Table 3. The Effect of Corn Price and Plant Size on the Cost of Producing a Gallon of Ethanol

Price of Corn, $/bu	Plant Capacity (gallons per Year)		
	60,000	1,000,000	3,000,000
$2.50	$2.09	$1.38	$1.19
2.75	2.17	1.43	1.24
3.00	2.24	1.48	1.28
3.25	2.32	1.53	1.33
3.50	2.39	1.58	1.37
3.75	2.47	1.63	1.42
4.00	2.54	1.68	1.46
4.25	2.62	1.72	1.51

Ethanol Production

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Summary

- Fuel grade ethanol can be produced from sugar or starch crops by fermentation and distillation.
- Since distillation cannot remove all water from alcohol, most on-farm stills produce 190 proof ethanol or less.
- Production plants require multiple fermentation tanks in order to have a continuous supply of fermented mash for distillation.
- The "Fuel from Farms" publication listed as a reference at the end of this article describes a small ethanol plant and lists the equipment required.
- The heat required for ethanol production may be supplied by biomass, wood, coal, solar, LP gas, natural gas or geothermal sources.
- Safety is of great importance in the planning and operation of an ethanol plant. National Fire Protection Association codes will furnish most of the information needed regarding safe practices in wiring, lighting, insulation, etc.
- USDA Farmers Home Administration offices have instructions on processing FmHA loans for plants that give details on performance guarantees that should appear in construction contracts.

The discussions today are concerned with fuel for and from farms. American agriculture is dependent upon foreign crude oil supplies at the present time. Our agricultural production could be seriously curtailed if crude oil supplies were cut off. Alcohol is a liquid fuel that can serve as a substitute for at least some of the petroleum based fuels we use. The Biomass Energy and Alcohol Fuels Act passed in June of this year as a part of the Energy Security Act was intended to promote production of fuel with present technology and with newly developing technologies. The Department of Agriculture was authorized to guarantee 600 million dollars in loans over the next two years. The Department of Energy was authorized to operate another 600 million dollars in biomass programs, including fuel alcohol projects.

The U.S. Department of Energy published a book titled "Fuel From Farms - A guide to Small Scale Ethanol Production"[1] early this year. The guide was prepared to supply information on fermentation ethanol, emphasizing small-scale production using farm crops as raw material. Information presented includes discussions of the questions that should be answered before ethanol production decisions can be made, basic ethanol production procedures and equipment required, and business planning procedure.

The two most common kinds of alcohol are ethyl alcohol (ethanol) and methyl alcohol (methanol). Ethanol for industrial uses has been produced from ethylene, a petroleum derivative. Beverage alcohol is produced from the fermentation of fruit or grain crop. Methanol historically was produced by "pyrolizing" wood or other carbon containing material at high temperatures to release gases that are then condensed in tanks. Further processing then was required before methanol was obtained from the condensate by distillation. Today, essentially all methanol is made from natural gas. The conversion process involves synthesizing carbon monoxide and hydrogen at high pressures and is not a process adapted to small on-farm production. At the present time it appears that production equipment for small scale methanol production is not available.

Fuel grade ethanol can be produced from sugar crops (sugar beets, sugar cane, fruit) by converting the sugar in these crops directly to alcohol by fermentation. Producing alcohol from starch crops (grain, rice, potatoes) requires that the starch first be converted to sugar before it can be fermented. The fermented mash will contain 8% to 10% alcohol and the next step calls for distilling the alcohol from the water in the mash. Alcohol boils at a temperature of 171°F (77°C), so by heating the mash above that temperature, alcohol vapors can escape and then can be condensed on a cooler surface. Some water is also included in the vapor however so the liquid obtained will not be pure alcohol. Further purification is required to obtain 200 proof (100% alcohol).

An ancient still used in Tibet about 800 B.C. distilled alcohol from a fermented rice liquor. The still consisted of a clay pot in which the fermented rice liquor was heated. The vapors were condensed on a pot cover shaped like a saucer and filled with water. A small pot was suspended beneath the saucer that acted as a condenser, and the alcohol dripped off the saucer into this suspended pot.

Simple pot stills using coil condensers were in use probably as early as 500 A.D. (See Figure 1). The use of a coil allowed more area for condensation and improved the quality and quantity of the product. This kind of still with some improvement was used to produce moonshine for many years in this country.

The column still development enabled high proof alcohol to be produced more rapidly commerically. (See Figure 2). In a column still, mash is pumped into a cylindical column that is fitted with a series of perforated plates. Steam rising in the column vaporizes alcohol from the mash and the water runs back to the base of the column. The alcohol vapor is then condensed. With proper temperature regulation, 190 proof (95%) ethanol can be obtained.

Fractional distillation as described above and as illustrated in Fig. 2 cannot remove all water from the alcohol when distilled at atmospheric pressure. A constant boiling mixture forms when the alcohol content is 95.6 percent alcohol and 4.4 percent water. Under vacuum distillation, the constant boiling vapors have about 98 percent alcohol. If anhydrous (200 proof) ethanol is required, benzene or gasoline is added to the 190 proof ethanol and the mixture is distilled again. This is the most common method practical today. Another method of removing water from the 190 proof ethanol is described in the "Fuel From Farms" publication mentioned earlier. This is accomplished by using molecular sieve drying columns. Molecular sieve drying columns are composed of columns containing dessicant material that absorbs water but not alcohol. Most on-farm stills do not attempt to produce anhydrous alcohol.

The pot still ethanol plant is often thought of as an improved "moonshine" still. It is not usually considered as a production still. The pot still has only one tank for preparing the mash, cooking, and fermenting. Most of these will have only one distilling column since the mash ordinarily will be heated in the fermenting tank. Some commercial units are available however with both stripping (beer) and rectifying (refining) columns. Purchasers of pot stills should obtain the operating characteristics of these stills from the manufacturer and be aware of the possible limitations. Ethanol production costs from low volume plants are considered to be high. Volumes will probably be less than 50,000 gallons per year, but could be more with continuous operation.

Larger stills have multiple fermentation tanks so a fermented mixture will be ready for distilling continuously. The plant should be designed so the equipment is used a maximum number of days each year. If the plant is to be operated as a business, it should be operated 250 to 300 days out of each year. If 100,000 gallons of ethanol are to be produced in 250 days, a plant capacity of 400 gallons per day will be required. The "Fuel From Farms" publication discussed earlier describes an ethanol plant and lists the equipment required for a 25 gallon per hour capacity. Grain is used as a feedstock and agricultural residue as a fuel in the example. The design is not intended as a recommendation but to teach production technology.

A flow diagram illustrating the production process for ethanol production is shown in Figure 3. Only two fermenting tanks are shown: however, most plants will probably have three or more depending upon the annual output planned. The diagram does not include equipment for recovering solids from the mash mixture. Some plants are planned so the entire mixture is put through the stripping or beer column, recovering the solids afterwards. Other designs separate the solid material from the beer by screening or centrifuging and pressing before the beer enters the first column.

If grain is to be used as a feedstock the following steps will usually be observed in producing 190 proof ethanol.

Grain preparation

Kernels to be broken by grinding or rolling
Measure accurately the batch size to be processed

Hydrolysis

Add 15-20 gallons of water per bushel of grain
Adjust pH to 6.0-6.5
Add alpha-amylase enzyme

Cooking

Cook 30-60 minutes at 190^{o}-200^{o}F
Cool to 140^{o}F
Adjust pH to 4.0-4.5
Add gluco-amylase enzyme
Hold at 140^{o}F for 15 to 30 minutes

Fermentation

Cool to 85^{o}-90^{o}F
Add water so final volume is 20-25 gals. per bushel
Add distillers yeast
Hold at 85^{o}-90^{o}F for 36-72 hours

Distillation

The fermented beer is ready to be distilled. The alcohol content of the beer will probably be between 6 and 10 percent depending upon the quantity of water that was used for the slurry. In distilling, the fermented mash or beer is heated by steam to vaporize the alcohol and the vapors are condensed to produce 190 proof or lower ethanol. For initial heating, the beer flows through a heat exchanger from the hot stillage that is being pumped into a stillage storage tank. Two distillation columns are ordinarily used. The first column will produce an ethanol of about 100 proof. The second column will refine the product to approximately 190 proof.

The heat required for ethanol production may be supplied by biomass, wood, coal, solar, LP gas, natural gas, or geothermal sources. LP and natural gas may seem undesirable since they are petroleum based, however a number of midwest plants are using them for at least some of the heat required. Much of the boiler equipment being sold can utilize a wide variety of fuels. At the present time solar equipment installation appear to be costly because an alternate heat source is required for continuous operation.

The following energy uses and fuel costs are given in a USDA publication titled "Small-Scale Fuel Alcohol Production".[2]

Table 1

Plant Size	Energy Use	Energy Cost	Fuel Cost/gal
60,000 gal/yr.	BTU/gal 43,000	*Natural gas @ $2 per mcf	$0.10
one million gal/yr.	61,000	**Coal @ $40/ton	$0.14

The above quoted price for natural gas is considered low.

*60 HP natural gas boiler
**300 HP (coal, wood or natural gas combination) boiler

In addition to fuel costs given above, approximately 3¢ per gallon electricity cost will be expected for plant operation with electricity costs at 5¢ per KWH.

Safety

Safety is a most important consideration for an ethanol production operation. Alcohol is more volatile than gasoline and extreme care is necessary in plant areas where vapors might exist. Equipment must be grounded to avoid a build-up of static electricity. Explosion proof motors should be used for all pumps. Fire extinguishers should be placed at easily accessible areas in the plant and buildings should be well ventilated.

The publication "Fuel From Farms" lists several safety precautions:

....Never smoke or strike matches around ethanol tanks, dehydration areas, distillation columns or condensers.

....Never use metal grinders, cutting torches, welders or related equipment near system containing ethanol. Flush and vent all vessels before performing any of these operations.

....Install, regularly maintain and check safety boiler "pop" valves set to relieve when pressure exceeds maximum safety pressure of boiler or delivery lines.

....Adhere strictly to boiler manufacturers' operating procedures. If a boilers pressure will exceed 20 pounds per square inch, it should be certified by the American Society of Mechanical Engineers. Maintain continuous operator attendance during boiler operation.

....To prevent scalding from steam, place baffles around flanges to direct any direct steam jets away from operating areas. Use Welded joints in steam lines. Insulate steam lines to prevent burns.

....Give special handling to bases and acids, many of which are dangerous. For example, concentrated acids should never be stored in carbon steel containers.

Codes developed by the National Fire Protection Association will supply most of the required information for plant wiring, lighting, insulation, etc. NFPA codes 10-19 refer to fire extinguishing systems, NFPA codes 68 and 69 are concerned with explosion prevention and NFPA code 70 relates to the electrical system requirements.

Ethanol must be stored properly not only for safety purposes but to prevent exposure to moisture. Commercially available vent caps prevent water vapor entry into tanks but allow venting of volatile vapors. Storage requirements are covered in the "Standards for the Storage of Flammable and Combustible Liquids on Farms and Isolated Construction Projects." NFPA code 395.

Purchasing a Plant

In a recent news release USDA officials pointed out that "fast buck artists" are trying to sell stills that have not been tested and may not produce fuel alcohol. The publication "Fuel From Farms" lists a number of resource people and organizations that can be contacted, however, these are not to be considered as recommendations.

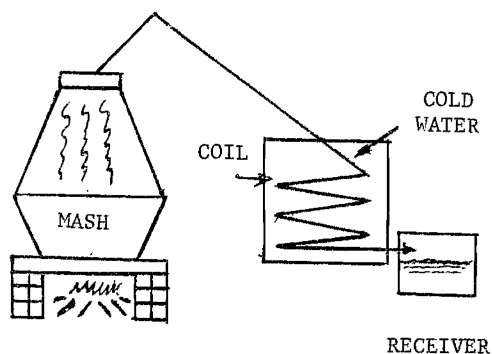
USDA's Farmers Home Administration offices have instructions on processing FmHA loans for plants that give details on performance guarantees that should appear in construction contracts. Custom plant design should be based upon the operation history of existing units. Packaged plants should be given a 60 consecutive day test period in which all inputs, outputs and operation times are certified to as being acceptable by some testing group or qualified engineer. Anyone building an ethanol plant or purchasing any packaged still should require the builder or supplier to furnish a performance bond and guarantees that the plant will produce ethanol. Plants that are installed with FmHA loans must have the supervision of a qualified engineer while the plant is being constructed or the FmHA loan official must be satisfied that the system will be built and installed by responsible concerns.

The National Center for Appropriate Technology in Butte, Montana is building a demonstration distillery and hopes to have it in operation yet this year. Another plant under construction is at Wabaska Hot Springs, Nevada. Several small ethanol plants are in operation in Arizona and feasibility studies are under way for several larger units.

REFERENCES

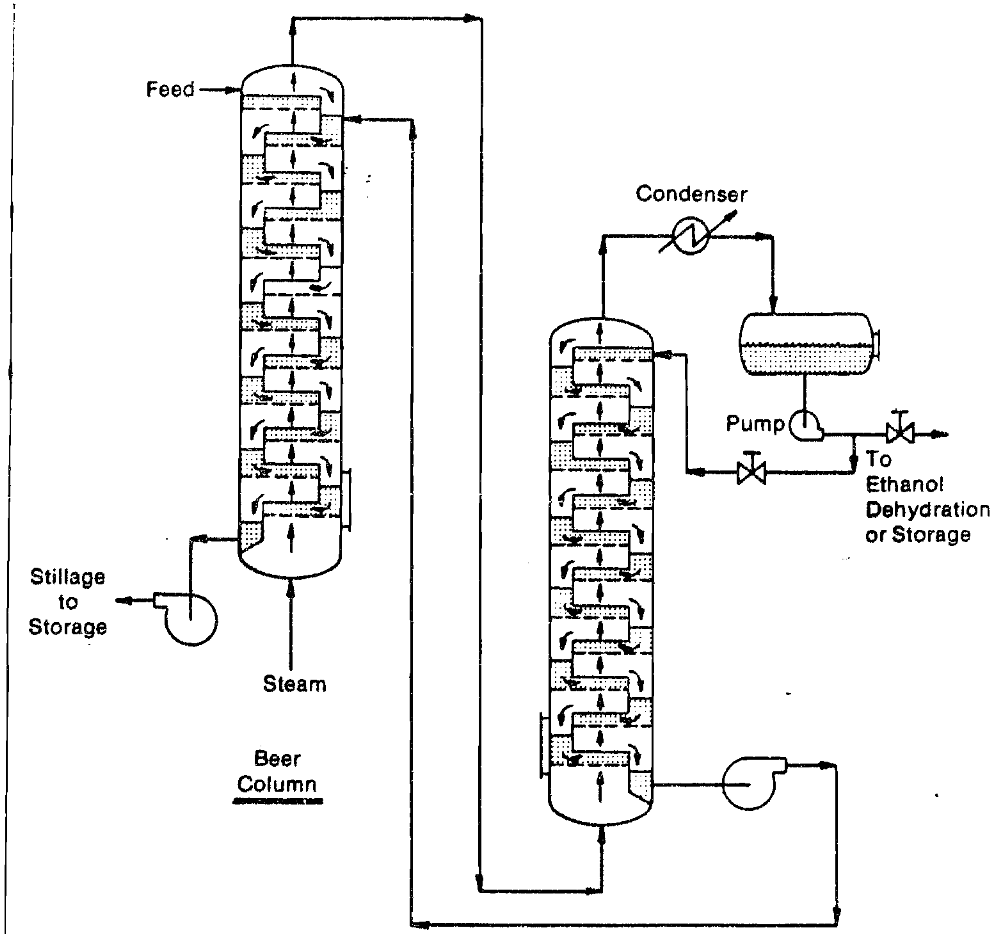
1. Fuel from Farms - A Guide to Small Scale Ethanol Production. Technical Information Center, U.S. Dept. of Energy. P.O. Box 62, Oak Ridge, Tenn. 37830.

2. Small-Scale Fuel Alcohol Production. Superintendent of Documents, U.S. Gov't Printing Office, Wash. D.C. 20201.



SIMPLE POT STILL
WITH COIL
CONDENSER

FIGURE 1



SIEVE TRAY DISTILLATION COLUMNS
SCHEMATIC DIAGRAM

FIGURE 2

FIGURE 3

ETHANOL PROCESS DIAGRAM