How Fuel Ethanol Is Made from Corn

Nathan S. Mosier and Klein Ileleji
Department of Agricultural and Biological Engineering
Purdue University

EXPERT REVIEWED

Introduction

Fuel ethanol has become a very important agricultural product over the past two decades. In 2005, more than 13% of U.S. corn production went toward making this fuel additive/fuel extender, which lessens U.S. dependence on foreign oil imports, is cleaner for the environment, and has substantial impact on the rural economy and agriculture production.

Fuel Ethanol

Ethanol is an alcohol produced by yeast from sugars. It is the same alcohol produced by yeast in beer, wine, and spirits. Fuel ethanol is ethanol that has been highly concentrated to remove water and blended with other compounds to render the alcohol undrinkable. Fuel ethanol can be used alone as a fuel, such as in Indy Racing League cars, or can be blended with gasoline and used as fuel.

All cars and trucks on the road today can use gasoline/ethanol blends of up to 10% ethanol (90% gasoline), also called "E10." Blends of up to 85% ethanol, also known as "E85," can be used as transportation fuel by cars and trucks with slight modifications (approximately $100 per vehicle). These flexible fuel vehicles can use either gasoline or ethanol blends, including E85.

Yeast's Role in Ethanol Production

All ethanol production is based upon the activity of yeast (*Saccharomyces cerevisiae*), an important microorganism to humans. Through a process called "fermentation," yeast eat simple sugars and produce carbon dioxide (CO_2) and ethanol as waste products. For each pound of simple sugars, yeast can produce approximately ½ pound (0.15 gallons) of ethanol and an equivalent amount of carbon dioxide.

Corn as Ethanol Feedstock

In 2005, approximately 11 billion bushels of corn were produced in the U.S. Indiana corn production in 2005 was approximately 889 million bushels (USDA, 2006). Ethanol production in the U.S. topped 4

billion gallons in 2005 and consumed 1.4 billion bushels of corn, valued at $2.9 billion (NCGA, 2005). This represents the third largest demand for U.S. corn after animal feed and export markets. With additional construction of ethanol plants and increasing ethanol demand, fuel ethanol production is expected to exceed 7.5 billion gallons before the year 2012 target set forth in the Energy Policy Act of 2005 (EPACT05).

Table 1. *Composition of Corn*

Component	Percent (average) Dry Matter
Carbohydrates (total)	**84.1%**
Starch	*72.0%*
Fiber (NDF)	*9.5%*
Simple Sugars	*2.6%*
Protein	**9.5%**
Oil	**4.3%**
Minerals	**1.4%**
Other	**0.7%**

(from *Corn: Chemistry and Technology*, 1987)

The value of corn as a feedstock for ethanol production is due to the large amount of carbohydrates, specifically starch, present in corn (Table 1). Starch can be rather easily processed to break it down into simple sugars, which can then be fed to yeast to produce ethanol. Modern ethanol production can produce approximately 2.7 gallons of fuel ethanol per bushel of corn.

Industrial Ethanol Production

Commercial production of fuel ethanol in the U.S. involves breaking down the starch present in corn into simple sugars (glucose), feeding these sugars to yeast (fermentation), and then recovering the main product (ethanol) and byproducts (e.g., animal feed). Two major industrial methods for producing fuel ethanol are used in the U.S.: wet milling and dry grind. Dry-grind ethanol production represents the majority of ethanol processing in the U.S. (> 70% of production), and all newly constructed ethanol plants employ some variation on the basic dry-grind process because such plants can be built at a smaller scale for a smaller investment.

Wet Milling

Wet milling is used to produce many products besides fuel ethanol. Large-scale, capital-intensive, corn-processing wet mills produce such varied products as high fructose corn syrup (HFCS), biodegradable plastics, food additives such as citric acid and xanthan gum, corn oil (cooking oil), and livestock feed.

Wet milling is called “wet” because the first step in the process involves soaking the grain in water (steeping) to soften the grain and make it easier to separate (fractionate) the various components of the corn kernel. Fractionation, which separates the starch, fiber, and germ, allows these various components to be processed separately to make a variety of products. The major byproducts of wet-mill ethanol production are two animal feed products, corn gluten meal (high protein, 40%) and corn gluten feed (low protein, 28%), and corn germ, which may be further processed into corn oil.

Dry Grind

In the dry-grind ethanol process, the whole grain is processed, and the residual components are separated at the end of the process. There are five major steps in the dry-grind method of ethanol production.

Dry-Grind Ethanol Processing Steps

1. Milling
2. Liquefaction
3. Saccharification
4. Fermentation
5. Distillation and recovery

Milling

Milling involves processing corn through a hammer mill (with screens between 3.2 to 4.0 mm) to produce a corn flour (Rausch et al., 2005). This whole corn flour is slurried with water, and heat-stable enzyme (α-amylase) is added.

Liquefaction

This slurry is cooked, also known as "liquefaction." Liquefaction is accomplished using jet-cookers that inject steam into the corn flour slurry to cook it at temperatures above 100°C (212°F). The heat and mechanical shear of the cooking process break apart the starch granules present in the kernel endosperm, and the enzymes break down the starch polymer into small fragments. The cooked corn mash is then allowed to cool to 80-90°C (175-195°F), additional enzyme (α-amylase) is added, and the slurry is allowed to continue liquefying for at least 30 minutes.

Saccharification

After liquefaction, the slurry, now called "corn mash," is cooled to approximately 30°C (86°F), and a second enzyme (glucoamylase) is added. Glucoamylase completes the breakdown of the starch into simple sugar (glucose). This step, called "saccharification," often occurs while the mash is filling the fermentor in preparation for the next step (fermentation) and continues throughout the next step.

Fermentation

In the fermentation step, yeast grown in seed tanks are added to the corn mash to begin the process of converting the simple sugars to ethanol. The other components of the corn kernel (protein, oil, etc.) remain largely unchanged during the fermentation process. In most dry-grind ethanol plants, the fermentation process occurs in batches. A fermentation tank is filled, and the batch ferments completely before the tank is drained and refilled with a new batch.

The up-stream processes (grinding, liquefaction, and saccharification) and downstream processes (distillation and recovery) occur continuously (grain is continuously processed through the equipment). Thus, dry-grind facilities of this design usually have three fermentors (tanks for fermentation) where, at any given time, one is filling, one is fermenting (usually for 48 hours), and one is emptying and resetting for the next batch.

Carbon dioxide is also produced during fermentation. Usually, the carbon dioxide is not recovered and is released from the fermenters to the atmosphere. If recovered, this carbon dioxide can be compressed and sold for carbonation of soft drinks or frozen into dry ice for cold product storage and transportation.

After the fermentation is complete, the fermented corn mash (now called "beer") is emptied from the fermentor into a beer well. The beer well stores the fermented beer between batches and supplies a continuous stream of material to the ethanol recovery steps, including distillation.

Distillation and Recovery

After fermentation, the liquid portion of the slurry has 8-12% ethanol by weight. Because ethanol boils at a lower temperature than water does, the ethanol can be separated by a process called "distillation." Conventional distillation/rectification systems can produce ethanol at 92-95% purity. The residual water is then removed using molecular sieves that selectively adsorb the water from an ethanol/water vapor mixture, resulting in nearly pure ethanol (>99%).

The residual water and corn solids that remain after the distillation process are called "stillage." This whole stillage is then centrifuged to separate the liquid (thin stillage) from the solid fragments of the kernel (wet cake or distillers' grains). Some of the thin stillage (backset) is recycled to the beginning of the dry-grind process to conserve the water used by the facility.

The remaining thin stillage passes through evaporators to remove a significant portion of the water to produce thickened syrup. Usually, the syrup is blended with the distillers' grains and dried to produce an animal feed called "**d**istillers' **d**ried **g**rains with **s**olubles" (DDGS). When markets for the feed product are close to the plant, the byproduct may be sold without drying as distillers' grains or wet distillers' grains.

Energy Use in Ethanol Production

It is true that the laws of physics dictate that energy will be lost in converting one form of energy to another. Thus, ethanol does have less energy than the corn used to produce it. However, this is also true for converting crude oil to gasoline and coal to electricity. The important questions about ethanol production are "is ethanol truly a renewable fuel?" and "how much fossil fuel is used?"

Yes; ethanol is a renewable fuel. The energy used to produce ethanol includes fuel for tractors, combines, and transportation of the grain to the ethanol plant, as well as the energy in processing the corn to ethanol. However, the largest portion of the total energy present in corn is solar energy captured by the corn plant and stored in the grain as starch. When these amounts are totaled, the energy in the ethanol exceeds the fossil fuel energy used to grow and process the corn by 20 to 40% (Farrell et al., 2006).

Most of the energy for processing corn to ethanol is spent on the distillation and DDGS drying steps of the process. When wet distillers' grain can be fed to livestock close to the ethanol plant, the savings in natural gas for drying can be as high as 20% of the total energy cost for processing corn to ethanol.

Conclusions

Modern dry-grind ethanol plants can convert corn grain into ethanol (2.7-2.8 gallons per bushel) and DDGS (17 pounds per bushel). This rather energy-efficient process produces a renewable liquid fuel that has significant impacts on the agricultural economy and energy use in the U.S.

Increasing ethanol production presents many opportunities and challenges for U.S. agriculture as demands on corn production for feed, fuel, and export markets increase. Additionally, advances in biotechnology and engineering are opening possibilities for new raw materials, such as switch grass and corn stover, to be used for even greater fuel ethanol production into the future.

References and Links to Further Information

Farrell, A. E.; Plevin, R. J.; Turner, B. T.; Jones A. D.; O'Hare, M.; Kammen, D. M. "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311(5760): 506 – 508, (2006).

National Corn Growers Association (NCGA) Annual Report (2005).

Purdue Laboratory of Renewable Resources Engineering <http://engineering.purdue.edu./LORRE>.

Rausch, K. D.; Belyea, R. L.; Ellersieck, M. R.; Singh, V.; Johnston, D. B.; Tumbleson, M. E. "Particle Size Distributions of Ground Corn and DDGS From Dry Grind Processing," *Transactions of the ASAE*, 48(1):273–277, (2005).

U.S. Department of Agriculture, National Agriculture Statistics Service <http://www.nass.usda.gov>.

Watson, S. A., "Structure and Composition," *Corn: Chemistry and Technology*, Watson, S. A. and Ramstad, P. E. (eds). American Association of Cereal Chemists, Inc. pp 53-82, (1987).

Visit <http://www.ces.purdue.edu/bioenergy> for free, downloadable copies of all of the publications in the Purdue Extension BioEnergy series.

Purdue Extension
Knowledge to Go
1-888-EXT-INFO

PURDUE AGRICULTURE

NEW 12/06

ID-328