CROP INSIGHTS

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Dry-grind Ethanol Production from Corn

by Steve Butzen and Doug Haefele

Summary

- Ethanol creates new markets for corn, provides new jobs in rural areas, reduces foreign oil imports, and burns cleaner than gasoline.
- These advantages have driven growth of the ethanol industry by over 25% per year since 2001. Production of 6.5 billion gallons in 2007 utilized over 2.3 billion bu. of corn (about 17.5% of the 2007 US corn crop).
- Most of the industry growth in recent years is from construction of new dry-grind plants. Process technologies in dry-grind ethanol production are advancing rapidly (e.g., low temperature starch hydrolysis and kernel fractionation).
- Pioneer's hybrid screening program has shown that some hybrids are clearly superior in the amount of ethanol produced per bushel of grain. Desirable grain traits include ***High Total Fermentables (HTF)*** and low occurrence of molds/diseases.
- Pioneer is leading the industry in developing analytical tools for determining ethanol yield potential (EYP) of grain, identifying hybrids with the highest ethanol potential, and developing new hybrids with desirable grain traits for dry-grind ethanol production.
- Increased demand, innovative production technologies and improved corn hybrids for ethanol production continue to drive an ethanol industry intent on meeting our nation's rising energy needs.

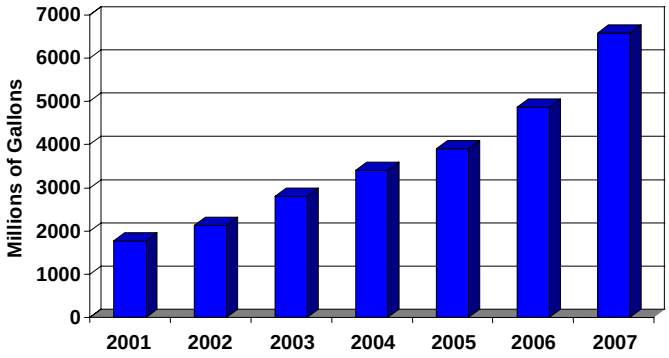
Introduction

The use of ethanol as a fuel for vehicles dates back to the very beginnings of the automobile – Henry Ford designed his 1908 Model T to run on ethanol. But the development of the oil industry in the US met the need for cheap, abundant vehicle fuel, and ethanol was temporarily shelved. Today's limited oil refining and insatiable demand for energy in the US, however, have created a pressing need for alternative energy sources, and ethanol has proven an attractive option.

Value of Ethanol

Ethanol has strategic value because it is a renewable energy source and reduces US dependence on foreign oil imports. It benefits farmers by creating a substantial new market for corn supplies. As a rapidly growing industry in the Midwest, it is creating new jobs in economically depressed rural areas and small communities. As a fuel component, it burns cleanly, reduces greenhouse gas emissions and increases the octane rating of gasoline (Farrell et al., 2006). These advantages, coupled with legislative initiatives, have driven significant growth of the US ethanol industry:

Annual US Ethanol Production



Source: Renewable Fuels Association

US Ethanol Production Statistics

Ethanol production in the US has grown by over 25% per year since 2001. In 2007, the ethanol industry produced 6.5 billion gallons, up from less than 5 billion gallons in 2006. This utilized over 2.3 billion bushels of corn, or 17.5% of the total corn produced that year.

Currently, over 130 plants are in operation in 26 different states, with 70 or more plants being built or expanded. Total production capacity now exceeds 7 billion gallons/year, with 6 billion gallons per year under construction. This is enough capacity to replace over 6% of annual gasoline usage in the US, which is approximately 140 billion gallons/year.

Ethanol Production Methods

Nearly all ethanol currently produced in the US is made from corn. Two processing methods are employed – dry-grind and wet milling. This article will focus on the dry-grind method of ethanol production from corn.

Dry-grind Ethanol Plants Increasing

Because constructing wet-milling plants is complex and capital-intensive, almost all new plants are dry-grind. Consequently, most ethanol is produced by the dry-grind method, and its percentage increases with each new dry-grind plant constructed. This trend is expected to persist into the

future, where the increased demand for ethanol from grain will continue to be met primarily by construction of new dry-grind plants.

Ethanol Performance and the Environment

- Ethanol has an octane rating of 113 (compared to 87 for regular unleaded gasoline and 93 for premium unleaded), making ethanol the highest rated performance fuel on the market.
- Ethanol contains 35% oxygen. The use of this oxygenate in US fuels has reduced CO2-equivalent greenhouse gas emissions by millions of tons, which is equivalent to eliminating emissions from over 1.5 million cars.
- Ethanol also replaces toxic gasoline components such as benzene, which is classified as a carcinogen. Unlike methyl tertiary butyl ether (MTBE, historically the most widely used fuel oxygenate), ethanol is non-toxic and quickly biodegradable.
- There are potential synergies for ethanol and fuel cells. Ethanol is easily stored and dispensed in the current fueling system and generates fewer greenhouse gas-forming emissions than conventional fuels. Tests have demonstrated that ethanol is more efficient to reform than gasoline to provide hydrogen for fuel cells.

The Dry-grind Ethanol Process

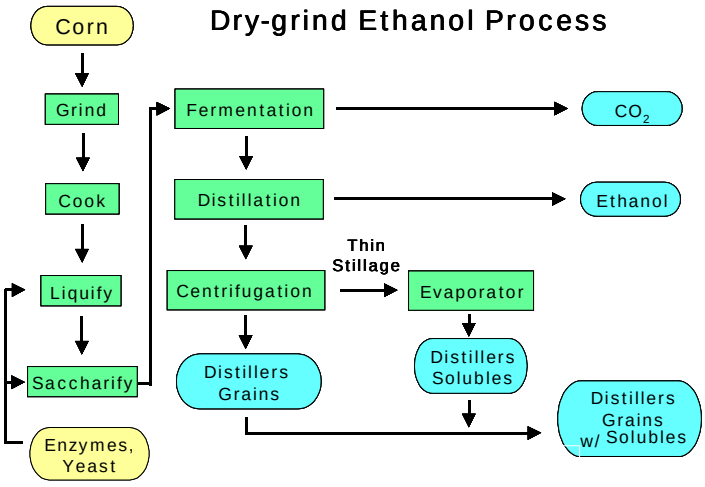
Utilizing the dry-grind method of ethanol production, processors can produce about 2.8 gallons of ethanol from a bushel of corn. This is because of improved production techniques, including use of hybrids specifically designated for dry-grind ethanol. Just a few years ago, processors were only able to extract 2.5 to 2.6 gallons of ethanol per bushel of corn, so the improvement is significant.

In the dry-grind method, the entire corn kernel is ground into a coarse flour, then slurried with water to form a "mash." The mash is then cooked, treated with enzymes, fermented and distilled. By-products of the dry-grind process include distillers grains, a high-quality livestock feed, and carbon dioxide, a food and industrial product. There is almost nothing wasted in this process.

As an intensive biological process, the dry-grind method requires stringent quality control for optimum results. For example, bacterial contamination at mashing may result in formation of acids that divert glucose from ethanol production and interfere with fermentation. Moldy grain, improper grain storage, faulty equipment, re-introduced stillage and air are some of the major sources of contamination.

Starch Conversion

Corn endosperm starch cannot be utilized directly by yeast, so it must first be broken down into simple sugars prior to



fermentation. To accomplish this conversion, enzymes are added to the mash during cooking. The first step in breaking down the starch molecule utilizes an alpha-amylase enzyme and steam (gelatinization and liquefaction). The next step involves adding gluco-amylase enzymes at a lower temperature to produce smaller fermentable sugars (saccharification).

Traditional batch cooking is often replaced by continuous cooking processes in new and remodeled ethanol plants. Continuous cooking is generally more energy efficient and, if designed and operated properly, can yield up to 8% more ethanol per bushel of grain.

Fermentation

After cooking, the mash is cooled and transferred to fermenters where yeast is added. *Saccharomyces cerevisiae* is the yeast species commonly selected because of its quick, efficient production of alcohol and its ability to withstand heat, osmotic stress and high alcohol concentrations.

The fermentation process generally takes about 50 to 60 hours. The goal is a timely conversion of glucose to ethanol. Batch or continuous fermentation systems may be used, although batch processing is more common. Some new fermentation systems are designed to minimize dilution water, which reduces the evaporation requirements in the feed processing stages after fermentation.

The carbon dioxide (CO_2) released during fermentation is often captured and sold, especially by larger dry-grind facilities. The CO_2 is used in carbonating soft drinks and beverages, manufacturing dry ice and other industrial processes.

Distillation and Dehydration

Distillation is the process of separating the ethanol from the solids and water in the mash. Alcohol vaporizes at 173° F and water at 212° F (at sea level). This difference allows water to be separated from the ethanol by heating in a distillation column.

Conventional distillation/rectification methods can produce 95% pure (190 proof) ethanol. At this point, the alcohol and

water form an azeotrope, which means further separation by heat cannot occur. In order to blend with gasoline, the remaining 5% water must be removed by other methods. Modern dry-grind ethanol plants use a molecular sieve system to produce absolute (100% or 200 proof) ethanol.

The anhydrous ethanol is then blended with about 5% denaturant (such as gasoline) to render it undrinkable and thus not subject to beverage alcohol tax. It is then ready for shipment to gasoline terminals or retailers.

Stillage Processing

The solid and liquid fraction remaining after distillation is referred to as "whole stillage". Whole stillage includes the fiber, oil and protein components of the grain, as well as the non-fermented starch. This co-product of ethanol manufacture is a valuable feed ingredient for livestock, poultry and fish.

Although it is possible to feed whole stillage, it is usually processed further before being sold for feed. First, the "thin stillage" is separated from the insoluble solid fraction using centrifuges or presses/extruders. The thin stillage is then sent to evaporator units to remove excess water. After evaporation, the thick, viscous syrup is mixed back with the solids to create a feed product known as Wet Distillers Grains with Solubles (WDGS).

Feed Products from Stillage Processing

WDGS, containing 65% moisture, can be used directly as a feed product. In fact, it is often favored by dairy and beef feeders because cattle seem to prefer the moist texture. However, WDGS has a shelf life of only one to two weeks. Unless the feedlot is within about 50 miles of the ethanol plant, handling and storage can be a challenge, especially in hot summer months when shelf life is very limited.

To increase shelf life and lower transportation costs, WDGS is usually dried to 10 to 12% moisture to produce a product known as Dried Distillers Grain with Solubles (DDGS). Drying distillers grains is energy-intensive, consuming about one-third of the energy requirements of the entire dry-grind plant. However, producing a uniform, stable, high-quality feed co-product is essential to the profitability of the plant, resulting in most plants producing DDGS rather than WDGS.

In 2007, dry-grind ethanol plants produced over 14.5 million tons of distillers grains. This valuable feed product is used domestically by livestock producers, and exported to Europe, Mexico, Canada and Southeast Asia as well.

New Process Technologies

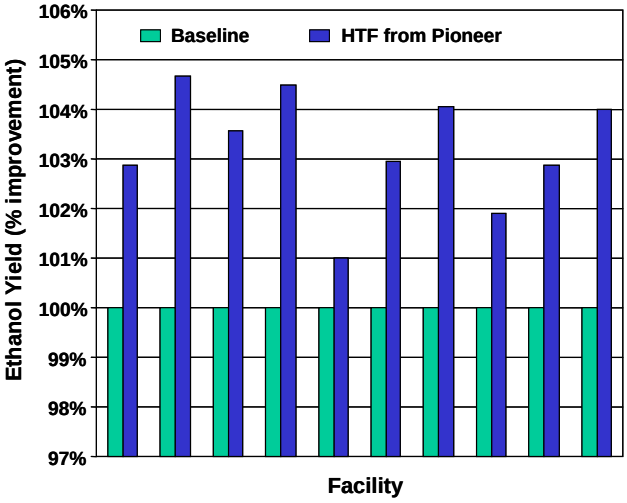
The process technologies used in dry-grind ethanol production are advancing as the industry grows. In November 2004, Broin & Associates (now Poet, LLC) and Novozymes North America announced the BPX process for starch hydrolysis (conversion of starch to the sugars used in fermentation) at low temperature. Driven by improvements in process engineering and advances in enzyme technology, this process requires less energy and attains high ethanol yields while reducing VOC emissions and improving DDGS properties.

Fractionation of the corn kernel before it enters the ethanol production process has also attracted the attention of several groups. The advantages of fractionation are the potential to capture high value co-products before processing and to increase the efficiency of fermentation by removing the non-starch portions of the kernel from the process before fermentation.

Corn Hybrids for Ethanol Production

In the dry-grind ethanol industry the cost of corn makes up more than 60% of the total production cost. It is therefore essential to get the most for every dollar spent purchasing corn. In order to help meet this challenge, Pioneer has been developing and selling corn hybrids that are best suited for dry-grind corn processing for a number of years. These hybrids are characterized by High Total Fermentables (HTF) and other traits conducive to processing efficiency and reliable supply.

HTF Hybrids from Pioneer Out-yield Commodity Grain for Ethanol Production.*



* Data from Pioneer's collaborator facilities, comparing Pioneer HTF hybrid package to facility baseline grain.

Pioneer research has shown that the HTF trait is a more accurate indicator of dry-grind ethanol production than total starch or extractable starch. HTF corn hybrids from Pioneer offer dry-grind ethanol producers grain with above average ethanol production potential in dependable, high-yielding hybrids (Haefele et al., 2004).

Selecting Hybrids

In addition to high yield and strong agronomic traits, growers can now include the Pioneer HTF trait in their hybrid selection criteria for corn acres intended for dry-grind ethanol

end-use. Pioneer has expanded its capabilities by building a team of business and technical experts to support and develop this market segment. As the dry-grind industry continues to grow, Pioneer will continue to provide growers and processors with the hybrids and information needed to maximize ethanol yields.

Pioneer Analytical Tools and Hybrids for the Dry-grind Ethanol Industry

- Pioneer has developed an industry-leading analytical tool (based on extensive laboratory and commercial fermentation data) that measures differences in ethanol yield potential (EYP) of corn grain. Pioneer has made this tool available to the industry for a point-of-sales assay of commercial grain. The Illinois Crop Improvement Association has confirmed that Pioneer's EYP calibration provides a reliable and rapid evaluation of grain EYP.
- Pioneer developed the QualiTrak℠ system which assists ethanol plants in measuring EYP and using the data to influence grain origination decisions. The system has been employed by multiple ethanol plants over the past year.
- The HTF designation is assigned to elite Pioneer® brand hybrids based on data from over 21,600 Pioneer plot samples over the past 5 years. Over 30 locations and 165 hybrids were sampled. These data suggest an ethanol yield variance of up to 7% among different hybrids.
- Pioneer is supplying cooperating ethanol facilities with a customized list of hybrids that exhibit above average ethanol potential for their facility. In all cases, these will be a package of elite, high performance seed products that growers are already demanding.
- Selecting individual Pioneer hybrids identified as HTF has been shown in commercial-scale test grinds to increase ethanol yield by up to 4% over utilizing "commodity" corn. In a 100 million gallon per year facility, this may represent an added value of $5-10 million dollars per year in profitability.
- Using modern biological techniques, Pioneer's researchers are working to produce the next generation of hybrids with even greater potential for ethanol production.

Future of Ethanol

The US ethanol industry has demonstrated its ability to expand production quickly and cost-effectively to meet our nation's rising energy needs. Growth will likely continue to dominate the ethanol industry. New facility construction and expansion of existing facilities is expected to increase production capacity to more than 10 billion gallons during 2009. Dozens of projects under development should ensure continued growth in the future.

In addition to current ethanol uses as a gasoline extender and fuel oxygenate, ethanol has enormous potential in future fuel cell technology. The use of fuel cells to power vehicles and produce electricity is widely anticipated as a future energy system. Fuel cells operate on hydrogen, which can be reformed or extracted from fuels such as ethanol. Ethanol is easier to reform than most fuels because of its simple molecular structure. Laboratory demonstrations have shown that ethanol provides higher efficiencies, fewer emissions, and better performance for this purpose than most other fuels, including gasoline. An added benefit is that the current infrastructure for gasoline distribution can be utilized to deliver a liquid fuel like ethanol.

Resources

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Websites and Articles:

Renewable Fuels Association

American Coalition for Ethanol

National Corn Growers Association – Ethanol Information

Clean Fuels Development Coalition

The Energy Balance of Corn Ethanol: An Update
(USDA Agricultural Economic Report No. 814.)

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