ECONOMICS
INFORMATION
REPORT

ECONOMICS OF SMALL SCALE ON-FARM ALCOHOL DISTILLERIES

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ECONOMIC INFORMATION REPORT NO. 64
DEPARTMENT OF ECONOMICS AND BUSINESS
NORTH CAROLINA STATE UNIVERSITY AT RALEIGH

EIR 64

JANUARY, 1981

Published by

THE NORTH CAROLINA AGRICULTURAL EXTENSION SERVICE

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Economics Information Report No. 64
Department of Economics and Business
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Raleigh, North Carolina
January 1981

ABSTRACT

This report documents the costs of producing ethanol from five small on-farm distilleries and compares the production costs with the value of ethanol when used as a motor fuel.

Important factors useful in planning a farm distillery are discussed in the first section of the report. These include the availability and cost of utilizing various sources of feedstock and a comparison of various fuel input costs. Also, values are imputed for hydrous ethanol and stillage used on the farm.

In the second section, production costs for five model distilleries, producing 190 proof ethanol and ranging in output from 840 gpy (gallons per year) to 201,600 gpy, are derived using a base set of input prices. The costs indicate that there are significant economies of scale in the production of ethanol within a range of small scale distillery outputs.

In the third section, a breakeven analysis is used to evaluate the profitability of each distillery. Using the base input prices, the ethanol breakeven values for each model distillery, listed in order of increasing distillery capacity, in dollars per gallon, are: $3.84, $2.34, $2.64, $2.16 and $1.99. Since gasoline is currently selling at $1.25/gal. and gasoline as a fuel has a higher value than does ethanol, none of the model distilleries represent a profitable investment. The sensitivity of the breakeven values to various combinations of discount rates and corn prices is also given in this section. Even with a discount rate of 8 percent and a corn cost of $1.80/bushel, none of the distilleries represent a profitable investment.

Other studies have suggested that there are economies of scale even within the large industrial distillery output range (10-100 million gpy). If these economies of scale do exist, it is unlikely that future small farm ethanol production will become profitable as gasoline prices and ethanol prices increase. Increased competition for distillery inputs (particularly grain) will favor the existence of the larger, more efficient industrial distilleries rather than the smaller, less efficient distilleries.

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ACKNOWLEDGMENTS

Appreciation is expressed to the N. C. Agricultural Extension Service for providing the financial support for this study. Helpful comments and suggestions were received from the following reviewers: Paul W. Cowgill, Industrial Extension Service; John W. Glover, Department of Biological and Agricultural Engineering; and E. C. Pasour, R. C. Brooks and David S. Ball, Department of Economics and Business.

Grateful acknowledgment is also due Mrs. Carol Joyner and Mrs. Cissie King for typing assistance and to Miss Ruth Good for editing the manuscript.

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INTRODUCTION

Background

Past interruptions and cutbacks in the quantity of petroleum supplies from oil producing states have caused the price of liquid motor fuels to increase sharply relative to those of agricultural raw materials. In response to those relative price changes and to the uncertain stability of price and supply of future quantities of liquid fuels, many farmers are considering processes for converting agricultural raw materials to liquid fuels. Farmers are examining ways to reduce their costs of liquid fuels and become more independent of the variability associated with the prices of conventional liquid fuels.

Ethanol, methanol and vegetable oils are the main products that are being studied for their feasibility as motor fuels produced from agricultural products and wastes. Of the three, ethanol is commonly considered to be the most feasible at the farm level because of the relative simplicity of the process and low investment costs of the equipment. Ethanol can be produced from any material containing either

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sugar or starch. The larger the quantity of sugar and starch per unit of a material the higher is its ethanol yield. In North Carolina, corn and milo will likely represent the most economical feedstocks for the next few years.

Ethanol distilleries range in annual output from a few hundred gallons to outputs greater than 50 million gallons. Ethanol distilleries vary considerably with respect to distillation method, plant design, plant locale, proof of ethanol and form of by-product as production scale increases. Characteristics of various ethanol distilleries by scale of output are shown in Table 1.

On-farm ethanol plants generally have outputs of less than one million gallons per year. These plants utilize both batch and continuous distillation systems to produce ethanol. Batch distillation requires that the distillation column be shut down after the ethanol has been distilled from each batch of mash. Continuous distillation, on the other hand, occurs without interruption as long as fresh mash is pumped in and spent mash is removed from the bottom of the stripper column.

Ethanol produced from farm distilleries will be below 196 proof. Ethanol, when distilled to about 196 proof, forms an azeotrope with the water and cannot be dried any further by ordinary

Table 1. Characteristics of Ethanol Distilleries by Scale of Output

Scale of Output 1000 gals.	Distillation Method	Plant Design	Plant Location	Proof of Ethanol	Form of By-Product
Less than 50	Batch	Homemade package	Farm	Less than 196	Wet stillage
50 to 1,000	Continuous	Package	Farm and community	Less than 196	Wet stillage
1,000 to 20,000	Continuous	Built on site	Community and industrial	Approx. 200	DDG or DDGS
Greater than 20,000	Continuous	Built on site	Industrial	Approx. 200	DDGS, or DDG, Corn oil, Gluten feed and Gluten meal

distillation procedures. Dehydration of the ethanol can be accomplished with a ternary azeotropic distillation system or a molecular sieve. Both systems require large investment costs and are not economical for small scale distilleries. Ethanol proof is related to the volume percentage of water contained in the ethanol. The relationship for determining the volume water percentage, given ethanol proof, is shown below:

$$\text{Volume percentage of water contained in ethanol} = \frac{200 - \text{Proof of ethanol}}{2}$$

Using the above equation, the volume percentage of water contained in 180 and 200 proof ethanol can be shown to be 10 percent and 0 percent, respectively. As water content increases in the ethanol, the fuel value decreases. Farm ethanol distilleries vary considerably in the actual proof of ethanol produced, but most will be designed to produce 170-190 proof ethanol. Farm produced ethanol can be defined as hydrous ethanol, indicating that the ethanol contains a significant amount of water.

Farm ethanol distilleries, using corn or other grains as a feedstock, produce a wet stillage by-product that contains much of the protein and fiber initially found in the whole grains. Ethanol is separated out of a fermented mash mixture by a process known as distillation. The mash is made by grinding the grain and cooking it in water. A liquefaction enzyme is added to convert the suspended grain starches into soluble high molecular weight sugars called dextrins. The dextrins are converted to fermentable sugars by adding a saccharifaction enzyme. The sugars are converted to ethanol by adding distiller's yeast. The yeast will require about two to five days to convert the sugars into ethanol. After the mash completes fermentation, it is distilled. The spent mash (wet stillage) is removed from the stripper column or distillation tank. It can then be used as an animal feed.

Neither the hydrous ethanol nor the wet by-product of farm distilleries is an established marketable commodity. Until reliable information becomes more widely known about the uses of these products and the economics of utilizing them, the primary use of these products will reside with the producer of the products.

Objectives

The objectives of this study are to provide information about the costs of producing ethanol from farm distilleries and the profitability of small farm ethanol production. Specifically this study will provide the following information:

1. Technical input/output data for five model farm ethanol distilleries.
2. Values for hydrous ethanol and wet stillage used on the farm.
3. Investment and operating costs for five ethanol distilleries.
4. An assessment of the profitability of small farm ethanol production.

Methodology

The economic-engineering approach was used to develop cost relationships for the model ethanol distilleries. Data for cost estimates were obtained from enzyme and equipment manufacturers, research publications, trade magazines and ethanol producers. Investment and operating costs were estimated for each of the model ethanol distilleries. All costs were expressed on an annual basis and then divided by the expected annual production for each model distillery, so that the costs are expressed on a per gallon of ethanol basis. The capital recovery formula was used to express the investment and permit costs on an annual basis, so that the assumed opportunity cost of the initial capital outlay is accurately accounted for in the profitability analysis.

Considerations

An efficient integration of a small ethanol distillery into a farm operation begins with a careful analysis of the farm's ability to utilize the products of ethanol production and its ability to obtain an economical source of production inputs.

The following points should be considered in planning a system:

1. The ability of the farm to utilize the ethanol it produces.

2. The type and number of livestock that can most economically utilize wet stillage.
3. The amount of feedstock and fuel required to produce ethanol.
4. An analysis of the cost of producing ethanol on the farm as a motor fuel replacement for farm machinery and vehicle applications.

Hydrous Ethanol Utilization and Value

Farm produced hydrous ethanol cannot be used for making gasohol because it performs poorly when mixed with gasoline. The hydrous ethanol separates out of the gasoline-ethanol mixture and causes the unmodified engine to run rough or stop. In the long run, industrial or community distilleries may add additional ethanol drying capacity and buy hydrous ethanol from nearby farms for conversion into anhydrous ethanol which then could be sold to make gasohol.

Farm produced hydrous ethanol has many potential uses; however, most uses will not yield a satisfactory return. In a recent report, the USDA has identified seven motor fuel applications for utilizing ethanol.[1] The three applications that utilized hydrous ethanol and have the best near-term potential are discussed below in this study. Two applications involve gasoline engine modifications and the third one involves a diesel engine modification. The first application is the Standard Compression, Spark Ignition Engine Application (SCSIEA). The modifications involved in converting the engine are simple and relatively inexpensive. The carburetor is adjusted to deliver a larger volume of fuel per unit of air to the compression chamber. Alcohol burns with a smaller air to fuel ratio than does gasoline. With this application, the engine can be readily adapted to use either ethanol or gasoline by making minor carburetor adjustments.

The second application is the High Compression Spark Ignition Engine Application (HCSIEA). The modification increases the compression ratio of the engine and allows the ethanol to be burned more efficiently than it is burned with the SCSIEA. The cost of the

[1]Small-Scale Fuel Alcohol Production, United States Department of Agriculture, Washington, D. C., March 1980. Pages 11-1 -- 11-35.

modifications involved will vary with the specific engine but are usually much higher than those for the SCSIEA. Also, once the modifications have been made, the engine can not be readily converted back to use gasoline. The last application is the Carbureted Ethanol Diesel Engine Application (CEDEA). The modifications for converting the engine are relatively expensive and allow the engine to utilize either diesel or diesel with ethanol carbureted into the diesel engine. When ethanol is utilized in this application, it must be utilized in conjunction with diesel fuel and cannot substitute for all the diesel fuel.

The value of farm produced hydrous ethanol, when used in farm engine applications, depends on how much liquid fuel a given volume of ethanol can replace (the volumetric value of ethanol), the market value of the liquid fuel, and the costs of retrofitting the farm engine to utilize the ethanol. The greater the amount of liquid fuel that can be replaced by a given volume of ethanol, the higher the value of the ethanol. The smaller the retrofit costs are relative to the amount of ethanol to be utilized in a particular application, the greater the value of the ethanol. Unfortunately, it is difficult to estimate accurately the volumetric fuel value for utilizing ethanol in a particular application before the engine is retrofitted. The actual fuel values will depend on the adjustments made to the engine, how the engine is used and the overall condition of the engine. In a recent study done at Iowa State University, the volumetric fuel value of 180-190 proof ethanol used in a standard compression spark ignition application was found to range from about 56 percent to 60 percent that of gasoline.[2] Assuming an average volumetric fuel value for 180-190 proof ethanol of about .58 that of gasoline, a farm planning to utilize all of its own ethanol as gasoline should plan to produce about (1 ÷ .58) 1.72 gallons of ethanol for each gallon of gasoline it plans to replace on the farm in a given time period. Since more gallons of ethanol must be used to replace a given volume of gasoline, the value of the ethanol

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[2]Tom Deardorff, Operation of a Spark-Ignition Engine with a Range of Ethanol and Water Mixtures, AE 490P, Nov. 1979, Agricultural Engineering Department, Iowa State University, Ames, Iowa. Figure 6, Appendix.

as a motor fuel will be less. Assuming negligible retrofit costs and a $1.20/gallon price for the gasoline to be replaced, the value of the ethanol as a gasoline substitute is (.58x $1.20) approximately $.70/ gallon.

Stillage Utilization and Value

Most ethanol distilleries currently being marketed for on-farm alcohol production use grain as their primary feedstock. Because of its availability, corn is currently the most widely used feedstock. This section of the study discusses the utilization and value of farm distillery corn by-products.

When stillage is first produced, it contains about 93 percent water. Because of the high moisture content of the whole stillage, animals have to consume large amounts of water to get a given amount of dry matter. Several farm distillery manufacturers are selling vibrating screens with their distillery package to be used for increasing the percentage solids content of the wet stillage. Some also have auger presses for additional water removal. By removing some of the moisture, the stillage is made easier to transport, handle and feed.

Vibrator screens and auger presses separate the thin stillage (liquid solubles) from coarse stillage (wet distillers grains). The amount of thin stillage removed depends on the particular type of separation system used. Most systems can increase the solids content of the wet stillage up to about 20 to 35 percent.

For a typical mash recipe, requiring 30 gallons of water per bushel of corn used, the amount of stillage initially available is about 257 pounds per bushel and contains about 6.6 percent solids. If the stillage is to be concentrated to a 30 percent solids content, about 226 pounds of the thin stillage per bushel of corn will need to be pressed or strained out of the whole stillage. The thin stillage removed contains about 6 pounds of solids per bushel of corn and has a solids content of about 2.67 percent. The remaining coarse stillage (distillers wet grains) weighs about 37 pounds per bushel of corn and has a solids content of about 30 percent. The amount of solids remaining is approximately 11 pounds.

Large industrial distilleries use dryers to further dry the wet distillers grains (WDG) and market the product as distillers dried grains (DDG). Some also use evaporators to dry the thin stillage portion and either market it as distillers dried solubles (DDS) or mix it with DDG and market it as distillers dried grains and soluble (DDGS). While further drying makes the by-product easier to handle and cheaper to transport, the investment cost of energy efficient drying systems usually makes them uneconomical for small scale operations and the fuel costs associated with conventional drying systems usually make them uneconomical for farm distilleries.

Farm distilleries will probably find it more economical to concentrate the stillage by using auger presses, vibrating screens or centrifuges. However, further drying of the WDG or thin stillage will probably not be economical for farm distilleries. The thin stillage portion removed will probably have to be treated as a waste product.

Research studies have been conducted in several states to determine the quantities of wet stillage that could be fed to different animals. In one study the percentage of wet distillers grains (70 percent moisture) that could be fed in a balanced ration was 37.0 percent for dairy cattle, 25.5 percent for 500-700 pound steers, 37.6 percent for 700-1100 pound steers and 43.0 percent for finishing swine.[3] The approximate daily intake of wet distillers grains are shown in Table 2, and the estimated number of animals required to utilize the stillage produced from a bushel of corn are shown in Table 3.

Certain precautions should be observed in feeding wet stillage to animals due to palatability and digestibility problems. These include:

- -- Stillage deteriorates rapidly and the rate of deterioration increases rapidly with temperature; it is recommended that for temperatures greater than 40°F, it be fed within 24 hours.
- -- Stillage should be fed constantly to keep animals from going off feed and reducing their production rate.

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[3] Alcohol Production and the Use of By-Products in Animal and Poultry Feeds, Purina Chow Research, February 6, 1980, St. Louis, MO.

Table 2. Use of Wet Distillers Grains in Animal Rations

Growing Swine

Ingredients	% Moisture	% Used in Ration	Approx. Daily Intake (lbs.) As Fed	D.M.
Corn	14	43.0	3.5	3.0
Wet Distillers Grains	70	43.0	3.4	1.0
Concentrate	10	14.0	1.1	1.0
TOTALS		100.0	8.0	5.0

Dairy Cows

Ingredients	% Moisture	% Used in Ration	Approx. Daily Intake (lbs.) As Fed	D.M.
Milk Chow Special 16%	10.0	20.0	16.0	14.6
Wet Distillers Grains	70.0	37.0	30.0	9.0
Corn Silage	67.0	37.0	30.0	9.9
Mixed Hay	10.0	6.0	5.0	4.5
TOTALS		100.0	81.0	38.0

Feedlot Cattle

		Growing - 500-700 lbs.			Finishing - 700-1100 lbs.		
			Approx. Daily Intake (lbs.)			Approx. Daily Intake (lbs.)	
Ingredients	% Moisture	% Used in Ration	As Fed	D.M.	% Used in Ration	As Fed	D.M.
Corn	14.0	6.8	3.7	3.2	43.2	15.3	13.1
Wet Dist. Grains	70.0	25.5	14.0	4.2	37.6	13.3	4.0
Corn Silage	67.0	65.6	35.0	11.6	16.1	5.7	1.9
Supplement	10.0	2.1	1.1	1.0	3.1	1.1	1.0
TOTALS		100.0	53.8	20.0	100.0	35.4	20.0

Source: Alcohol Production and the Use of By-Products in Animal and Poultry Feeds, Purina Chow Research, February 6, 1980, St. Louis, MO.

-- Stillage fed a short time before milking may result in off-flavor milk.

-- Stillage fed in the late finishing stages of pork production may cause soft pork.

-- Stillage containing aflatoxins should not be fed.

Market values for distillers feeds are reported every week in Feedstuffs, for five major markets.[4] Monthly prices were collected over a 3-year period for the distillers feeds in the five major markets. Average annual prices for each year and each market are shown in Table 4. For purposes of valuing WDG, a simple average of the 1979-80 market prices for the distillers feeds was calculated and expressed on a dry weight basis, assuming the average moisture content of the distillers feeds is 10 percent, the value per pound of dry weight is [$155.58/(2000 x .90)] 8.6 cents. Assuming that 11 pounds of solids are recovered from each bushel of corn, in the form of wet distillers grains, the value of the feed recovered is about 94.6 cents per bushel of corn used or (94.6/2.5) about 38 cents per gallon of ethanol.

Table 3. Number of Animals Needed to Utilize Wet Distillers Grains (30 percent solids)[a]

Type of Animal	Estimated number of animals needed to be fed per bushel of corn used in mash formula
Growing Swine - Finishing Swine	11
Dairy Cow	1.2
Feedlot Cattle	
Growing 500-700 pounds	2.6
Finishing 700-1100 pounds	2.75

[a]These estimates are based on 11 pounds of solids recovered per bushel of corn used in mash.

[4]Feedstuffs, Miller Publishing Co., 2501 Wayzata Blvd., Minneapolis, MN.

Table 4. Market Prices for Distillers Feeds at Various Markets

Year	Atlanta	Boston	Buffalo	Chicago	Memphis
			(dollars per ton)		
Sept. 77 - Aug. 78	133.75	146.33	126.31	115.83	123.42
Sept. 78 - Aug. 79	157.92	160.25	144.08	128.08	126.75
Sept. 79 - Aug. 80	169.25	172.58	158.56	138.33	139.17
3-year average	153.64	159.72	142.98	127.44	129.78

Source: Averages were calculated from weekly price data obtained from Feedstuffs.

Feedstock Availability and Costs

The feedstock cost is usually the largest production cost for farm ethanol distilleries. In North Carolina, feedgrains such as corn, sorghum, wheat, barley, oats and rye represent the most economical feedstock sources. In Table 5, the estimated average regional production of several feed grains is given. The average amount of ethanol equivalent which could be produced from these feedgrains is given in Table 6 for the three major regions of North Carolina. Corn is the most available feedstock for all three regions in North Carolina. Wheat is the second most available feedstock in the Piedmont and Mountain regions while oats is the second most available in the Coastal region.

Supplies of agricultural raw materials are subject to external factors, i.e., weather conditions, and often fluctuate randomly. Fluctuations in supply often result in a larger percentage fluctuation in price because of the inelastic nature of the demand for raw agricultural products. The per gallon cost of a feedstock is its market price divided by the gallons it can produce. Therefore, variations in feedstock market prices will cause variations in the feedstock costs and the profitability of on-farm ethanol production. Corn, in general, will be the most available and economical feedstock. However, other feed

Table 5. Estimated Average Regional Production, Yield and Acreage of Various Feedgrains in North Carolina

Crop	Average Production by Region			Average Acreage by Region			Average Yield by Region		
	Coastal	Piedmont	Mountain	Coastal	Piedmont	Mountain	Coastal	Piedmont	Mountain
		(bushels)			(acres)			(bushel/acre)	
Corn[a]	65,044,586	41,744,318	4,297,543	933,948	570,413	67,515	70	73	64
Wheat[a]	2,099,109	5,156,993	416,905	64,089	153,543	11,583	33	34	36
Oats[a]	1,090,961	2,957,188	213,055	19,893	60,304	4,622	54	49	46
Barley[b]	507,688	2,026,165	93,730	11,503	45,833	4,842	44	44	45
Grain Sorghum[b]	399,084	3,465,211	71,880	9,011	66,461	1,609	44	52	45

[a]Eight-year averages for 1971-78 crop years.

[b]Seven-year averages for 1972-78 crop years.

Table 6. Estimated Average Ethanol Yield per Acre from Various Feedgrains and Total Ethanol Production Equivalent by Regions in North Carolina

Crop	Ethanol Yield per Bushel (gals./bu.)	Average Ethanol Equivalent Yield by Region (gals./acre)[a]			Average Total Ethanol Equivalent by Region (gallons)[b]			
		Coastal	Piedmont	Mountain	Coastal	Piedmont	Mountain	Total
Corn	2.5	175	183	160	162,611,465	104,360,795	10,743,858	277,716,118
Wheat	2.5	83	85	90	5,247,773	12,892,483	1,042,263	19,182,519
Oats	1.0	54	49	46	1,090,961	2,957,188	213,055	4,261,204
Barley	1.9	84	84	86	964,607	3,849,714	178,087	4,992,408
Grain Sorghum	2.5	110	130	110	997,710	8,663,028	179,700	9,840,438

[a] Estimated average per acre yield times alcohol yield per bushel.

[b] Estimated average regional production times alcohol yield per bushel.

grains such as barley and grain sorghum may represent more economical feedstocks in some areas. Also, culled white potatoes and sweet potatoes may represent economical feedstock sources in some areas. However, marketable sweet potatoes and white potatoes are relatively more expensive than grains to use as ethanol feedstocks.

In Table 7, the feedstock cost per gallon is estimated for several crops in North Carolina. Each crop's price is taken as the 1979-80 season average price received by North Carolina farmers for the crop.

Table 7. Estimated Average Feedstock Costs for Producing 190-Proof Ethanol

Crop	Yield per Unit	Cost of Crop (1979-80 Season Average Price Received by N.C. Farmers)	Per Gallon Feedstock Cost
	(gal./unit)	($/unit)	($/gal.)
Corn	2.5/bu.	2.80/bu.	1.12
Wheat	2.5/bu.	3.70/bu.	1.48
Oats	1.0/bu.	1.30/bu.	1.30
Barley	1.9/bu.	1.70/bu.	.89
Sorghum	2.5/bu.	2.44/bu.	.98
Rye	2.2/bu.	2.85/bu.	1.30
White Potatoes	1.2/cwt	5.24/cwt	4.37
Sweet Potatoes	1.7/cwt	5.70/cwt	3.35

Fuel Input Costs

Much has been written recently on whether ethanol distilleries produce a positive or negative net energy balance. The issue is critical when an equally high or higher valued source of fuel is used to produce a lower valued source of fuel. It becomes of less importance when relatively low valued sources of fuels are used to produce higher valued ones. It can be economical to have a net energy loss when producing alcohol if the value of the energy and by-products produced is greater than that of the production inputs. Regardless of the energy balance for a particular distillery, the appropriate issue should be whether the products produced by the distillery are higher in value than the inputs utilized in the production process.

Fuel oil, natural gas and LP gas are the main types of fuels utilized by manufactured farm ethanol distilleries. These fuels are relatively more expensive than coal and wood but are usually more convenient to utilize or require less expensive equipment to utilize them. In Table 8, a comparison of energy contents and costs of various fuels is shown. Actual fuel prices may vary considerably depending on specific plant location and fuel quantities ordered.

Table 8. Comparision of Energy Contents and Costs of Various Fuels

Fuel	Cost per Unit[a]	BTU Content	Combustion Efficiency	Usable BTU Content (per unit)	Cost per Million of Usable BTUs
	(dollars)		(percent)		(dollars)
Coal	49/ton	26,000,000	.825	21,450,000	2.28
Fuel Oil (No. 2)	.92/gal.	138,000	.80	110,400	8.33
Natural Gas	.003270/therm	1,000	.778	778	4.20
LP Gas	.55/gal.	92,000	.80	73,600	7.47
Wood Residues	9/ton	9,000,000	.67	6,030,000	1.49
Whole Tree Chips	15/ton	9,000,000	.67	6,030,000	2.49
Pelletized Wood	50/ton	16,000,000	.77	12,320,000	4.05
Wheat Straw (dry)	60/ton	17,200,000	.60	10,320,000	5.81
Corn Cobs (dry)	7.50/ton	18,600,000	.60	11,160,000	0.63

[a]The fuel costs are industrial rates obtained during July 1980 for North Carolina. They do not include delivery cost from the North Carolina fuel producer or distributor to the alcohol plant site.

MODEL ETHANOL DISTILLERIES

Currently, few small farm distilleries are actually operating. In North Carolina several small experimental stills have been built, but none are operating on a regular basis. Therefore, technical input and output information for the model farm distilleries presented in this report are not based on firsthand data from actual operating on-farm distilleries. Instead, the information is synthesized from correspondence with ethanol distillery manufacturers, individuals interested in farm distillery ethanol production and agricultural engineers. Other sources of information include farm distillery sales literature and various research publications.

Model Ethanol Distillery Descriptions and Investment Costs

Five farm ethanol distilleries were modeled in this study. Two of the distilleries are batch distillation distilleries (batch distilleries) and three are batch fermentation-continuous distillation distilleries (continuous distilleries). The smallest distillery is similar to some of the small homemade distilleries currently operating in North Carolina. The other distilleries are similar to those that are commerically marketed as package units by firms who intend to mass produce them. A summary of the characteristics of the model distilleries is given in Table 9.

The type and amount of equipment provided in a given package unit varies widely from firm to firm. Some items typically included in continuous distillery package units are given in Table 10. In addition to the equipment provided in a package unit, additional equipment and facilities usually must be obtained in order to operate the distillery efficiently. The amount of additional equipment and facilities required will depend on the equipment and facilities already on the farm and their availability for use in ethanol production. As a general rule, the larger the distillery becomes relative to a farm's size, the more supporting equipment and facilities the farm will need to add to the basic package unit. In all distilleries modeled, land is assumed to be available for ethanol production at zero cost. A brief

Table 9. Characteristics of Model Ethanol Distilleries

Distillery	Distillation Rate or Fermentation Tank Capacity	Annual Production[a]	Investment Cost	Investment Cost/ Gallon of Annual Production
		(gallons)	(1980 dollars)	(dollars/gallon)
Small Batch Distillery	5 bushels	840	2,000[b]	2.38
Large Batch Distillery	100 bushels	28,000	45,000[b]	1.61
Small Continuous Distillery	22.5 gallons/hr.	45,000	153,000	3.40
Medium Continuous Distillery	22.5 gallons/hr.	90,000	187,000	2.08
Large Continuous Distillery	25 gallons/hr.	201,600	360,000	1.79

[a]Annual production is based on a 48-week operating year.

[b]No building or grain grinding equipment included in these investment costs.

description of each of the model distilleries is given below along with its estimated investment cost.

Small Batch Distillery

The small batch distillery is capable of producing about 12.5 gallons of 190 proof ethanol from a 5-bushel batch of corn. One batch is cooked and prepared for fermentation, while a previous batch that has completed fermentation is distilled on the same day. Cooking and distillation take about 8 labor hours. Fermentation takes about 4 days to complete; however, no labor is needed during the fermentation process. Because of the high labor input per gallon of ethanol produced, few homemade distilleries operate regularly; most are used for experimental purposes. If the above distillery operated on a regular basis over a 48-week production period, it could produce about 67 batches annually, yielding about 840 gallons of 190 proof ethanol. The materials for building this distillery were estimated at about $1,000 and the labor involved in building it was estimated at about $1,000. The basic distillery consists of 1 cooker-fermentation tank, 1 distillation tank, distillation column, condenser, agitator, 2 wood fireboxes, 1 ethanol storage tank and 4 temperature gauges and a hydrometer. The rest of the supporting equipment and facilities are assumed to be provided by

Table 10. Items Usually Included in a Package Distillery

Boiler (usually gas)
Cooker
Fermentation tanks with water cooling coils and agitators
Distillation, rectification and condensing equipment
Instrumentation
Steam and mash transport system
Tank cleaning system
Alcohol storage tank
Stillage storage tank
Stillage partial drying system (vibrator screen or auger pressing system)
Erection and Installation
Training for distillery operators
Grain cleaning and grinding equipment

the farm at no cost. The total investment for this distillery is estimated to be about $2,000.

Large Batch Distillery

The large batch distillery is capable of producing about 250 gallons of 190 proof ethanol from a 100-bushel batch of corn. One batch is cooked and prepared for fermentation while another previously fermented batch is distilled. Fermentation takes about two and a half days, but requires practically no labor input. The total labor needed to produce a batch is estimated to be about 10 hours. If the distillery operated regularly over a 48-week production year, it could produce about 28,000 gallons of 190 proof ethanol. The basic distillery package unit includes cooker/fermentation tank equipped with cooling coils and agitator, diesel oil boiler, distillation tank, distillation column, condenser, and 2 alcohol storage tanks. The package distillery units cost about $35,000 and include installation and operator training. The grain storage, grinding and cleaning equipment, housing and water supply for the distillery are assumed to be available on the farm at no cost. Additional grain and product storage facilities, along with some site preparation, may be needed to adapt the distillery to the farm. These costs are estimated at about $10,000. The total investment for this distillery is assumed to be about $45,000.

Small Continuous Distillery

This distillery can produce about 937.5 gallons of 190 proof ethanol per week from 375 bushels of corn. It operates continually and requires about nine and a half man-hours of labor, 6 days per week or 57 man-hours per week. If operated regularly over a 48-week production year, it could produce 45,000 gallons of 190 proof ethanol per year. The basic package unit includes all of the items mentioned in Table 10. In addition, this particular unit comes with a water tower and sells for about $125,000. In addition to the items included in the package unit, the distillery will require a 30' by 40' insulated building with a 20' ceiling, estimated to cost about $18,000. Also, $10,000 for site preparation and miscellaneous expenses are included in the investment cost of this distillery. The total investment cost for this distillery is assumed to be about $153,000.

Medium Continuous Distillery

This distillery can produce about 1,875 gallons of 190 proof ethanol per week from 750 bushels of corn. It operates continually and requires about 19 man-hours of labor per day, 6 days per week or 114 man-hours per week. If operated regularly over a 48-week production year, it could produce about 90,000 gallons of 190 proof ethanol per year. The basic package unit includes all of the items mentioned in Table 10, plus a water tower. It sells for about $145,000. Also a 30' by 50' insulated building with a 20' ceiling is required to house the distillery. The cost of the building is assumed to be about $22,000. Also $20,000 for site preparation and miscellaneous expenses are included in the investment costs for this distillery. The total investment cost for this distillery is assumed to be $187,000.

Large Continuous Distillery

This distillery can produce 4,200 gallons of 190 proof ethanol per week. It will require 24 man-hours per day, 7 days a week or about 168 man-hours of labor per week. If the distillery is operated regularly over a 48-week production year, it can produce about 201,600 gallons of 190 proof ethanol per year. The basic distillery package unit includes all of the items shown in Table 10 and costs about $250,000. A 40' by 70' insulated building with a 20' ceiling costing about $35,000 will probably be needed to house the distillery. Other items, including site preparation and a water tower, are needed to adapt the distillery to the farm. It is assumed to cost $75,000 for the additional items. The total investment cost of the model farm distillery is assumed to be $360,000.

As shown in Table 9, the investment cost per gallon of annual production decreases with size within distillery types. When going from the large batch distillery to the small continuous distillery, the investment cost per gallon of annual production increases mainly because less equipment and facilities are assumed to be available from the farm at zero cost for the small continuous distillery than are assumed available for the large batch distillery.

Model Ethanol Distillery Operating Costs

The operating costs for each of the five model ethanol distilleries are divided into direct and indirect operating costs. The direct costs include costs for corn, fuel, electricity, enzymes, yeast, chemicals and labor. They are generally the most variable costs associated with ethanol production. The indirect operating costs include property taxes, maintenance and repairs and miscellaneous expenses. In addition, some distilleries have tax bond payments and/or a salary for a manager to handle the general administration activities of the plant. These costs are usually less variable than those found in the direct operating cost category.

Corn is the feedstock chosen for all the model distilleries because it is the most available in North Carolina and has a relatively low cost. The price taken for the corn is the 1979-80 season average price of $2.80 per bushel received by North Carolina farmers. Using this corn price, the corn cost per gallon of 190 proof ethanol, assuming a 2.5 gallon per bushel yield, is [$2.80/2.5] = $1.12 per gallon.

Fuel costs vary considerably among farm ethanol distilleries. Generally the larger distilleries can produce ethanol by using less fuel input per gallon of ethanol. Tests conducted at North Carolina State University indicated that small experimental distilleries can require 100,000 Btu's per gallon or greater for the process heat required to produce ethanol. The process heat requirement was assumed to be 100,000 Btu per gallon for each of the batch distilleries, 60,000 Btu per gallon for the small continuous distillery and 43,000 Btu per gallon for the two larger distilleries. While there may be considerable variability in these Btu requirements, their ranking should be correct. Continuous distilleries are usually more energy efficient than batch distilleries. Continuous distilleries that distill alcohol on a 24-hour basis are usually more energy efficient than those that shut down their columns daily. The shut down causes the columns to cool and more energy is required to heat them up again.

The annual fuel consumption by each of the model distilleries was estimated from the data in Table 8. The annual rate of fuel usage equals the Btu requirement per gallon of ethanol, multiplied by the annual distillery ethanol output, divided by the number of usable Btu's supplied by each unit of fuel used. The small batch distillery requires (100,000 x 840/6,030,000) = 13.93 tons of whole tree chips. The cost of the chips is assumed to be $15/ton; so the annual cost and per gallon cost of fuel for the small batch distillery are (13.93 x $15) $209/yr. and ($209/840) = $.25 per gallon, respectively. The large batch distillery requires (100,000 x 28,000/110,400) = 25,362.32 gals./yr. of fuel oil. The cost of fuel oil is assumed to be $.92/gal.; so the annual cost and per gallon cost of fuel are (25,362.32 x $.92) $23,333.33/yr. and ($23,333.33/28,000) = $.83/gal., respectively. All of the continuous distilleries are assumed to use natural gas. The annual quantity of LP gas used for the small, medium and large batch continuous distilleries are (60,000 x 45,000/73,600) = 36,684.78 gals./yr., (43,000 x 90,000/73,600) = 52,581.52 gals./yr. and (43,000 x 201,600/73,600) = 117,782.61 gals./yr., respectively. The cost of LP gas is assumed to be at $.55/gal., so the annual fuel costs for the three largest distilleries are (36,684.78 x $.55) = $20,177/yr., (52,581.52 x $.55) = $28,920/yr. and (117,782.61 x $.55) = $64,780/yr., respectively. The fuel cost per gallon of ethanol for the three largest distilleries are ($20,177/45,000) = $.45/gal., ($28,920/90,000)= $.32/gal. and ($64,780/201,600) = $.32/gal., respectively.

In addition to the fuel required to supply the process heat requirement, each distillery uses electricity to run its pumps, agitators and other electrical components. Each is assumed to require about .5 kwh for each gallon of ethanol it produces. The electrical rates vary with total quantities of electricity used. For the three smallest distilleries the electric rate is taken at about $.06/kwh. For the 90,000 gpy and 201,600 gpy distilleries the electric rates are taken at about $.05 and $.03, respectively. The cost per gallon of electricity supplied the five model distilleries in order of increasing output are ($.06 x .5) = $.03/gal, ($.06 x .5) = $.03/gal., ($.06 x .5) = $.03/gal., ($.05 x .5) = $.025/gal., ($.05 x 3) = $.015/gal., respectively.

Each of the model distilleries uses an alpha-amylase enzyme, gluco-amylase enzyme and a distiller's yeast to convert corn starch into ethanol. THe quantities of enzyme and yeast used per bushel of corn vary for different brands and ethanol production processes. For the model distilleries, the smallest distillery is assumed to use 2 ounces of alpha-amylase per bushel of corn and the rest of the distilleries are assumed to use 1.5 ounces of alpha-amylase per bushel. All distilleries are assumed to use 34 milliliters of gluco-amylase per bushel of corn and 1 ounce of distiller's yeast per bushel.

Prices for the enzymes and yeast vary with respect to quantities ordered. The four smaller distilleries are assumed to pay about $2.25/lb. of alpha-amylase and $4.05/liter of gluco-amylase. The largest dis-distillery is assumed to pay about $1.44/lb. for alpha-amylase and $2.85/liter for gluco-amylase. The smallest distillery is assumed to pay about $2.35/lb. for yeast; the three next larger distilleries are assumed to pay $1.66/lb. for yeast, and the largest distillery is assumed to pay $1.05/lb. for yeast.

The per bushel cost of the enzymes and yeast for each distillery is computed by multiplying the quantities used per bushel times the cost per unit. The per bushel costs of alpha-amylase are [($2.25) (2/16)] = $.28 for the smallest distillery, [($2.25) (1.5/16)] = $.21 for the next three larger distilleries and [($1.44) (1.5/16)] = $.135 for the largest distillery. The per gallon alpha-amylase costs for the five model distilleries, in order of increasing output, are $.11, $.08, $.08, $.08 and $.05, respectively. The per bushel costs of the gluco-amylase for each distillery in order of increasing output are [($4.05) (34/1000)] = $.138 for the first four distilleries and [($2.85) (34/100)] = $.097 for the largest distillery. The per gallon costs of gluco-amylase for each distillery in order of increasing output are $.06, $.06, $.06, $.06 and $.04, respectively. Each distillery is assumed to use one ounce of distiller's yeast per bushel of corn. The per bushel yeast costs for each distillery, given in order of increasing output, are [($2.35) (1/10)] = $.147, [($1.66) (1/16)] = $.104, $.104, $.104 and [($1.05) (1/10)] = $.066, respectively. The per gallon costs of distiller's yeast, given in order of increasing output, for the model distilleries are $.06, $.04, $.04, $.04 and $.03, respectively.

In addition to enzyme and yeast, distilleries use other chemicals to make pH adjustments and for cleaning equipment. The costs of these chemicals are assumed to be about two cents per gallon of ethanol produced.

The model distilleries differ with respect to the amount of labor required to produce a gallon of ethanol and the wage rate. The labor required to produce a gallon of ethanol is calculated by dividing labor hours by the weekly ethanol output for each distillery. The average labor inputs given in order of increasing ethanol production are .638 hours/gallon, .040 hours/gallon, .066 hours/gallon, .066 hours/gallon, and .043 hours/gallon, respectively, for each of the model distilleries. The wage rate was taken at $4.07/hr. for labor employed by the batch distilleries and $5.00/hr. for labor employed by the continuous distilleries. The batch distilleries do not require full-time labor, so labor costs were expected to be lower than the continuous distilleries which require full-time labor. Batch distilleries may be able to take advantage of lower cost labor sources, but continuous distilleries would need to offer a competitive wage with other industries to attract full-time labor. The average labor cost for each of the model distilleries can be calculated by multiplying the average labor requirement for each distillery times the wage rate. The average labor costs, in order of increasing output, are $1.96/gal., $.12/gal., $.33/gal., $.33/gal., and $.22/gal., for the model distilleries.

Property taxes for each of the ethanol distilleries were calculated on the basis of $.55 per $100 of investment costs.

Annual maintenance and repairs were assumed to cost each distillery about 3 percent of its total investment cost.

Ethanol distilleries producing over 10,000 proof gallons of ethanol per year must post a Distilled Spirits bond. One proof gallon is equal to a gallon of 100 proof equivalent of alcohol. One gallon of 190 proof ethanol is (190/100) 1.9 proof gallons.

The Distilled Spirits bond is $1000 for each 10,000 proof gallons (or fraction) of annual distillery production, for distilleries producing less than or equal to 500,000 proof gallons but greater than 10,000 proof gallons. The Distilled Spirits bond on the small batch distillery is zero since it is assumed to produce (840 x 1.9) 1,596 proof gallons per year. The Distilled Spirits bonds for the other distilleries equal $6,000 for the large batch distillery, $9,000 for the small continuous distillery, $18,000 for the medium distillery and $39,000 for the large continuous distillery. Tax bond payments are taken at $12 per 1,000 of the tax bond requirement. The Distilled Spirts bond payments for each of the distilleries, in order of increasing ethanol output, are \$0, \$72, \$108, \$216 and \$468, respectively.

Miscellaneous expenses for the five model distilleries include various items such as fuel alcohol distiller's state license (\$10 per year), general liability insurance, fire coverage, workman's compensation, social security payments, cost of working capital and some administrative services. The largest distillery was assumed to require a full-time manager to handle the administrative work and provide some of the labor input for running the large plant. His annual salary was assumed to be \$17,200.

The direct and indirect operating costs which are calculated on an annual and a per gallon basis are shown in Tables 11-15. The overhead costs associated with buildings, equipment and state fuel alcohol distiller's permits are also included in these tables. To express the initial capital outlay as an equivalent uniform annual cost, the Capital Recovery formula was used.

The general formula for determining the equivalent uniform annual cost can be written as follows:

$$A = P \left[\frac{i\ (1+i)^n}{(1+i)^n - 1} \right]$$

where A = equivalent uniform annual cost

P = initial capital outlay

i = discount (cost of capital) rate

n = expected economic life of plant.

The discount rate was taken as 12 percent and the expected economic life of the equipment was expected to be 10 years with no salvage value in year n.

The total production costs for each of the distilleries are shown in Tables 11-15.

Table 11. Production Costs for Small Batch Distillery (840 GPY)

Item	Description	Value	Annual Costs	Average Costs
		(dollars/unit)	(dollars/year)	(dollars/gallon)
Direct Operating Costs				
Corn	336 bushels	2.80	941	1.12
Wood chips	13.93 tons	15.00	209	.25
Electricity	424 kwh	.06	25	.03
Alpha-amylase enzyme	42 pounds	2.25	95	.11
Gluco-amylase enzyme	11.4 liters	4.05	46	.05
Distiller's yeast	21 pounds	2.35	49	.06
Labor	536 hours	3.07	1,645	1.96
Other chemicals	2 cents per gallon of ethanol produced		17	.02
Indirect Operating Costs				
Property tax	$.55/$100 of $2,000 investment cost		11	.01
Maintenance and repair	3% of $2,000 investment cost		60	.07
Miscellaneous expenses	5% of $2,000 investment cost		100	.12
Equivalent Uniform Annual Cost of Initial Capital Outlay [EVAC]	Initial capital outlay = $2,000 investment cost plus $10 state permit cost. Capital recovery factor = .1770, assuming 10-year economic life and 12% discount rate. EVAC = .1770 x $2,010		356	.42
Total Production Cost			3,554	4.22

Table 12. Production Costs for Large Batch Distillery (28,000 GPY)

Item	Description	Value	Annual Costs	Average Costs
		(dollars/unit)	(dollars/year)	(dollars/gallon)
Direct Operating Costs				
Corn	11,200 bushels	2.80	31,360	1.12
Fuel oil	25,362.32 gallons	.92	23,333	.83
Electricity	14,000 kwh	.06	840	.03
Alpha-amylase enzyme	1,050 pounds	2.25	2,363	.08
Gluco-amylase enzyme	380.8 liters	4.05	1,542	.06
Distiller's yeast	700 pounds	1.66	1,162	.04
Labor	1,120 hours	3.07	3,438	.12
Other chemicals	2 cents per gallon of ethanol produced		660	.02
Indirect Operating Costs				
Property tax	$ .55/$100 of $45,000 investment cost		248	.01
Maintenance and repair	3% of $45,000 investment cost		1,350	.05
Miscellaneous expenses	5% of $45,000 investment cost		2,250	.08
Distilled Spirits bond payment	$12/$1,000 of $ 6,000 Distilled Spirits bond		72	.00
Equivalent Uniform Annual Cost of Initial Capital Outlay [EVAC]	Initial capital outlay = $45,000 investment cost plus $10 state permit cost. Capital recovery factor = .1770, assuming a 10-year economic life and 12% discount rate. EVAC = .1770 x $45,010		7,967	.28
Total Production Cost			76,585	2.72

Table 13. Production Costs for Small Continuous Distillery (45,000 GPY)

Item	Description	Value	Annual Costs	Average Costs
		(dollars/unit)	(dollars/year)	(dollars/gallon)
<u>Direct Operating Costs</u>				
Corn	18,000 bushels	2.80	50,400	1.12
LP gas	36,684.78 gals.	.55	20,177	.45
Electricity	22,500 kwh	.06	1,350	.03
Alpha-amylase enzyme	1,687.5 lbs.	2.25	3,797	.08
Gluco-amylase enzyme	612 liters	4.05	2,479	.06
Distiller's yeast	1,125 lbs.	1.66	1,868	.04
Labor	2,964 hours	5.00	14,820	.33
Other chemicals	2 cents per gallon of ethanol produced		900	.02
<u>Indirect Operating Costs</u>				
Property tax	$ .55/$100 of $153,000 investment cost		842	.02
Maintenance and repair	3% of $153,000 investment cost		4,590	.10
Miscellaneous expenses	5% of $153,000 investment cost		7,650	.17
Distilled Spirits bond payment	$12/$1,000 of $ 9,000 Distilled Spirts bond		108	.00
<u>Equivalent Uniform Annual Cost of Initial Capital Outlay [EVAC]</u>	Initial capital outlay = $153,000 investment cost plus $10 state permit cost. Capital recovery factor = .1770, assuming a 10-year economic life and 12% discount rate. EVAC = .1770 x $153,010		27,083	.60
<u>Total Production Cost</u>			136,064	3.02

Table 14. Production Costs for Medium Continuous Distillery (90,000 GPY)

Item	Description	Value	Annual Costs	Average Costs
		(dollars/unit)	(dollars/year)	(dollars/gallon)
Direct Operating Costs				
Corn	36,000 bushels	2.80	100,800	1.12
LP gas	52,581.52 gals.	.55	28,920	.32
Electricity	45,000 kwh	.05	2,250	.03
Alpha-amylase enzyme	3,375 pounds	2.25	7,594	.08
Gluco-amylase enzyme	1,224 liters	4.05	4,957	.06
Distiller's yeast	2,250 pounds	1.66	3,735	.04
Labor	5,928 hours	5.00	29,640	.33
Other chemicals	2 cents per gallon of ethanol produced		1,800	.02
Indirect Operating Costs				
Property tax	$ .55/$100 of $187,000 investment cost		1,029	.01
Maintenance and repair	3% of $187,000 investment cost		5,610	.06
Miscellaneous expenses	5% of $187,000 investment cost		9,350	.10
Distilled Spirits bond payment	$12/$1,000 of $ 18,000 Distilled Spirits bond		216	.00
Equivalent Uniform Annual Cost of Initial Capital Outlay [EVAC]	Initial capital outlay = $187,000 investment cost plus $10 state permit cost. Capital recovery factor = .1770, assuming a 10-year economic life and 12% discount rate. EVAC = .1770 x $187,010		33,101	.37
Total Production Cost			229,002	2.54

Table 15. Production Costs for Large Continuous Distillery (201,600 GPY)

Item	Description	Value	Annual Costs	Average Costs
		(dollars/unit)	(dollars/year)	(dollars/gallon)
Direct Operating Costs				
Corn	80,640 bushels	2.80	225,792	1.12
LP gas	117,782.61 gallons	.55	64,780	.32
Electricity	100,800 kwh	.03	3,200	.02
Alpha-amylase	7,560 pounds	1.44	10,886	.05
Gluco-amylase	2,741 liters	2.85	7,812	.04
Distiller's yeast	5,040 pounds	1.05	5,292	.03
Labor	8,736 hours	5.00	43,680	.21
Other chemicals	2 cents per gallon of ethanol produced		4,032	.02
Indirect Operating Costs				
General administration	1 manager		17,200	.09
Property tax	$ .55/$100 of $360,000 investment cost		1,980	.01
Maintenance and repair	3% of $360,000 investment cost		10,800	.05
Miscellaneous expenses	5% of $360,000 investment cost		18,000	.09
Distilled Spirits bond payment	$12/$1,000 of $ 39,000 Distilled Spirits bond		468	.00
Equivalent Uniform Annual Cost of Initial Capital Outlay [EVAC]	Initial capital outlay = $360,000 investment cost plus $10 state permit cost. Capital recovery factor = .1770, assuming a 10-year economic life and 12% discount rate. EVAC = .1770 x $360,010		63,722	.32
Total Production Cost			477,644	2.37

ECONOMIC ANALYSIS OF MODEL ETHANOL DISTILLERIES

Ethanol Breakeven Values for Model Distilleries

Breakeven values for ethanol produced in each of the model distilleries can be calculated by subtracting the value of the wet distiller's grains from the average production cost. Assuming a value of 38 cents per gallon of ethanol for the wet distillers grains (see earlier section on stillage utilization and value), the breakeven values for the ethanol given for each model distillery listed in order of increasing distillery capacity are \$3.84/gallon, \$2.34/gallon, \$2.64/gallon, \$2.16/gallon and \$1.99/gallon. If the ethanol is valued at 58 percent of the value of gasoline (see earlier section on motor fuel value of ethanol), the breakeven prices of gasoline corresponding to the breakeven values of ethanol for each model ethanol distillery, listed in order of increasing annual output, are \$6.62/gallon, \$4.03/gallon, \$4.55/gallon, \$3.72/gallon and \$3.43/gallon. The corresponding breakeven gasoline prices are probably understated since an increase in gasoline prices of these magnitudes would probably drive up ethanol distillery input prices as well, which in turn drive up further the breakeven price of ethanol and the corresponding breakeven price of gasoline. For example, if gasoline prices increased fuel oil prices, natural gas prices and, to some extent, wood prices would be expected to increase. Increases in the prices of gasoline would increase the demand for these fuels to substitute for gasoline directly or indirectly.

Sensitivity of Breakeven Ethanol Values to Changes in the Price of Corn and Changes in the Discount Rate

Corn prices and discount rates often vary considerably over time. Fluctuations in both corn prices and discount rates can have large impacts on the cashflow of a distillery. To test the sensitivity of ethanol breakeven values to changes in corn prices and discount rates, higher and lower values for these variables were used. The results are shown in Tables 16, 17 and 18. The underlined values in Table 17 are the base values for the breakeven ethanol values given earlier.

Table 16. Breakeven Values for Ethanol, Given for Various Corn Prices, Assuming a Discount Rate of 8 percent and All Other Variables Held Constant

Distillery	Price of Corn (dollars per bushel) 1.80	2.30	2.80	3.30	3.80
			(dollars per gallon)		
Small Batch	3.38	3.58	3.78	3.98	4.18
Large Batch	1.90	2.10	2.30	2.50	2.70
Small Continuous	2.15	2.35	2.55	2.75	2.95
Medium Continuous	1.70	1.90	2.10	2.30	2.50
Large Continuous	1.54	1.74	1.94	2.14	2.34

Table 17. Breakeven Values for Ethanol, Given for Various Corn Prices, Assuming a Discount Rate of 12 percent and All Other Variables Held Constant

Distillery	Price of Corn (dollars per bushel) 1.80	2.30	2.80	3.30	3.80
			(dollars per gallon)		
Small Batch	3.44	3.64	<u>3.84</u>	4.04	4.24
Large Batch	1.94	2.14	<u>2.34</u>	2.54	2.74
Small Continuous	2.24	2.44	<u>2.64</u>	2.84	3.04
Medium Continuous	1.76	1.96	<u>2.16</u>	2.36	2.56
Large Continuous	1.59	1.79	<u>1.99</u>	2.19	2.39

Table 18. Breakeven Values for Ethanol, Given for Various Corn Prices, Assuming a Discount Rate of 16 percent and All Other Variables Held Constant

Distillery	Price of Corn (dollars per bushel)				
	1.80	2.30	2.80	3.30	3.80
	(dollars per gallon)				
Small Batch	3.52	3.72	3.92	4.12	4.32
Large Batch	1.99	2.19	2.39	2.59	2.79
Small Continuous	2.34	2.54	2.74	2.94	3.14
Medium Continuous	1.82	2.02	2.22	2.42	2.62
Large Continuous	1.64	2.84	2.04	2.24	2.44

Tax Benefit for On-Farm Ethanol Distillers

In the above ethanol breakeven value analysis the effects of taxes and tax benefits were ignored to simplify the analysis. However, there is a wide variety of tax benefits available for farm fuel ethanol distillers. The laws governing their application to individual distilleries are complex. Anyone planning to build a distillery should give careful consideration to the various tax incentives provided by both federal and state governments. Qualified accountants, lawyers, or agents of the internal revenue service can assist management in determining how the laws will be implemented for a particular type of distillery and marketing plan for disposal of the ethanol.

Generally, there are two federal investment tax credits and a state investment tax credit available for qualified North Carolina farm fuel alcohol distillers. In addition, there are two types of federal alcohol fuel credits available for qualified ethanol producers. Also, the state of North Carolina has reduced its road excise tax requirements on fuel alcohol.

The federal government's investment tax credits are the regular investment tax credit and the energy investment tax credit. Farm distillers can receive up to 10 percent of the cost of qualifying ethanol distillery investment components as an investment tax credit for each of the federal investment tax credits, making the total investment tax credit equal to 20 percent of the cost of qualifying distillery investment. The regular investment credit is permanent. The energy investment credit is available through 1982 without regard to the fuel source used. After December 31, 1982, the energy investment credit will still be available for distillers who use fuel other than oil, natural gas, or a product of petroleum to supply more than 50 percent of the full energy requirements of the distillery. The federal energy investment tax credit will no longer be in effect after the end of 1985.

For taxable years, beginning January 1, 1980, North Carolina provides farm fuel alcohol distillers with a 20 percent to 30 percent state investment tax credit on qualifying distillery components. If the distillery is powered primarily by an alternative fuel source, the alcohol distillery can qualify for the 30 percent investment tax credit. Alternative fuel sources include agricultural and forestry products, waste petroleum products and peat, but do not include other petroleum products, coal, or natural gas. If the distillery is not powered by an alternative fuel source, then the alcohol distillery can qualify for the 20 percent investment tax credit.

Qualifying farm distillers can receive up to 40 cents a gallon as an alcohol fuel credit. There are two types of alcohol fuel credits available. One is the alcohol mixture credit and the other is the alcohol credit. Only one of the credits can be taken on the alcohol. A method for determining the per gallon alcohol fuel credit is shown in Table 19. Alcohol fuel credits are available from October 1, 1980, until the end of 1992. The alcohol fuel credit is added to gross income to determine taxable income that is credited against the tax liability of the producer. If all the credit for a taxable year cannot be used, then the portion not used must be carried forward to the earliest available year until it is exhausted or there are no more years available. No amount of unused alcohol fuel credit can be carried forward to any taxable year after 1994. The alcohol fuel credit is limited to the distiller's tax liability.

The state of North Carolina has not granted an alcohol fuel credit similar to those granted by the federal government. Instead, it exempts farm produced ethanol from the state excise tax of 9 cents a gallon if

Table 19. Determination of Alcohol Fuel Credit for Various Marketing Options

Option 1

Ethanol is used by the farm distiller (straight or in blend).

- If the ethanol used is greater than or equal to 190 proof, the alcohol fuel credit is $.40 per gallon of ethanol.
- If the ethanol used is less than 190 proof but greater than or equal to 150 proof, the alcohol fuel credit is $.30 per gallon of ethanol.

Option 2

Ethanol is sold retail by farm ethanol distiller for motor fuel uses (straight or in a blend).

- Ethanol is sold for motor fuel uses, which are exempted from the federal excise tax, because of a provision other than the exemption for alcohol fuels.
  - If the ethanol used is greater than or equal to 190 proof, the alcohol fuel credit is $.40 per gallon of ethanol.
  - If the ethanol used is less than 190 proof but greater than or equal to 150 proof, the alcohol fuel credit is $.30 per gallon of ethanol.
- Ethanol is sold for motor fuel uses, which are not exempted from the federal excise tax, because of a provision other than the exemption for alcohol fuels.
  - If the ethanol used is greater than or equal to 190 proof, the alcohol fuel credit is $.36 per gallon of ethanol.
  - If the ethanol used is less than 190 proof but greater than 150 proof, the alcohol fuel credit is $.26 per gallon of ethanol.

Option 3

Ethanol is sold wholesale by farm ethanol distiller.

Farm ethanol distillers do not receive any alcohol fuel credit. However, since the retailer is exempt from the 4 cents a gallon federal excise tax on gasoline, the ethanol or ethanol blend is subsidized at the retail level and under competitive conditions wholesale ethanol suppliers are expected to capture some of the subsidy in terms of higher prices for the ethanol or the ethanol blend.

it is used by the producer. If it is sold, then the state excise tax on it will be the same as that placed on gasohol. From January 1, 1981, through June 30, 1981, the state excise tax will be 5 cents per gallon. From July 1, 1981, through June 30, 1982, the tax will be 6 cents per gallon. From July 1, 1982, through June 30, 1983, the tax is 7 cents per gallon. From July 1, 1983, through June 30, 1984, the tax is 8 cents per gallon. After June 30, 1984, the excise tax will be 9 cents a gallon.

Analysis of the Profitability of Small Farm Ethanol Production

With retail prices of gasoline currently about $1.20 per gallon, all of the model ethanol distilleries have breakeven prices greater than the price of gasoline. Since hydrous ethanol has a motor fuel value less than gasoline (see earlier section on Hydrous Ethanol Utilization and Value), none of the model ethanol distilleries are profitable, assuming the base input prices. Even if the price of corn is assumed to be $1.80/bushel instead of $2.80/bushel and the discount rate is assumed to be 8 percent instead of 12 percent, none of the model distilleries can produce ethanol for less than the price of gasoline, as shown in Table 16.

Even if the model distilleries could obtain and utilize the maximum amount of the fuel alcohol tax credit obtainable ($.40/gallon), none of the ethanol distilleries would be profitable given the discount rate and prices of corn. Furthermore, if each distillery could also obtain and use an investment tax credit of 40 percent of the investment cost (50 percent of the investment cost for the small batch distillery), none of the model ethanol distilleries would be profitable given an 8 percent discount rate and the price of corn at $1.80 per bushel. Allowing for both the maximum amount of fuel tax credit and investment tax credit available, the breakeven values of the ethanol for each of the distilleries, listed in order of increasing output, are $3.23/gallon, $1.83/gallon, $2.00/gallon, $1.61/gallon and $1.46/gallon. These values are still greater than the price of gasoline ($1.20/gallon) and the calculated value of ethanol (.58 x $1.20) = $.70/gallon given earlier.

Effects of Economies of Scale on the Profitability of Small Farm Ethanol Production

The production costs given in this study suggest that there are economies of scale present in small farm ethanol production. Lower investment costs per unit of output and quantity discounts in the purchase of inputs were the primary factors contributing to the economies of scale.

Other studies also present evidence that suggest that economies of scale in the production of ethanol exist in industrial size distilleries. In Table 20 the calculated ethanol breakeven price, reported in the Grain Motor Fuel Alcohol Technical and Economic Assessment Study, is given for several industrial distillery capacities.[5] As it is, these data should not be compared directly with similar data given in this study because of the differences in methodology and base years used in each of the reports. However, the ethanol breakeven price data show that there are economies of scale in the range of annual ethanol production from 10,000,000 gallons to 100,000,000 gallons.

In Table 21, total investment cost data, initially given in the Economics of Gasohol study, are presented.[6] Again, these data are not directly comparable to data given in this study. However, the data do suggest that per unit investment costs decrease as plant capacity increases over a large range of ethanol distillery capacities.

If economies of scale in ethanol production do exist into the industrial alcohol production levels, this could have a negative impact on the profitability of farm size distilleries. Even if the real price of gasoline increases substantially in the future, small farm ethanol distilleries may continue to be unprofitable.

An increase in the real price of ethanol could make ethanol production in general more profitable. Potential investors seeking to capture some of the potential profits will increase the supply of ethanol if

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[5]Grain Motor Fuel Alcohol Technical and Economic Assessment Study, December 1978. Prepared for U. S. Department of Energy by Raphael Katzen Associates, Cincinnati, Ohio. Published June 1969. Pages 15, 16.

[6]Economics of Gasohol by Mary Litterman, Vernon Eidman and Harold Jensen. Economic Report ER 78-10, Department of Agricultural and Applied Economics, University of Minnesota, December 1978. Page 33.

they expect ethanol production to be profitable. The ethanol supply is expanded by new firms entering the industry or old firms expanding their ethanol capacity. In the short run, small farm ethanol production could appear profitable because they can come on line quicker than the industrial distilleries and will not have to compete with them. When the industrial distilleries come on line, they will be bidding up the price of ethanol production inputs (particularly grain for feedstock). Since there are economies of scale in ethanol production, the larger industrial distilleries, on the average, will be more efficient and will be able to pay higher prices for the production inputs. As the ethanol market approaches equilibrium (economic profits approach zero in the industry), only the most efficient firms will be able to pay the higher price for production inputs and earn a return equal to or slightly greater than their opportunity cost of the resources used by the distilleries. Many of the less efficient distilleries will yield poor returns on investment and others will find it more economical to shut down their distilleries.

Table 20. Estimated Ethanol Breakeven Selling Price for Producing Anhydrous Ethanol in Distilleries with Capacities of 10, 50, and 100 Million Gallons per Year (1978 dollars)

Plant Capacity	Ethanol Breakeven Price, Assuming 15 Percent Rate of Return
(MM gallons/year)	(dollars/gallon)
10	1.55
50	1.05
100	.98

Table 21. Capital Investment Costs of Various Size Ethanol Plants (1976 dollars)

Plant Capacity	Total Investment Cost Divided by Annual Production
(gallons/year)	(dollars/gallon)
4,212,000	2.37
8,424,000	1.84
12,636,000	1.60
16,848,000	1.44
21,060,000	1.33
25,272,000	1.25
29,484,000	1.18
33,696,000	1.13

CONCLUSIONS

Under present conditions, ethanol production from corn and other feed grains will not be a profitable enterprise for the farmer. High costs of corn and low values for the products were the main reasons why the model distilleries were shown to be unprofitable.

Admittedly, the budgets shown in this study were based on the assumption of constant relative input and output prices over the analysis period. If recent trends in the relative prices of motor fuels to feed grain prices is a good indicator of future trends, then prices of motor fuels may rise relative to prices used to produce ethanol over the analysis period. In the event that this does occur, farm ethanol production, using grains as feedstock, may still be uneconomical because of economies of scale.

Potential investors in farm ethanol distilleries should consider not only what their own production costs are, but whether their production costs will allow them to compete economically with industrial ethanol distilleries for production inputs. Farmers with a strong preference for energy independence may wish to consider other options for hedging against uncertain supplies and prices of liquid fuels. Arrangements where corn or other feedgrains could be traded directly for ethanol from a large industrial distillery represent one such option. Another option would be for investors who perceive high returns from ethanol production to purchase shares in large industrial distilleries. This way farmers could participate in profits (or losses) generated by the large industrial distilleries.

Farm distilleries do not have a comparative advantage in ethanol production using readily available feed grains. They may have a comparative advantage in producing ethanol if they can use locally available waste products. However, most distilleries being designed for farm ethanol production utilize grain or some other high valued feedstock to produce ethanol. This may indicate that currently utilizing agricultural wastes to make farm fuel is more costly than utilizing grains to make farm fuels. More research information on the availability, technical input/output relationships and costs of collecting and handling agricultural wastes will be needed before the profitability of utilizing agricultural wastes for farm ethanol production can be examined in depth.

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