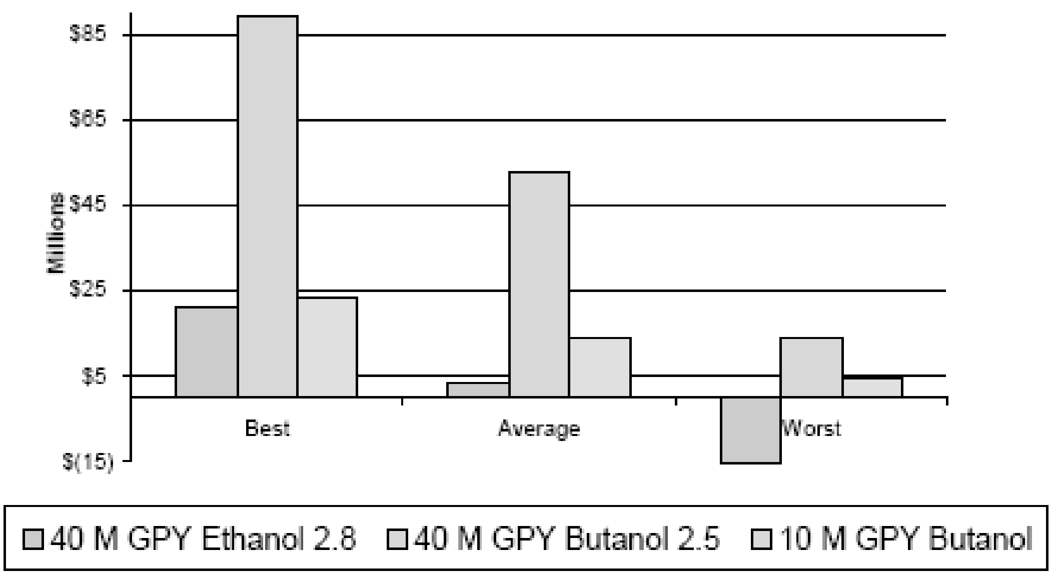

Source: Renewable Fuel Association 2005.

Figure 9. Entire Corn Stover Process from Corn Stover Entering the Plant to Ethanol Leaving.




Source: Environmental Energy Inc. 2004.

Figure 10. Comparison of Cost.




Source: Environmental Energy Inc 2004.

Figure 11. Showing the Best, Average, and Worst Case Scenarios of Net Income for Ethanol vs. Butanol.

1) Dry or wet milling

2) Conversion of biomass into usable sugars

3) Butyric acid and hydrogen fermentation (acidiogenic)

4) Butanol fermentation (solventogenic)

5) High grading: gas-stripping/adsorption/desorption/condensing/decantation

6) Distillation: High purity

7) By-product recovery

Source: Environmental Energy Inc 2004.

Figure 12. Butanol production's seven-stage process.

| Technologies | Used/ Not Used | One Sentence description | Ranking |
|---|---|---|---|
| Corn Starch | used | The making of ethanol from the starch in the corn kernel though wet and dry milling. | 1 |
| Corn Starch and gluten | Used | Using the cellulosic technique to utilizing the fiber from the corn kernel to produce additional gallons of ethanol | 2 |
| Corn Cob | Used | Making ethanol from corn cobs using a cellulosic technique. | 2 |
| Corn Stover | Not Used | Using the whole corn plant; the stalk, leaves, and cob, to make ethanol by turning them into sugars that can be made into ethanol | 3 |
| Butanol | Not Used | Butanol uses a lot of the same process as ethanol but make a higher energy fuel that is being looked as an option. | 4 |

Figure 13. Ranking, Popularity and Description of Technologies.

| Plant Size, Million Gallon | Cost of Corn, a Million Dollars | Plant Cost, b Million Dollars | Cost of Inputs, c Million Dollars | Fixed Cost, d Million Dollars | Total Cost , e Million Dollars | Cost Per Gallon , f | Dollars Per Gallon Ethanol |
|---|---|---|---|---|---|---|---|
| 35 | 38.85 | 56 | 30.17 | 4.38 | 73.40 | 2.10 | 1.59 |
| 40 | 44.40 | 64 | 34.48 | 5.01 | 83.89 | 2.10 | 1.59 |
| 45 | 49.95 | 72 | 38.79 | 5.63 | 94.37 | 2.10 | 1.59 |
| 50 | 55.50 | 80 | 43.10 | 6.26 | 104.86 | 2.10 | 1.59 |
| 55 | 61.05 | 88 | 47.41 | 6.88 | 115.34 | 2.10 | 1.59 |
| 60 | 66.60 | 96 | 51.72 | 7.51 | 125.83 | 2.10 | 1.59 |
| 65 | 72.15 | 104 | 56.03 | 8.14 | 136.32 | 2.10 | 1.59 |
| 70 | 77.70 | 112 | 60.34 | 8.76 | 146.80 | 2.10 | 1.59 |
| 75 | 83.25 | 120 | 64.65 | 9.39 | 157.29 | 2.10 | 1.59 |
| 80 | 88.80 | 128 | 68.96 | 10.01 | 167.77 | 2.10 | 1.59 |
| 85 | 94.35 | 136 | 73.27 | 10.64 | 178.26 | 2.10 | 1.59 |
| 90 | 99.90 | 144 | 77.58 | 11.26 | 188.74 | 2.10 | 1.59 |
| 95 | 105.45 | 152 | 81.89 | 11.89 | 199.23 | 2.10 | 1.59 |
| 100 | 111.00 | 160 | 86.20 | 12.52 | 209.72 | 2.10 | 1.59 |
| 105 | 116.55 | 168 | 90.51 | 13.14 | 220.20 | 2.10 | 1.59 |
| 110 | 122.10 | 176 | 94.82 | 13.77 | 230.69 | 2.10 | 1.59 |
| 115 | 127.65 | 184 | 99.13 | 14.39 | 241.17 | 2.10 | 1.59 |
| 120 | 133.20 | 192 | 103.44 | 15.02 | 251.66 | 2.10 | 1.59 |

Figure 14. Corn Ethanol Cost Table.

a) Cost of Corn calculated as (Cost of Corn per Gallon * Plant Size)
b) Plant Cost calculated as (Plant Size * 1.6)
c) Cost of Inputs calculated as ( Plant Size * .862)
d) Fixed Cost calculated as ((=PMT(.06,25,-Plant Cost,0,0))/(Plant Size))
e) Total Cost calculated as (Cost of Corn + Cost of Inputs + Fixed Cost)
f) Cost per Gallon calculated as ( Total Cost / Plant Size)

| Plant Size, Million Gallon | Cost of Milo, a Million Dollars | Plant Cost, b Million Dollars | Cost of Inputs, c Million Dollars | Fixed Cost, d Million Dollars | Total Cost, e Million Dollars | Cost Per Gallon, f | Dollars Per Gallon Ethanol |
|---|---|---|---|---|---|---|---|
| 35 | 40.25 | 56 | 30.17 | 4.38 | 74.80 | 2.14 | 1.59 |
| 40 | 46 | 64 | 34.48 | 5.01 | 85.49 | 2.14 | 1.59 |
| 45 | 51.75 | 72 | 38.79 | 5.63 | 96.17 | 2.14 | 1.59 |
| 50 | 57.5 | 80 | 43.10 | 6.26 | 106.86 | 2.14 | 1.59 |
| 55 | 63.25 | 88 | 47.41 | 6.88 | 117.54 | 2.14 | 1.59 |
| 60 | 69 | 96 | 51.72 | 7.51 | 128.23 | 2.14 | 1.59 |
| 65 | 74.75 | 104 | 56.03 | 8.14 | 138.92 | 2.14 | 1.59 |
| 70 | 80.5 | 112 | 60.34 | 8.76 | 149.60 | 2.14 | 1.59 |
| 75 | 86.25 | 120 | 64.65 | 9.39 | 160.29 | 2.14 | 1.59 |
| 80 | 92 | 128 | 68.96 | 10.01 | 170.97 | 2.14 | 1.59 |
| 85 | 97.75 | 136 | 73.27 | 10.64 | 181.66 | 2.14 | 1.59 |
| 90 | 103.5 | 144 | 77.58 | 11.26 | 192.34 | 2.14 | 1.59 |
| 95 | 109.25 | 152 | 81.89 | 11.89 | 203.03 | 2.14 | 1.59 |
| 100 | 115 | 160 | 86.20 | 12.52 | 213.72 | 2.14 | 1.59 |
| 105 | 120.75 | 168 | 90.51 | 13.14 | 224.40 | 2.14 | 1.59 |
| 110 | 126.5 | 176 | 94.82 | 13.77 | 235.09 | 2.14 | 1.59 |
| 115 | 132.25 | 184 | 99.13 | 14.39 | 245.77 | 2.14 | 1.59 |
| 120 | 138 | 192 | 103.44 | 15.02 | 256.46 | 2.14 | 1.59 |

Figure 15. Milo Ethanol Cost Table.

a) Cost of Milo calculated as (Cost of Milo per Gallon * Plant Size)
b) Plant Cost calculated as (Plant Size * 1.6)
c) Cost of Inputs calculated as (Plant Size * .862)
d) Fixed Cost calculated as ((=PMT (.06,25,-Plant Cost,0,0))/(Plant Size))
e) Total Cost calculated as (Cost of Milo + Cost of Inputs + Fixed Cost)
f) Cost per Gallon calculated as ( Total Cost / Plant Size)


Figure 16. Corn Ethanol Average Cost Curve with Assumptions in 2007.


Figure 17. Milo Ethanol Average Cost Curve with Assumption in 2007.

| Company Name | City | State | Feedstock | Status | Submitted |
|---|---|---|---|---|---|
| Everton Energy | Concordia | KS | N/A | Planned | 7/20/2007 7:50 |
| Nexsun Energy | Ulysses | KS | Grain Sorghum | Planned | 7/20/2007 7:50 |
| ESE Alcohol Inc. | Leoti | KS | Seed corn | Operational | 7/20/2007 7:50 |
| North American Bioenergy Resources Inc. | Ulysses | KS | N/A | Planned | 7/20/2007 7:50 |
| Emerald Renewable Energy LLC | Topeka | KS | corn | Planned | 7/20/2007 7:50 |
| Western Plains Energy, LLC | Campus | KS | Corn | Operational | 7/20/2007 7:50 |
| East Kansas Agri-Energy, LLC | Garnett | KS | Corn | Operational | 7/20/2007 7:50 |
| E3 Biofuels | Washington | KS | Corn | Planned | 7/20/2007 7:50 |
| Abengoa Bioenergy Corp. | Colwich | KS | Corn | Operational | 7/20/2007 7:50 |
| Arkalon Energy LLC | Liberal | KS | Corn/Milo | Under-Construction | 7/20/2007 7:50 |
| Panda Ethanol | Haskell County | KS | Corn/Milo | Planned | 7/20/2007 7:50 |
| E Caruso, LLC | Goodland | KS | Corn | Under-Construction | 7/20/2007 7:50 |
| MGP Ingredients, Inc. | Atchison | KS | Corn | Operational | 7/20/2007 7:50 |
| U.S. Energy Partners, LLC (White Energy) | Russell | KS | Milo/wheat starch | Operational | 7/20/2007 7:50 |
| Bonanza BioEnergy LLC | Garden City | KS | Corn/milo | Under-Construction | 7/20/2007 7:50 |
| Gardenview BioEnergy | Garden City | KS | Feedstock N/A | Planned | 7/20/2007 7:50 |
| Reeve Agri-Energy | Garden City | KS | Corn/milo | Operational | 7/20/2007 7:50 |
| Kansas Ethanol, LLC | Lyons | KS | Corn/Milo | Under-Construction | 7/20/2007 7:50 |
| Orion Ethanol, LLC | Hugoton | KS | Corn | Planned | 7/20/2007 7:50 |
| Prairie Horizon Agri-Energy, LLC | Phillipsburg | KS | Corn | Operational | 7/20/2007 7:50 |
| Boot Hill Biofuels | Wright | KS | Corn | Planned | 7/20/2007 7:50 |
| Dial Energy Corp. | Dodge City | KS | Corn | Planned | 7/20/2007 7:50 |
| Gateway Ethanol, LLC | Pratt | KS | Corn/Grain Sorghum | Under-Construction | 7/20/2007 7:50 |

Source: DTN Ethanol Center 2007.

Figure 18. List of Ethanol Companies in Kansas along with Status and Type of Feedstock used.

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