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Basics of alcohol fuel production from grain

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Quick Facts

Interest in alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices.

Any material that contains sugar can potentially be fermented to produce alcohol.

Making fuel ethanol from grain is a well-established technology, but it is not simple nor cheap.

Effective use of distiller's grains is essential to economical alcohol fuel production.

One bushel of corn will yield about 2.5 gallons of anhydrous (200 proof) alcohol.

This is the first in a series of five information sheets on alcohol fuel production.

Alcohol has been used as a fuel for internal combustion engines since their invention. Reports on the use of alcohol as a motor fuel were published in 1907 and detailed research was conducted in the 1920s and 1930s. Interest in alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices.

Any material that contains sugar can potentially be fermented to produce several kinds of alcohols. This report will only discuss the use of grains, particularly corn, to make ethyl alcohol or ethanol. This is the first in a series of five information sheets which will cover grain alcohol fuel production, raw materials for alcohol fuels, use of alcohol fuels by-products, distillation of alcohol, and economics of alcohol fuel production.

Ethanol fermentation is the simple biological conversion of sugar into ethanol and carbon dioxide. It is represented by the chemical equation:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 + \text{heat}$$

$$1 \text{ glucose} \rightarrow 2 \text{ ethanol} + 2 \text{ carbon dioxide}$$

The maximum possible yield is about 51 pounds of ethanol for every 100 pounds of glucose or sugar. Actually, the attainable yield is somewhat less than this, about 47 to 49 pounds of ethanol per 100 pounds sugar. This corresponds to about 2.5 gallons of alcohol per bushel of corn or around 90 gallons per ton of grain. Achieving these alcohol yields requires the proper types and amounts of all materials and proper management of a correctly designed and constructed fermentation and distillation system. About 18 pounds of distiller's dried grain and 16 pounds of carbon dioxide are also produced from each bushel of corn. Effective use of these alcohol fuel by-products, especially the distiller's grains, is important to a successful overall operation and is discussed in another sheet.

The technology to make ethanol from grain is well established and details are available in numerous handbooks and other references. However, making fuel-grade ethanol from grain is not the simple, cheap and easy process many popular press articles describe. Operation of a still requires know-how and time-consuming attention. Conversion of grain to alcohol involves chemistry, steam engineering, microbiology, plumbing, economics, meticulous cleanliness and housekeeping, careful management, and rigid observance of government regulations.

The following is a simplified outline of the basic steps for making ethanol from cereal grains:

- Grain preparation — Grind or crush the grain into fairly uniform "fine" sizes. A 4 mesh per inch hammermill screen works well. All kernels must be broken. Hammermill power requirements will increase for finer grinds and as the grain moisture increases. Too fine a grind makes stillage separation more difficult.
- Batch formulation — Make a slurry by adding water to the milled grains — for grains about 20 gallons of water per bushel. Bring the mash to between pH 6 and 7 by adding acids or alkalis. An enzyme such as alpha amylase is added to completely breakdown the starch.
- Cooking — Cook the mash at or near boiling for about 60 minutes while stirring constantly to gelatinize the starch. As the starch gelatinizes, the mixture will thicken and the power requirements for mixing will increase. Cooking is best done by steam injection. Due to uneven heating, direct fired cooking is often not totally successful.
- Saccharification — After cooking, cool quickly to 140 °F and adjust the pH level to 4.0 to 4.5 range with acid diluted with cool water. A second enzyme, gluco-amylase, is then added and mixed with the 140 °F slurry for about 30 minutes. This step converts the gelatinized starch to simple sugars for fermentation. Continue to agitate the slurry.
- Cooling — Thin and cool cooked slurry mash by adding about 20 gallons of water per bushel to obtain a final temperature of about 90 °F. Test the specific gravity to maintain a sugar content of 21 percent or lower (1.08 sp. gr.). Inoculate the mash with a brewer's or baker's yeast culture and agitate to mix in the yeast.

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Note: The actual sequence of events, temperatures and proportions given above may change somewhat depending on the enzymes and yeasts used. Manufacturer's instructions should provide adequate detail.

- Fermentation — Allow to ferment with gentle agitation in the absence of free oxygen for about 72 hours at around 85 to 90 °F. Carbon dioxide is released during fermentation as is some heat, usually less than 10 to 15 Btu/gallon of fermenter capacity-hour. As the fermentation progresses, the pH of the mash decreases. At the end of the fermentation, the mixture contains 6 to 12 percent alcohol, water and distiller's grain. The alcohol-water mixture is referred to as the beer.
- Separation — Screen out stillage by-product, leaving beer mixture.
- Distillation — Run beer at near boiling temperatures into an upright distillation column fitted with appropriate baffle plates. Some experimenters recommend running the entire fermented mash mixture (distiller's grains, water and alcohol) through the distillation column. This requires a larger column and more heat, but apparently has the advantage of removing nearly all of the alcohol from the mash. A mixture of alcohol and water vapor exits from the top of the column while distiller's grains and water are removed from the bottom and separated. The baffle plates serve two main purposes: regulation of material flow through the column and additional contact area for the heat transfer. Column heating is usually accomplished with steam. On-farm ethanol plants will probably have two distillation columns. The first or beer column removes about 50 percent of the water, while the second or refining column removes an additional 45 percent of the initial water.
- Condensation — The ethanol vapors at the top of the refining column are run through cooling coils to condense into fluid ethanol. Low-proof (below 140) ethanol should be recirculated through the distillation system to reduce the water content.
- Extractive distillation — Add agents such as benzene, cyclohexane or pentane to break the azeotrope (constant composition boiling mixture) and remove the last 5 percent water from the ethanol mixture to yield 200 proof ethanol. (This step is more complicated and energy-intensive and is usually done at a larger, centralized commercial plant.) Further details and options on the distillation process are given in another sheet in this series.
- Denaturing — Fuel ethanol must be a denatured (rendered unsuitable as a beverage) under federal direction and supervision provided by the Bureau of Alcohol, Tobacco and Firearms of the U.S. Treasury Department.

A simplified flowsheet of the alcohol fuel production process is given in Figure 1. A 1,000 gallon (anhydrous alcohol or 200 proof) per day plant requires 400 bushels of grain and 14,000 gallons of water. It produces 4,400 pounds of distiller's grains at 8 to 10 percent moisture and 13,200 gallons of waste water and solubles.

Many excellent publications are available on alcohol fuel production. Two of these are listed below:

Ethanol Production and Utilization for Fuel, January 1980, Cooperative Extension Service, University of Nebraska, Lincoln, Nebraska 68583. Price $2.

Fuel from Farms — A Guide to Small-Scale Ethanol Production, May 1980, order from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, Stock number 061-000-00372-0. Price $4.50.

More information is available from alcohol fuel associations. Three of these are:

- National Alcohol Fuel Producers' Association, 1760 Reston Avenue, Suite 102, Reston, Virginia 22090. (703) 471-1611.
- National Center for Appropriate Technology, P.O. Box 3838, Butte, Montana 59701. (406) 494-4572.
- National Gasohol Commission, Inc., Suite 5, 521 South 14th Street, Lincoln, Nebraska 68508. (402) 475-8044.

The U.S. Department of Energy has a toll-free number for answers to general questions on alcohol production (800) 525-5555. Detailed information and assistance on alcohol fuel production in Colorado can be obtained through the Colorado Gasohol Promotion Committee, 1525 Sherman, 4th Floor, Denver, Colorado 80203. (303) 866-3218.

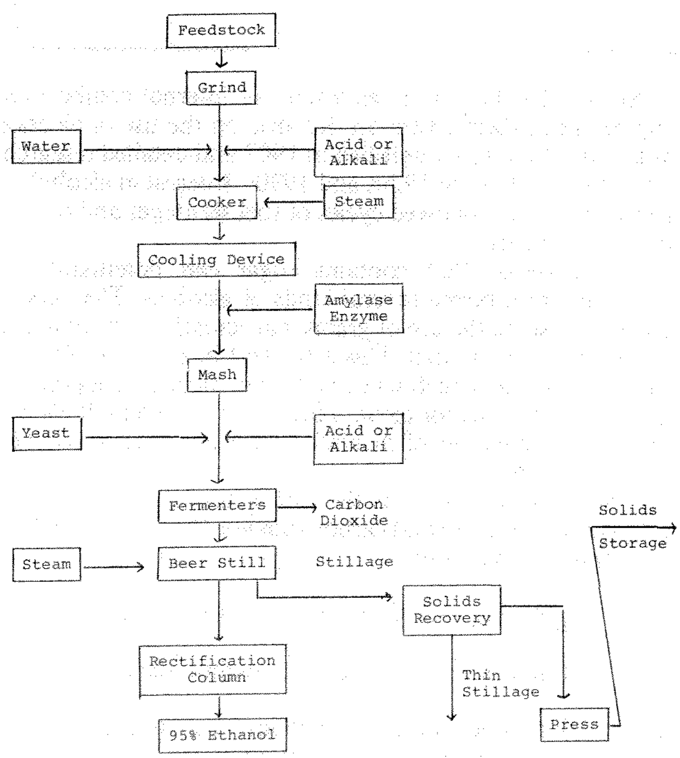

Figure 1. Alcohol production flow chart (190 proof ethanol).