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COST OF PRODUCTION OF FUEL ETHANOL IN FARM—SIZE PLANTS

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CHAPTER I

INTRODUCTION

In the past few decades, U.S. agriculture has become increasingly dependent upon purchased inputs as farmers increased the use of chemicals and machinery while reducing labor. Dependence on various energy intensive inputs is currently so great that if supply channels are disrupted, production suffers greatly. Furthermore, rapid escalation in the prices of these inputs, coupled with relatively low prices for farm commodities, has subjected the American farmer to an ever tighter price/cost squeeze.

Concerns about high prices and uncertain supplies of liquid fuels have made the on-farm production of alcohol a popular topic. Conflicting claims and numbers bombard farmers, who attempt to evaluate the feasibility of producing fuel alcohol. Proponents laud the virtues of ethanol as a cheap, easy to produce, cure-all for farmers' liquid fuel problems. Advantages claimed for the production of fuel alcohol include:

a) Assurance of a fuel supply with reduced dependence on foreign oil, and

b) Provision of a market for surplus grain and elimination of costly government set aside programs.

Additional advantages are claimed for "on-farm" ethanol production, as follows:

a) Control by the farmer of his fuel supply with the resultant insurance against interruption of supplies;

b) Elimination of middlemen in the markets for both the feedstock and the fuel;

c) Utilization of off-season labor with low opportunity costs; and

d) Capability of utilizing wet stillage and ethanol containing water, thus reducing energy requirements.

Possible disadvantages of fuel ethanol production common to plants of all sizes include:

a) Higher costs than petroleum based fuels;

b) The prices of feedstocks and of food will increase if sufficient quantities are produced to augment fuel supplies significantly; and

c) The inherent inefficiencies of the fermentation process itself, since two carbon atoms are lost in the form of carbon dioxide for every four converted into ethanol.

Disadvantages of producing in a small-scale versus a larger scale plant also appear likely. These include:

a) Higher capital investment per unit of output;

b) Lack of access to the heavily subsidized highway fuel markets;

c) High labor requirements per unit of output;

d) No recovery of gluten meal, corn oil, or carbon dioxide;

e) Lower yields per unit of feedstock;

f) Performance by unskilled operators of a highly technical biochemical process requiring relatively high levels of expertise;

g) Incompatibility of current engines with fuel ethanol;

h) A relatively primitive technology with questionable efficiency and durability;

i) Safety hazards for untrained personnel in handling live steam and explosive ethanol; and

j) Absence of standards in the design and construction of the plants.

The Problem

Few, if any, small-scale plants are operating on a consistent basis in the country; thus most of the material available concerning small plants has been derived by extrapolation from experience in large commercial installations. Furthermore, much of the published material emanates from sources which have financial or political incentives to promote fuel alcohol. Consequently, farmers who are considering building a plant have severe problems in acquiring information which will permit them to make an intelligent decision. Those, who are contemplating such a venture, need better information concerning design, economies of size, financing arrangements, profitability, and the impacts of this enterprise on other farm operations.

This study is intended to identify and present the various costs of producing alcohol in on-farm plants with currently available technology. The study is further designed to provide a method whereby these costs can be quantified for specific plants. This information should be of value to those considering the construction of a small-scale alcohol plant, as well as for persons involved in related public policy and financial decisions.

The Objectives

The general intent of this study is to investigate the costs of producing alcohol in on-farm plants. Specifically, the objectives are:

1) To identify and quantify the costs of producing ethanol in well designed and efficiently run small-scale plants;

2) To provide a means whereby the potential producer can evaluate the cost of producing ethanol in his own plant;

3) To illustrate the impacts on fixed and total costs of utilizing plants at different levels of intensity; and

4) To provide better information to policy makers and financial institutions dealing with small plants.

Review of Literature

Despite widespread interest, little authoritative material has been written on the economics of small-scale plants. A majority of studies relating to the production of grain alcohol have centered on large-scale operations. The Department of Energy in the summer of 1979 issued a policy review report on alcohol fuels. The report addressed the potential feedstocks, energy balances, and policy issues of an ethanol program based on large-scale plants. The report did say; however, that "though economies of scale can notably reduce conversion costs, costs of collecting, transporting, and storing raw materials may make some smaller plants more economical overall. --- Small-scale operations are; however, particularly sensitive to capital availability and to federal requirements concerning operation and reporting."

Small-scale ethanol plants are specifically addressed in a Department of Energy publication.[1/] The publication is a type of workbook which attempts to aid the farmer in assessing his situation and determining his costs of production. Certain principles of basic ethanol production, feedstocks, plant design, and business planning are discussed. However, the productive capacity of the plant presented is considerably larger than the requirements for an individual farm. Furthermore, much of the technology assumed in the document has not been tested in an operating plant and many of the assumptions made were based on the operations of large-scale plants.

The Department of Agriculture has also published a report on small-scale ethanol production.[2/] The report discusses ethanol as a fuel, basic production methods and other topics similar to those addressed in the DOE report. More attention is given to the evaluation of the stillage. The report points out that the cost of a boiler system designed for solid fuels is much higher than a system using gas. Cost of production for plants of various sizes were estimated, with the smallest plant having a volume of 16,000 gallons per year. This hypothetical plant was a primitive pot still without a building.

1/ Fuel From Farms, A Guide to Small Scale Ethanol Production, Department of Energy SERI/SP-45-519, Washington, D.C. 1980.

2/ Small-Scale Fuel Alcohol Production, USDA, Washington, D.C. 1980.

CHAPTER II

METHOD OF INVESTIGATION

Research Method

The economic engineering method of cost analysis is used in this study. This approach involves the "synthesis," or construction and operation, of a plant on paper. In order to synthesize a plant, the researcher must a) develop or select a design for the plant, b) calculate the required investment, c) determine a practical method of operation, d) price the inputs and e) calculate the cost of production from the above data. This method of analysis allows variables to be changed in order to examine the sensitivity of the cost of production to the selected changes. French, Sammet, and Bressler present a detailed description of the economic engineering approach to cost studies.[1]

Scope of the Study

This study is limited to two small-scale ethanol production plants. The impacts on costs of production of utilizing each plant at two different levels of intensity are examined. No attempt has been made to determine costs of production of either small "hobby" type plants or of intermediate or large-scale plants.

Procedures

Various sources of information were utilized in the construction and operation of the hypothetical plants. These included various references, engineering firms and educational institutions. Required inputs and operational procedures consistent with the current "state of the art" were assumed for the hypothetical plants. The staff of the Agricultural Engineering Department of Iowa State University at Ames have constructed and are operating a small-scale still on campus. Their plant design, cost data and operating procedures were most helpful; although they are in no way responsible for the assumptions made in this study.

Based upon the required inputs, a model was constructed which facilitates the use of various cost data. The various costs were calculated under different categories and the sum of costs per gallon of ethanol from each category was obtained. Fixed inputs are those incurred if the plant is operated at any capacity and do not vary in total directly with different production levels. Variable costs are those which change little per unit of output but increase or decrease in total with changes in production levels.

1/ B.C. Fench, L.L. Sammet, and R.G. Bressler, "Economic Efficiency in Plant Operations with Special Reference to the Marketing of California Pears," Hilgardia, 24(19) (Berkeley: California Agricultural Experiment Station, University of California, July 1956), pp. 543-721.

The amounts and prices of the required inputs were inserted into the model and the various cost components calculated. The synthesized costs were added and fixed, variable and total costs arrived at for two levels of output from each of the two plants. The smaller plant was budgeted for 6,000 and 12,000 gallons of ethanol per year; the larger plant 20,000 and 40,000 gallons per year.

The 6,000 gallon per year operation is assumed to provide the liquid fuel for a dryland farm of moderate size. Storage tanks for 600 gallons of fuel are assumed to be on hand prior to the construction of the ethanol plant. The plant is operated only during the six months from November through April. Twenty percent of the winter production (1200 gallons) is assumed to be burned during these months. The remaining 80 percent of the fuel is to be used during the months of May through October when the plant is not in operation.

The 12,000 gallon operation is assumed to provide the fuel for a farm similar in size to the preceeding but with irrigation. This farm is also assumed to have 600 gallons of fuel storage and to consume 1200 gallons of fuel during the winter months. The 12,000 gallon plant is nearly identical to the 6,000 gallon plant with the additional output produced by operating the plant 12 months per year rather than six.

The 20,000 gallon operation is assumed to be a joint venture of three dryland farmers. Each farm is assumed to have 600 gallons of fuel storage prior to construction of the plant for a total of 1800 gallons capacity. Additional fermentation tanks are added to the above plant to permit production of the 20,000 gallons in six months of operation (November through April). As with the 6,000 gallon operation, twenty percent of the production (4,000 gallons) is consumed during the winter months while the plant is in operation.

As with the 20,000 gallon operation, the 40,000 gallon operation is assumed to provide fuel for three farms with these three using ethanol to power irrigation systems. Existing fuel storage is assumed to be 1800 gallons with 4,000 gallons of ethanol consumed during the winter months. The 40,000 gallon operation is operated year around.

Operations of An On-Farm Ethanol Plant

The process of producing ethanol from grain involves four basic operations. These will be discussed briefly here and in more detail in following chapters.

The first operation involves the preparation of the substrate. Corn, which is assumed to be the substrate for this study, will need to be ground. The farm operator is assumed to have a hammermill capable of grinding the corn, so as to reduce particle size sufficiently to facilitate saccharification, or conversion of starches to sugars.

The second operation, saccharification of the substrate, is accomplished by cooking and enzyme treatment. In this process, the starches are broken down to simple five and six carbon sugars; which are "available" for fermentation. At this point, water is added to cool and dilute the mash.

The third operation is fermentation.[1/] Yeast, which is introduced upon the completion of saccharification, metabolizes the simple sugars. The products of this metabolism are ethanol and carbon dioxide. This process generally requires from 48 to 72 hours. At the end of this time, the alcohol concentration has reached a level of approximately 10 to 12 percent. This concentration is toxic to the yeast. With sufficient water content, all of the sugar will have been converted to ethanol before the concentration reaches proportions lethal to the yeast cells. On the other hand, excess water will increase the energy required for distillation.

The fourth operation is distillation which separates the ethanol from the "beer," as the alcohol-water mixture is called. Distillation involves evaporating the alcohol from the mash in a distillation column. This column consists of a tube inside of which are a number of perforated plates on which successive evaporation-condensation processes occur. As the distillation process proceeds, ethanol vapors, containing some water, are driven from the top of the column while most of the water and the solids proceed to the bottom.

The alcohol vapors are condensed into a liquid with a proof varying from 100 to slightly over 190, depending upon the design and operation of the column. Proof, an industry term indicating the concentration of alcohol in the mixture, is a number double the percentage of alcohol. For example, 90 percent alcohol (10 percent water) would be 180 proof.

The solid material from the distillation column is known as distiller's dark grains (DDG) or stillage. Distiller's dark grains have a higher concentration of protein than the feedstock since most of the starch and none of the protein has been converted to ethanol. A portion, about 40 percent, of the protein in the grain has also gone into solution in the conversion process. In large plants this portion is often dried and added to the distiller's dark grains to make distiller's dark grains with solubles (DDGS). DDG and DDGS are both marketed as protein supplements for livestock. The stillage from these small plants contains similar nutrients and is assumed to be utilized for the same purpose.

[1/] As an alternative, the liquid and solids of the mash could be separated prior to fermentation. A major advantage would be that clogging problems in the distillation column would be avoided. At this point a substantial amount of water is added for cooling and dilution. Successive washing and pressing of the mash should ensure that only a small residue of sugar would remain in the solids. Removal of the solids before fermentation would result in a feed with a somewhat different nutrient analysis than that assumed herein for wet stillage.

CHAPTER III

THE PHYSICAL PLANT

Most current literature concerning on-farm alcohol plants gives little information concerning the actual physical equipment required. This chapter will describe the plant synthesized for the study, the cost and the function of the equipment. The following chapter will discuss the operation of the plant and the costs of production at the four levels of output. The main components of the conversion plant are similar to the plant at Iowa State. For costs of the equipment see Appendix 1. Costs were as of late 1979 or early 1980.

Substrate Preparation, Storage, Measuring and Handling Equipment

Ground grain will be used in 40-bushel batches. To avoid having to grind for each batch separately, a storage bin is provided to store 200 bushels. A wooden storage bin with a 40-bushel hopper will be constructed inside the building for the 6,000 and 12,000 gallon operations. For the 20,000 and 40,000 gallon operations. a 300-bushel, weather-proof storage bin with bottom scale is located outside the building. The feedstock is transported from measuring devices to the cooking tank by a three inch-fifteen foot auger.

Building and Fixtures

The plant is housed in a forty by fifty foot steel building. With the smaller plant, space is available inside for the grain storage bin and to permit expansion if desired. The building is insulated to reduce heat loss during the winter months. An Acme Fan Jet ventilation system and exhaust fans are installed to provide adequate air flow. Air circulation must be substantial to remove the large amounts of moisture in the air and to prevent alcohol vapors or CO_2 buildup to dangerous levels. For the plants that are to be operated during the summer months (i.e., 12,000 and 40,000 gallons), additional ventilation capacity is required to keep the inside temperature within tolerable operating temperatures. A back-up propane heater is included to prevent winter freeze-ups should the plant break down or operations are interrupted for other reasons. Concrete footings are poured to support the various tanks and other equipment. A four-inch concrete pad is poured over the footings. The building is assumed to be constructed by a contractor.

Cooking and Fermentation Vats

The cooking and fermentation vats are assumed to be 1500 gallon, mild steel,[1/] upright, round-bottomed tanks. One tank is used for cooking the mash. Two fermentation tanks are provided in the 6,000 and 12,000 gallon per year operations. Seven fermentation tanks are used in the 20,000 and 40,000 gallon per year operations. Each tank is equipped with an agitator to stir the mash. A steam ring is attached to the bottom of each tank for injection of live steam for heating when required. The interior of each vat is painted with a substance to provide protection against corrosion of the mild steel. This substance will probably have to be applied yearly. A desirable feature not provided for would be covers for the fermentation tanks to reduce contamination and permit outside venting of the CO_2.

Plumbing, Pumps and Water Storage

A pump is required to transfer the mash from the cooling vat through the heat exchange equipment to the fermentation vat. The mash may also have to be cooled during fermentation. Also, beer with solids will have to be transported to the distillation column. To perform this function, provision was made for a feed pump with motor, a mass transfer pump and the necessary plumbing. For the plant with seven fermentation tanks, two feed and mass transfer pumps are required.

Water is required for the cooking and saccharification steps as well as for cooling. To insure the required amounts of water in a short period of time, two overhead water tanks are provided. The capacity of each tank is 2,000 gallons. The second tank permits the storage of warmed water from the heat exchanger. The warmed water is used for cooking and for make-up water for the boiler.

Stripping and Distillation Column

The stripping and distillation column consists of a ten-inch diameter steel tube. Inside the column are a series of steel plates with holes of precisely determined size and spacing to permit water and solids to pass downward and the alcohol-water vapors upward. Valves and ports are required to permit the beer to be introduced, the steam to be injected, and the alcohol vapors as well as water and solids to be removed. The column is not assembled when purchased. The builder is assumed to have access to persons of sufficient skill to drill the plates and assemble the column.

[1/] Tanks made of fiberglass, such as those produced by Snyder Industries, Lincoln, Nebraska may be a superior alternative.

Heat Exchangers and Condensers

As will be discussed later, a heat exchanger is provided to cool the mash after cooking and before fermentation as well as at other times during the process. The heat exchanger transfers heat from a warmer mass (the mash) to a cooler one (usually water). As indicated above, the warmed water is stored and subsequently used to reduce energy consumption for successive batches. One heat exchanger was deemed sufficient for the lower volume plant. For the larger capacity plant, a second heat exchanger of lower capacity is provided to cool the mash in the fermenters while the larger is used to cool the cooked mash should both operations be required at the same time.

A condenser is provided to liquify the alcohol-rich vapors from the distillation column. The unit used in this plant is constructed on the farm from an empty fuel drum and pipe. Cold water is used to cook the alcohol vapors. Alternatively, the heat exchanger could be used to condense the vapors while simultaneously preheating the beer going into the distillation column.

Yeast Culture Equipment

A small vat to culture yeast is included to reduce the amount of purchased yeast consumed in the plant. Two such vats are installed for the 20,000 and 40,000 plants. One pound of seed yeast is purchased for each batch.

Enzyme Storage

A used refrigerator is included in the plant to store the enzymes, thus prolonging their active life. Two refrigerators are installed for the 20,000 and 40,000 gallon operations.

Stillage Extraction and Handling Equipment

A sump pump will be installed to remove the stillage from the bottom of the distillation column. The stillage is to be pumped out of the plant to a container designed to drain off the liquid portion and retain the wet solids for livestock feed. The operator is assumed to have equipment capable of handling the wet stillage.

Control Equipment

The plant is not fully automated. However, monitoring and control equipment is installed to maintain proper temperatures within the cooking and fermentation vats. This equipment will cool the mash, should the mash become too hot, by causing it to be circulated through the heat exchanger. If additional heat is required, steam will be injected through the steam rings.

Boiler and Supporting Equipment

A boiler capable of producing 1,150,000 BTU's (British Thermal Units) per hour was installed within the plant. The boiler was installed to permit the injection of steam at a constqnt pressure and temperature while simultaneously cooking and distilling. Although some pot stills are being sold with fire boxes under the cooking vat and the distillation column, such a design was ruled out because of the problems of achieving an even heat production and distribution throughout the cooking and distillation processes. Steam generators are also being sold in lieu of more expensive boilers, but were rejected for these plants because of their inherent inefficiency.

Propane was chosen as the boiler fuel. Crop residues were examined as a process fuel and rejected because of the high capital costs of the processing and utilization equipment. Furthermore, crop residues are not an inexpensive fuel when their full cost is taken into account. The cost of crop residues as a fuel includes not only that incurred in their harvesting, storage and processing but also the benefits forgone as a consequence of removing the materials from the land. Crop residues on the land a) contain plant nutrients, b) provide protection against soil erosion by wind and water, c) contribute to moisture penetration and retention and d) improve soil tilth. These values vary with soil type but are substantial. Natural gas was not used because of the question of availability and the possibility of service interruption during the peak demand periods of winter. Coal was eliminated due to high costs of solid-fuel boilers and handling equipment and questions concerning availability of coal in many areas of Nebraska.

A local contracting company was contacted for an estimate of the cost for installing the boiler. The installation includes pressure relief valves, piping, and other required equipment. A ten-inch diameter, triple-walled stack 12 feet in height was recommended by the manufacturer of the boiler.

Water Treatment

A water softening unit is included in the plant to reduce calcification of the boiler tubes, heat exchangers and the water distribution system. Hard water would greatly reduce the life and operating efficiency of such equipment. The water softening unit installed is a conventional household unit capable of treating about 100 gallons per hour. The unit will treat incoming water as it is pumped to the overhead storage tanks. Salt consumption figures were provided by the dealer.

Alcohol Storage

Storage for the non-denatured alcohol must be provided until an Alcohol, Tobacco, and Firearms representative can denature the alcohol. A 1500 gallon storage tank is included for this purpose.

Additional storage for the alcohol fuel will be required on the farm. The 600 gallons of fuel storage already on each farm will be inadequate. Additional storage required will depend upon the fuel consumption pattern of the farm operations. For the 6,000 and 12,000 gallon operations, a 4,500 gallon storage tank is provided. Storage for the entire production is not required; since some of the fuel will be consumed during the period of time the plant is in operation. In fact, for the 12,000 gallon operation, the rate of consumption during the spring and summer months is assumed to be higher than the rate of production. The supplies of fuel are assumed to be reduced to near zero by the beginning of the November to April production period. The 20,000 and 40,000 gallon operations are provided with 14,800 gallons of additional storage. A metered pump is installed in the larger plants to measure the amount of alcohol distributed to each farmer-owner.

Liquid Waste Disposal Equipment

The liquid portion of the stillage contains soluble nutrients found in the grain and some yeast. Since the plants of this size will not dry the solubles, some manner of disposal is required. Forcing livestock to drink the material would likely require limiting the availability of water, a practice which would reduce feed conversion. Mixing the liquid stillage with dry feeds may permit use of some portion. However, for most farmers the least-cost alternative would be disposal of the liquid in a lagoon. This study assumes that the farmers have such facilities for treatment of livestock wastes. The fertilizer value of the effluent is assumed to cover the cost of transporting the liquid to the lagoon by a buried pipeline and the added cost of operating the lagoon.

Boiler Fuel Storage

A tank for propane is assumed to be provided by the propane company and located adjacent to the plant.

Costs of Equipment and Installation

Various equipment dealers in Lincoln and Omaha, as well as the Agricultural Engineers of Iowa State, were contacted to obtain cost information for the plant equipment. The cost of the material for the 6,000 gallon per year plant totals $31,355 (See Table III-1). This cost does not include installation, except in the case of the steam pipe plumbing. The building cost was estimated at eight dollars per square foot excluding the ventilation and heating system but including labor for the concrete pad and the shell. The labor cost for installing the ventilation system is included in the estimated assembly cost.

To obtain estimates of the cost of assembling the plant, several local construction firms, as well as University of Nebraska Agricultural Engineers, were contacted. A general rule of thumb often mentioned was that the costs of installation would equal the purchase price of the equipment and material.

However, in this study the operator and family is assumed to provide a significant portion of the labor, and that this labor could be provided at a cost lower than professional contractors. For this reason, the decision was made to lower the assembly cost to two-thirds of the cost of the bare equipment. The investment required for the plants of four different capacities are presented in Table III-1.

Table III-1. Investment Required for Plants of Four Different Capacities.[a/]

Item	Annual Production (In Gallons)			
	6,000	12,000	20,000	40,000
Equipment & Materials	$31,355	$31,355	$ 50,295	$ 50,295
Building & Fixtures	21,940	23,440	22,300	23,740
Assembly	20,900	20,900	33,500	33,500
Total	$74,195	$75,695	$106,095	$107,535

a/ For a listing of plant components, see Appendix 1 - Materials and Equipment List.

CHAPTER IV

OPERATION OF THE PLANT AND COSTS OF PRODUCTION

This chapter consists of a description of the plant and the manner used to compile the costs of production. Included within the description of operations are the assumptions and cost data used in the study. The actual breakdown of costs follows. Figure IV-1 presents a schematic of an ethanol plant. The operation of the plant will be discussed in the following paragraphs. The areas within the boxes are plant operations. Items entering and exiting the boxes are assumed to be purchased from or sold to the farm business.

Plant Operations

Substrate and Substrate Preparation

The substrate utilized is assumed to be ground corn. Whenever additional corn is required the operator will grind it into the bin with a farmer-owned tractor and hammermill. Forty bushels of ground corn are removed from the storage bin and augered to the cooking vat for each batch.

Saccharification

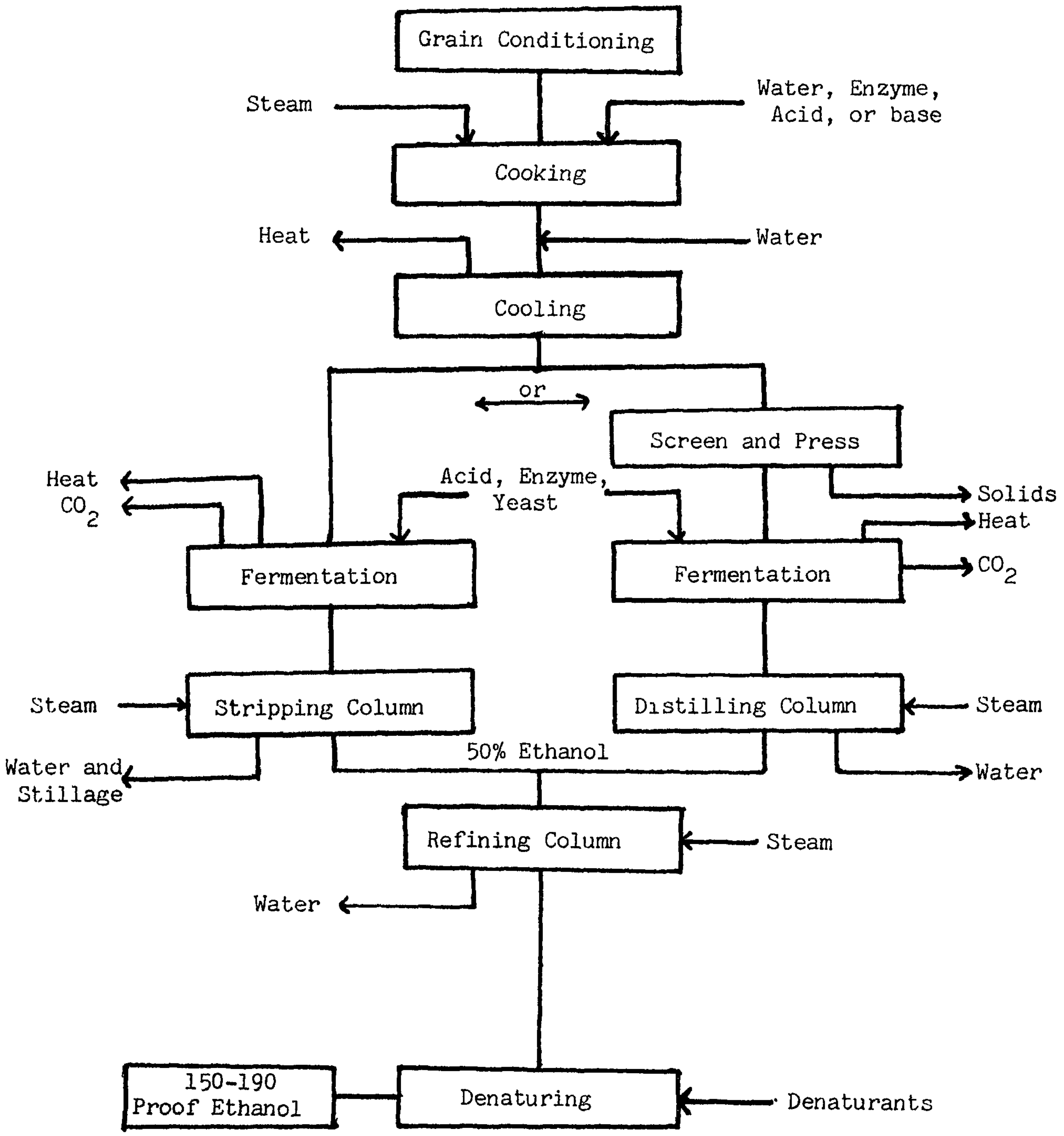
The ground corn is augered into the cooking vat, which has already had warm water added from the overheat tank. The liquid is agitated as the grain is added. Steam from the boiler is concurrently introduced at the bottom of the cooking tank. The steam raises the temperature of the liquid-grain mash to about 166 degrees Fahrenheit at which time an enzyme is added. The temperature is then increased to 212 degrees Fahrenheit and maintained for 30 minutes. The temperature is then reduced to 166 degrees Fahrenheit and a second enzyme is introduced. The temperature is held at this level for 15 minutes and then reduced to 136 degrees Fahrenheit. The pH is reduced to 5.0 by the addition of an acid and a third enzyme is added. After 30 minutes the temperature is further reduced to 85 degrees Fahrenheit by the addition of cold water and by the heat exchanger. Saccharification should be completed at this time and the mixture ready for transferral to a fermentation vat.

Yeast Propagation and Fermentation

The process of fermentation is the metabolism of the simple sugars by yeast. The yeast must be at a high enough initial concentration to immediately begin fermentation at a sufficient rate. This rate should be rapid enough to suppress the multiplication of competing strains of yeast or of anaerobic bacteria. The required quantity of yeast can be purchased or cultured within the plant from a smaller initial "seeding." For this study the operator of the plant is assumed to culture yeasts to avoid the high cost of purchasing sufficient yeast for each separate batch.[1/]

1/ The amount of dry yeast required would be about 9.5 pounds per batch costing about $.16 per gallon of ethanol.

Figure IV-1. Schematic of Ethanol Plant Operations



The yeast is propagated in an aqueous solution of nutrients. The appropriate quantities and concentrations of nutrients were obtained by consulting the Iowa State Agricultural Engineers.

The "seed" yeast (assumed to be one pound per 40-bushel batch) is added to a small amount of the water-nutrient mixture. As the yeast multiplies, additional water and nutrients are added. After a period of 24 to 48 hours, the yeast-rich liquid is ready to add to the substrate-water mixture. The yeast culture is pumped to the fermentation tanks where fermentation begins.

The fermentation process will require about 48 to 72 hours to complete. During this time, the operator will have to monitor the temperature and pH occasionally. Heat will be released by the fermentation process, since the process is exothermic, but the temperature control equipment should maintain the temperature at around 85 degrees F. If sufficient heat is not lost from the surface and through the vat walls, the heat exchanger will be activated to prevent overheating.

The fermentation will be completed when all of the fermentable sugars are digested or the alcohol reaches a concentration toxic to the yeast of about 10 to 12 percent.

Distillation

The fermentation process is followed by distillation, a process by which the ethanol is separated from the mash. Ethanol has a lower boiling point than water which permits the alcohol to be evaporated from the mash. However, in the distillation process some water is driven off with the alcohol vapors. A distillation column with its series of plates permits repeated evaporations and condensations until alcohol-rich vapors are driven from the top of the column.

In the distillation process, the beer is introduced into the column as steam is injected into the bottom. The steam injection rate is determined by the column design and size as is the injection rate of the "beer." As the ethanol vapors are driven upward, the water and solids progress to the bottom of the column. The alcohol vapors, driven from the top of the column, pass through a condenser-preheater where heat is transferred from the vapors to the beer being pumped into the column. The cooling of the vapors causes condensation to an ethanol-rich liquid hopefully approaching 180-190 proof. At a concentration of about 96 percent alcohol (i.e., 192 proof), an azeotrope is formed. The mixture at this concentration has a lower evaporation point than either alcohol or water; thus, further concentration by simple distillation is impossible.

Other Plant Operations

The condensed alcohol is pumped to a sealed tank where the ethanol can be stored until being denatured. The denaturing process is required to make the ethanol non-potable. Denaturing is presently done by an agent of the Bureau of Alcohol, Tobacco, and Firearms and is accomplished by adding toxic liquids to the ethanol. The denatured alcohol is pumped to storage tanks outside the plant for utilization as a fuel.

The stillage is removed from the bottom of the distillation column and transferred by a sump pump to a concrete pad outside the plant. The liquids are allowed to drain off and are emptied into a liquid waste lagoon. The wet solids are fed to livestock, in this case dairy cows, on the farm.

Costs of Production

In the following paragraphs, the procedure for determining the costs of production will be discussed. As was stated earlier, a model has been developed which permits the insertion of cost data. The model differentiates between fixed costs and variable costs. Fixed costs are further broken down into a) plant, b) bonds and licensing fees, c) property taxes, d) insurance and e) fixed labor charges. Variable costs are broken down into a) production plant variable (i. e., operations), b) substrate, c) labor, d) utilities and e) interest on working capital. Each of the cost areas will be discussed in detail with the specific assumptions made in each. The order of discussion will follow that of the model itself.

Fixed Costs

Production Plant Fixed Costs. The two areas of costs included under production plant fixed costs consist of a) amortization of the plant and b) maintenance and repair.

Plant amortization costs were calculated using the Uniform Series Present Value equation, as follows:

$$\text{U.S.P.V.} = A\,\frac{1-(+i)^{-n}}{1} = A\ (\text{U.S.P.V. Table Factor})_{i,n}$$

Where:

U.S.P.V. = The present value or current cost of an item.

A = The annuity or periodic receipt or payment.

i = The interest rate or opportunity cost.

n = The number of times the receipt or payment occurs.

Changing the order of the equation gives:

$$A = \frac{\text{U.S.P.V.}^{1/}}{\text{U.S.P.V. Table Factor}_{i,n}}$$

The annual cost of an investment can be determined if the plant cost, the appropriate interest rates, and the amortization period of the investment are known. The interest rate and lifetime are used to obtain the proper factor from the amortization tables.

1/ Barry, Peter J., John A. Hopkin, and C.B. Baker, Financial Management in Agriculture (Interstate Printers and Publishers, Inc., Danville, Illinois), pp. 238-243.

The costs of the four plants have already been listed (See Table III-1). The interest rate (11 percent) was approximately the market rate during the later months of 1979. The market rate represents the opportunity cost for capital as indicated by what investors are willing to pay.

A lifetime of ten years is assumed for the equipment and 20 years for the building. Based on its construction cost and straight-line depreciation, the value of the building at the end of year 10 is \$8,000. This value, discounted to its present value, is subtracted from the initial cost to give a net capital cost for the building. The present value of the salvage is determined by use of an equation, as follows:

Eq. IV-2. $Vo = P_n(1+i)^{-n}$

$$= P_n \text{ (Future Sum Present Value Table Factor)}i,n$$

Where:

V_o = Present Value

V_n = Future Value

i = Interest Rate

n = Lifetime or Time Periods.

The Future Sum Present Value Table Factor (PVF) for 11 percent and ten years is .352. Multiplying \$8,000 by .352 gives a present value of \$2,816 for the salvage value adjustment. This number is subtracted from the plant investment to obtain the net cost of the plant. The net plant cost is then divided by the amortization (U.S.P.V.) factor to obtain an annual cost. Amortization combines annual depreciation and interest into one figure. The U.S.P.V. factor from the amortization tables (See Appendix 4) is 5.889 when using 11 percent interest and a ten-year depreciation period. The annualized plant cost is divided by the annual output to obtain the cost per gallon of ethanol.

Agricultural engineers at the University of Nebraska estimated that the annual maintenance and repair cost would approximate the cost of the plant divided by the lifetime. The above cost includes paid labor as well as equipment replacement. However, the assumption was made that most of the maintenance and repairs could be performed by the plant operator during regular plant operations for which time is budgeted. In any case, much of the maintenance is associated with plant operation and is more properly classified as a variable cost. On this basis, estimated annual maintenance and repair costs were projected to be approximately one-third of the engineers' suggested figure. The estimated annual maintenance and repair costs are divided by the annual production to obtain maintenance and repair costs per gallon.

The amortized plant costs and the maintenance and repair costs are added to obtain the production plant fixed costs. The production plant fixed cost per gallon is \$2.40 for the 6,000 gallon per year operation and are \$1.22, \$1.05, and \$.53 for the 12,000, 20,000, and 40,000 gallon operations, respectively.

Bonds, Licensing, and Fees. A bond is required by the Bureau of Alcohol, Tobacco, and Firearms for any plant producing ethanol. The bond serves to protect the tax revenue lost should any of the ethanol be diverted for use as a beverage. The required bond must cover two weeks of normal production multiplied by the liquor tax on an equivalent amount of drinking alcohol. The federal tax is $10.50 per 100 proof gallon or $21.00 per gallon (anhydrous equivalent). Multiplying the expected two week production (480 gallons for the 6,000 and 12,000 gallon plant and 1600 gallons for the 20,000 and 40,000 gallon plant) gives a bond requirement of $10,080 for the smaller plant and $33,600 for the larger. A representative of a local bonding company quoted an annual charge of $12.00 per thousand dollars of coverage up to $25,000 and $5.00 per thousand dollars of coverage from $25,000 to $50,000. Coverage for the 6,000 and 12,000 gallon plant would cost $121.00 per year. Coverage for the 20,000 and 40,000 gallon plant would cost $343.00 per year.

Licensing may require legal assistance in certain cases. Also, licensing fees may be levied in certain locations. The expenses for these items may be one-time or annual depending on the situation. One-time costs are properly amortized over the lifetime of the plant as with other initial plant costs.

The estimated annual bond, licensing, and fee costs were totaled and divided by the annual production to obtain the cost per gallon of ethanol. For this study, the assumption was made that the farmer-operator filed his own operating permit request with the Bureau of Alcohol, Tobacco, and Firearms and incurred no legal or feed expenses. The only annual cost incurred under this category would be the bond costs. Dividing the annual cost by the annual output yielded a cost per gallon for bonds, licensing, and legal fees of $.02 per gallon for the 6,000 gallon per year operation. The costs for the 12,000, 20,000, and 40,000 gallon operations are $.01, $.02, and $.01, respectively.

Property Taxes. Property taxes will be assessed against the value of the plant in most jurisdictions. The actual assessed value will be difficult to predict due to the lack of comparable facilities for comparative purposes. Technically, assessed value should be based on the total plant cost. However, the tax basis will likely be lower than this due in part to operator labor utilized in construction. For several reasons, the values placed on property by assessors are often lower than market value and this study assumes this to be the case. The assumed value used is one-half the cost of the plant derived above. This lower value is then multiplied by 35 percent to obtain an assessed value.

The Lancaster County Assessors Office was contacted and the mill levies of several surrounding communities checked. A mill levy of 63 was selected from the middle range of the various levies. Multiplying the mill levy by the assessed value gives the annual property taxes to be paid on the plant. The estimated annual property taxes were divided by the annual production to obtain a cost per gallon of ethanol of $.14 for the 6,000 gallon operation. Costs per gallon are $.07, $.06, and $.03 for the 12,000, 20,000, and 40,000 gallon operations, respectively.

Insurance. Insurance coverage in addition to that normally carried will be required in most cases. The plant should be insured against fire, theft, and storm damage. The operator is assumed to have sufficient liability insurance; so only hazard insurance was acquired. Several Nebraska insurance agents were contacted. None reported having insured an alcohol plant. However, their estimates of annual premiums ranged from under one percent to up to three percent of the cost of the plant. The rate for this coverage will not likely vary greatly with the volume of output.

If labor must be hired to operate the plant, workman's compensation insurance will also be required. One person, in addition to the owner-operator, is assumed to be required for the 20,000 and 40,000 gallon operations. Workman's compensation for one employee was determined to cost about $200 per year.

The additional annual insurance costs for the 6,000 and 12,000 gallon operations were thus estimated to be $700 per year. The cost for the 20,000 and 40,000 gallon per year plant is estimated at $900 per year. Dividing these cost figures by the annual production gives the insurance cost per gallon of ethanol. The costs for the 6,000, 12,000, 20,000, and 40,000 gallon operations are $.12, $.06, $.04, and $.02 per gallon, respectively.

Labor Fixed Charges. Certain overhead operations will be required regardless of plant output. These operations will include bookkeeping and office work when ordering supplies. Five hours are assumed to be required for these and any other miscellaneous labor required per week. A charge of $4.80 per hour is made for this time. The labor cost amounts to $.10 per gallon for the smaller plants and $.05 per gallon for the larger.

Total Fixed Costs. The total fixed cost is determined by summing the fixed costs discussed above. The total fixed cost per gallon for the 6,000 gallon operation is $2.78. The costs per gallon for the 12,000, 20,000, and 40,000 gallon per year operations are $1.46, $1.20, and $.62 per gallon, respectively (See Table IV-1). The annual total fixed costs would be $16,680, $17,520, $24,000, and $24,800 for the 6,000, 12,000, 20,000, and 40,000 gallon operations, respectively.

Table IV-1. Fixed Costs Per Gallon (Anhydrous Equivalent) of Ethanol.

Item	Annual Production (In Gallons)			
	6,000	12,000	20,000	40,000
Production Plant Fixed Costs	$2.40	$1.22	$1.05	$ .53
Bonds, Licensing, and Fees	.02	.01	.02	.01
Property Taxes	.14	.07	.06	.03
Insurance	.12	.06	.04	.02
Labor	.10	.10	.03	.03
Total Fixed Costs Per Gallon	$2.78	$1.46	$1.20	$ .62
Annual Total Fixed Costs	$16,680	$17,520	$24,000	$24,800

Variable Costs

The variable costs are classified under the headings of substrate, labor, utilities, and interest on working capital. A credit is given for the value of the stillage which has the effect of reducing variable costs. Each item will be discussed in detail below with the assumption made in determining the costs.

Operations. Operating costs include yeast, yeast culture nutrients, enzymes, denaturants, pH adjustment chemicals, boiler fuel, and salt for water softening. The amounts required and prices of the individual chemicals are listed in Appendix 2.

One pound of yeast is assumed to provide the "seed" for a yeast culture. To reduce contamination risk a new culture is started for each batch processed. Thus, one pound of yeast is purchased for each 40 bushels of corn or 80 gallons of ethanol. The cost of yeast was quoted at $1.35 a pound by G.B. Fermentation Industries (G.B.F.I.) of Des Plaines, Illinois. The amount of yeast per batch is assumed to be the same for all four operations as are the amounts of the other chemicals.

The yeast culture nutrients and the amounts required were obtained from the Iowa State Agricultural Engineers. The chemicals are potassium phosphate monobasis, epsom salts, ammonium chloride, slaked lime and sugar. Prices of the chemicals were obtained from chemical companies listed in the phone directory in Omaha and Lincoln. The cost of the yeast culture nutrients per bushel comes to $.025.

The choice and amounts of enzymes utilized were based on recommendations from G.B.F.I. Three enzymes are utilized in the process. Two of these are added at the same time in constant proportions. The enzyme cost per gallon of ethanol is $.083.

The cost of the denaturants (kerosene and methyl isobutyle ketone)[1/] was not charged against the cost of the ethanol, since the denaturants have a relatively high fuel value. In effect, when denaturants are being purchased, fuel is being purchased as well. Thus no charge is made for the denaturants as their fuel value is assumed equal to their cost.

[1/] Ethyl Alcohol For Fuel Use, Department of the Treasury - Bureau of Alcohol, Tobacco, and Firearms, U.S. Government Printing Office, Stock No. 048-012-00045-1, p. 23.

The chemicals used to adjust the pH are propionic acid and caustic soda. The amounts of these chemicals required on a per bushel basis were assumed to be equal to that in a larger plant budget.[1/] The prices were obtained by contacting local companies. The cost of the pH control chemicals amounts to $.01 per gallon of ethanol. The cost of the yeast, enzyme, and chemicals amounts to $.135 per bushel.

The cost of boiler fuel is a function of the amount of process steam required per unit of ethanol, the efficiency of the boiler system, and the cost of the boiler fuel itself. Approximately 1,000 British Thermal Units (B.T.U.s) are required per pound of steam generated. The assumed steam requirement in the study plants is 45 pounds per gallon of ethanol, an estimate relecting the judgement of Iowa State Agricultural Engineers, based upon experiences with their plant. This figure is subject to a good deal of variance on the high side; but the consensus of the engineers consulted was that the steam requirements would not drop lower with the plant design used. The net energy requirement was estimated to be 45,000 B.T.U.s per gallon of ethanol. If the boiler is 85 percent efficient, 52,941 gross B.T.U.s would be required to obtain 45,000 net B.T.U.s. Propane has 94,500 gross B.T.U.s per gallon, which would provide the process energy for 1.78 gallons of ethanol. Propane was priced in the Fall of 1979 at $.486 per gallon. On the basis of these assumptions, the boiler fuel cost would be $.27 per gallon of ethanol.

Salt is required to soften the water used in the plant. In Lincoln, approximately three pounds of salt are required to soften 1,000 gallons of water. G.B.F.I. indicates that about 32 gallons of water are required per bushel of corn. Local salt prices are approximately $.05 per pound.

The sum of the above cost items is $.41 per gallon of ethanol. This cost is constant for all four operations (see Table IV-2).

Substrate Costs. Substrate costs consist of two charges. As discussed earlier, the cost of the substrate includes the cost of the grain itself and the cost of grinding the grain to facilitate saccharification. The ground grain is purchased from the farm.

The assumed cost of corn is $2.50 per bushel. The assumed yield per bushel of corn is 2.0 gallons ethanol anhydrous equivalent. Large, sophisticated, wet milling plants achieve yields of 2.5 gallons of anhydrous ethanol per bushel. However, farm size plants will not achieve such yields. No small-scale plants were located which were currently averaging a yield of two gallons of ethanol (anhydrous equivalent) per bushel of corn; but this does not appear to be an unrealistic goal. Such a yield has been achieved in the Iowa State Plant and could, presumably, be duplicated with a well-designed plant operated by a skillful and diligent person.

1/ Unpublished communications with Vogelbusch Division, Bohler Bros. of America Inc., Houston, Texas. Propionic acid was substituted for the sulfuric acid in Vogelbusch's budget as suggested by the Iowa State Agricultural Engineers.

Grinding charges were estimated from several budgets prepared by farm management specialists. The operator is assumed to own a grinder and utilize it in other enterprises as well as for alcohol production. The grinding charge of $5.00 per ton of corn does not include labor. Depreciation, repairs, maintenance, and fuel costs are assumed to be covered by the above charge. Labor will be included in a following section. One ton of corn consists of about 35.7 bushels of corn. This amount of corn will produce about 71.5 gallons of ethanol. The grinding cost per ton of corn divided by the assumed yield of ethanol yields a cost of $.14 per bushel or $.07 per gallon. Adding the corn cost and the grinding cost gives a substrate cost of $1.32 per gallon.

Labor Costs. The estimated labor requirement per batch is 8.7 hours for each of the operations. The labor total consists of 0.2 hours to grind the substrate, 2.0 hours to monitor fermentation, 6.0 hours to distill, and 0.5 hours for yeast culturing. As indicated above, the assumption is made that the operator will have time for repair and maintenance during plant operations. Plant monitoring is exceedingly important but not full time.

No labor is allocated for cooking or for cooling the substrate; since the distillation and cooking processes are assumed to overlap. After distillation is initiated the operator will have to remain close by to monitor the process and make adjustments in steam or beer input as required. During this time, he should also be able to cook a batch and add enzymes and pH adjustment chemicals as needed. The operator should be able to accomplish both operations simultaneously. The labor estimates were derived by consulting the Iowa State Agricultural Engineers, who have had considerable experience in operating their own plant.

Labor is charged to the plant at a rate of $4.80 per hour. This figure was derived from various University of Nebraska crop and livestock budgets for 1979 and 1980. Given a 40 bushel batch yielding 80 gallons of ethanol, a labor requirement of 8.7 hours per batch, and a labor charge of $4.80 per hour, the labor cost is $.52 per gallon.

Utility Costs. Utilities consumed consist of water and electricity to power the plant equipment and to provide light. Electricity is consumed by the various pumps, the ventilation system, and the lights. Since no farm-scale ethanol plants could actually be monitored for this study, data are limited concerning power usage. For this reason an estimate of power consumption was derived from an engineering firm. They estimated consumption of 1.3 kilowatt hours of electricity per gallon of ethanol for a plant producing one to three million gallons per year. A local utility company quoted a charge of $.04 per kilowatt hour, given the consumption levels of the farm operations. Assuming the above rates, the electricity cost is $.052 per gallon.

Even though a space heater was installed for emergencies, the heat generated by the plant is assumed to keep the plant from freezing up in winter operations. Assuming that the plant operates on a consistent basis, an insignificant amount of propane will be required specifically to heat the plant and was ignored.

Water is assumed to be purchased from the farm water system. The price paid for the water is assumed to cover the delivery costs to the plant. Given the assumption that the marginal cost of water from a farm system would approximate municipal water rates, the assumed charge is $.50 per 1,000 gallons of water. The water consumption per gallon of ethanol was determined to be 16 gallons and was derived by adding the amount of water used in cooking and fermentation, as recommended by G.B.F.I., to the 45 pounds of water necessary to make 45 pounds of steam. Sixteen gallons of water would cost $.008 per gallon. Adding the cost of the electricity to that of the water results in a utility charge of $.06 per gallon of ethanol (See Table IV-2).

Interest on Working Capital. An interest charge on the inputs consumed in producing the ethanol is necessary to reflect the opportunity cost of the funds required or the actual cost of borrowing funds to purchase the inputs. Consumption of the inputs is assumed to be linear during the production period. Interest is charged against the average cost of the inputs in the ethanol throughout the year. Average ethanol inventories are 2400 gallons for the 6,000 and 12,000 gallon operations and 8,000 gallons for the 20,000 and 40,000 gallon operations (See Appendix 4). The cost of the various inputs per gallon, excluding the amortized plant costs and the substrate costs, but including the credit for the stillage, are summed to obtain the value of the inputs invested in the average inventory of ethanol. An interest rate of 11 percent per year is used here as was used earlier in amortizing the plant. The resulting product is the annual interest charge for these inputs.

The estimated annual maintenance and repair costs are included because they are incurred annually and have no incorporated interest rate. A credit is made for the stillage, since it is available for livestock feed as the plant is operated and thus reduces requirements for purchased feed.

The corn converted to ethanol would likely have been held for some time on the farm before marketing if not converted to ethanol. If this were the normal practice, an interest charge on the value of the corn in the ethanol should be levied against the ethanol only for a portion of a year. This time period would be the time the ethanol is held beyond the normal holding time of the corn. For this study, corn is assumed to be held on the farm an average of six months in the absence of the ethanol plant. The substrate cost is multiplied by the average ethanol inventories and interest rate as done above for the other costs. However, the product is then reduced by one-half to account for holding the average ethanol inventory one-half year beyond when the corn would normally be held. The reduced amount is the annual interest charged against the substrate.

Before the total annual interest charge can be calculated, credit must be given to the ethanol production for eliminating the need for conventional fuel inventories. As stated earlier, the farm is assumed to have 600 gallons of existing fuel storage in the absence of the 6,000 and 12,000 gallon per year operations. The assumed storage capacity on the farms with the 20,000 and 40,000 gallon plant is 1800 gallons of fuel. The assumption that the fuel consumption patterns of these farms are linear and that the tanks can be instantly refilled provides the basis for projecting an average fuel inventory of 300 gallons for the smaller two operations and 900 gallons for the larger two (See Appendix 4).

Local fuel dealers were contacted for quotes on bulk diesel fuel deliveries. A price of $.90 per gallon was used. Multiplying the price by the average fuel inventories and 11 percent gives the annual credit to the ethanol operations. Adding the annual interest charges for the substrate and the other inputs and subtracting the credit for reduced conventional fuel inventories gives the net annual interest charge on working capital. Dividing this charge by the annual production results in a per gallon interest charge on working capital of $.08, $.03, $.06, and $.03 for the 6,000, 12,000, 20,000, and 40,000 gallon operations, respectively.

By-Product Credit. A by-product of the alcohol production process is stillage, the residue remaining after the process is complete. The stillage contains water and that portion of the grain not converted to ethanol or CO_2 and yeast. Commercial ethanol plants normally dry the stillage and sell it as a high protein livestock feed, called distiller's dark grains, plus solubles (DDGS). For the budgeted plants, the stillage is assumed to be fed in a "wet" or high moisture state. The DDG produced by large ethanol plants contains approximately 29.8 percent crude protein. The protein content of the solubles is about 28.9 percent crude protein. Almost all of the original protein in the grain is present in either the DDG or the solubles portion, with approximately 39 percent of the protein in solution. Most studies or reports on small plants have tended to assume that the recovery by large plants of distiller's dark grains with solubles (DDGS) is applicable to small plants. However, in most cases, the liquid portion of the stillage from the small plant will have little net value as feed being only five percent solids by weight. For this study only the solids portion of the stillage will be assumed to be fed with the solubles being discarded except for that portion contained in the high moisture solids.

Since less of the starch is converted to alcohol in the farm plant, as compared to the large plants, the nutrient content of the stillage differs from commercial DDGS. The stillage from the small plant will contain the unconverted starch which will lower the percentage of the protein but increase the energy value of the feed. For this study, the assumption is made that the unconverted starch will remain in the solids portion of the stillage. The relative amount of protein in the solids versus the solubles is assumed to be the same. The protein content of the wet solids portion of the stillage is calculated to be 18.6 percent, dry weight, given the above assumptions.

The value of the stillage was estimated through the use of a least-cost feed formulation program on the AgNet System.[1/] An estimated nutrient analysis (See Appendix 4) was inserted into the equation for a ration for high producing dairy cows. The price at which the stillage would come into the solution (the shadow price) is approximately $.07 per pound (dry basis). To avoid having to make site-specific assumptions concerning handling facilities for the wet material, the stillage was discounted to $.06 per pound. The one cent per pound discount is assumed to cover the additional handling costs involved in utilizing the wet feed, which is susceptible to spoilage and freezing. Approximately 17.4 pounds (dry basis) of stillage are produced per bushel of grain. Based upon the above assumptions, the value of the stillage produced is $1.04 per bushel of corn or $.52 per gallon of ethanol. The value of the stillage is subtracted from the cost of the ethanol to obtain a net average total variable cost (See Table IV-2). For a more detailed description of the evaluation of the by-product feed and livestock utilization see Appendix 4 - Study Calculations.

Table IV-2. Variable Costs Per Gallon (Anhydrous Equivalent) of Ethanol.

Item	Annual Production (In Gallons)			
	6,000	12,000	20,000	40,000
Production Plant Variable Costs	$ .41	$ .41	$ .41	$ .41
Substrate Costs	1.32	1.32	1.32	1.32
Labor Costs	.52	.52	.52	.52
Utility Costs	.06	.06	.06	.06
Interest on Working Capital	.08	.03	.06	.03
Total Variable Cost Per Gallon	$2.39	$2.34	$2.37	$2.34
Less By-Product Credit	-.52	-.52	-.52	-.52
Net Variable Cost Per Gallon	$1.87	$1.82	$1.85	$1.82

[1/] AgNet is a remote access computer system based at Lincoln, Nebraska. Access is gained by phone by approved users. University of Nebraska Animal Science Department scientists have built a least-cost ration model on AgNet which enables the user to determine least cost rations or to evaluate the value of feedstuffs available in his area.

Total Variable Cost. The total variable cost is $1.87, $1.82, $1.85, and $1.82 per gallon for the 6,000, 12,000, 20,000, and 40,000 gallon operations, respectively. The small differences in cost reflect differences in the interest on working capital. This cost has both fixed and variable aspects but for this study is categorized as variable.

Total Cost

Total costs per gallon are derived by adding the average total fixed costs and the average total variable costs. The resulting total costs per gallon for the 6,000, 12,000, 20,000, and 40,000 gallon operations are $4.65, $3.28, $3.05, and $2.44, respectively. (See Figure IV-3.) The variation in costs of production indicate significant economies of size as reflected by the fact that costs of production in the larger plant, even when operated for only half the year, are below those of the smaller plant. However, the costs per gallon can be seen to decrease dramatically also as each p;ant is utilized more intensively.

Figure IV-2 on page 27 presents the above costs in graphical form. The cost of producing 12,000 gallons in the larger plant has been included. The fixed, variable, and total costs at 6,000, 12,000, 20,000 and 40,000 gallons are indicated by X's. The curves plotted are the results of interpolating and extrapolating from these points. Production in each of the plants cannot exceed a certain level. This level in the small plant is 12,000 gallons per year. In the larger plant this level is 40,000 gallons per year. At these points the output is limited by bottlenecks within the plants.

Table IV-3. Total Costs Per Gallon (Anhydrous Equivalent) of Ethanol.[a]

Item	Annual Production (In Gallons)			
	6,000	12,000	20,000	40,000
Fixed Costs	$2.78	$1.46	$1.20	$ .62
Variable Costs	1.87	1.82	1.85	1.82
Total	$4.65	$3.28	$3.05	$2.44

[a] The ethanol produced in on-farm plants will range from 150 to 180 proof (i.e., 10 to 25% H_2O). However, costs are presented on an anhydrous equivalent basis. The gallons of liquid produced will be greater depending on the proof.

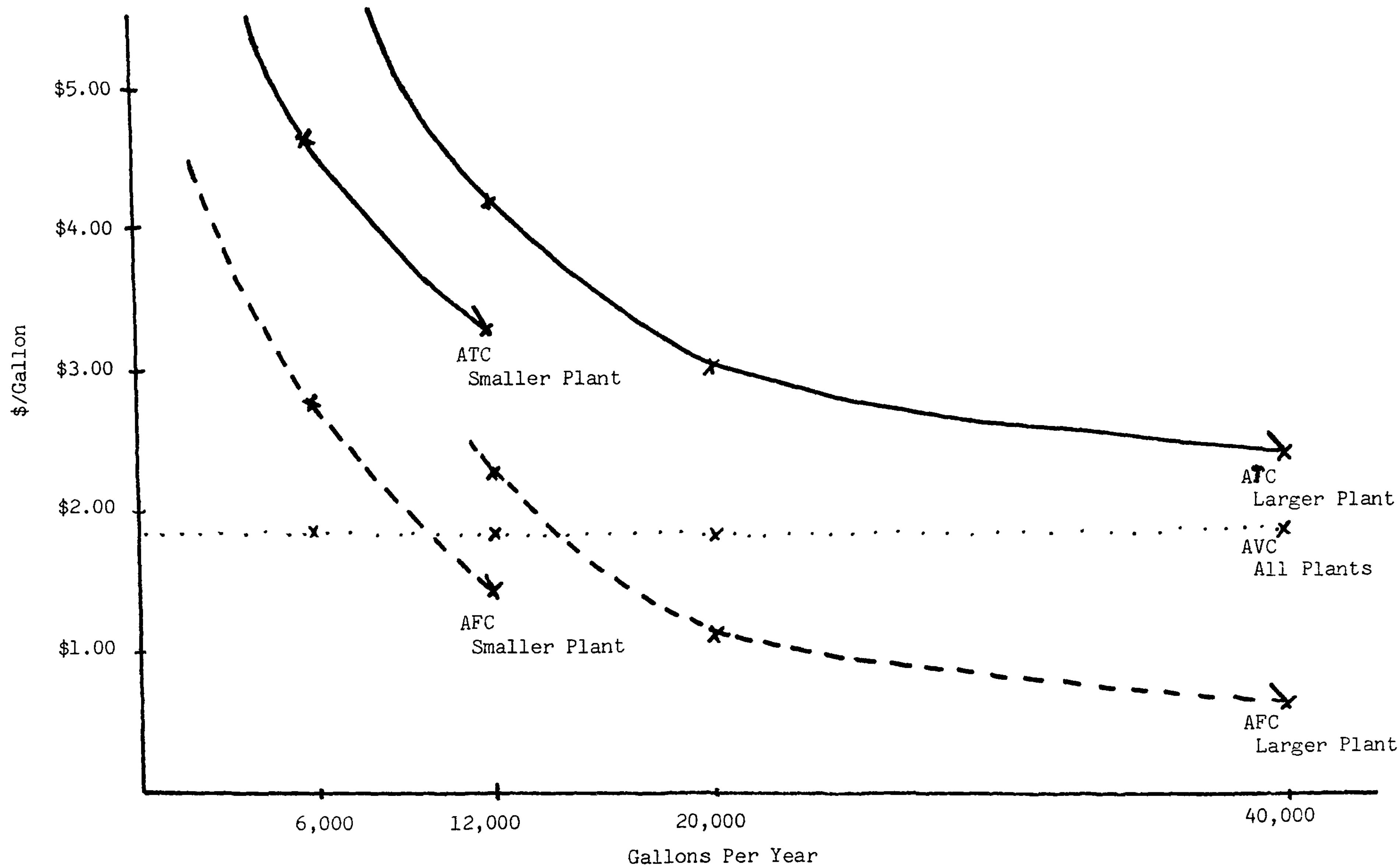


Figure IV-2. Fixed, Variable, and Total Costs Per Gallon by Plant Output.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Certain advantages are claimed for the on-farm production of fuel ethanol, the most important being self sufficiency in liquid fuels. Yet farmers can not be indifferent to the cost of achieving any objective, no matter how desirable. Thus an important concern in evaluating the potential for on-farm production of fuel ethanol is the cost. However, information available concerning costs of production of fuel ethanol is largely limited to that put out by those with vested interests. The purpose of this study was to examine the cost of producing fuel ethanol on the farm. Specifically, the objectives of this study were:

1) To estimate the cost of producing fuel ethanol in small plants;
2) To provide a model whereby the potential producer can estimate the cost of production in his own plant;
3) To examine the impacts on cost of production of differences in size of plants and of intensity of operations; and
4) To provide better information to public policy makers and financial institutions concerning the construction and operation of small plants.

An economic engineering approach was employed to derive costs of producing ethanol. Various firms and agricultural experiment station personnel were contacted to determine the required inputs and procedures for ethanol production. Costs were synthesized for two plants, each operated at two levels of intensity. The smaller of the two plants was budgeted at 6,000 and 12,000 gallons annual output. The larger plant was budgeted at 20,000 and 40,000 gallons annual output.

Costs of production were categorized as fixed and variable. Costs classified as fixed include plant amortization, maintenance and repair, bonds, licensing and legal fees, property taxes, insurance, and a portion of the labor. Costs classified as variable included the balance of the labor, plant operations (yeast, enzymes, fuel, etc.), substrate, utilities, and interest on working capital. The variable costs were reduced by a credit for the feed value of the stillage.

Estimated costs of production of ethanol ranged from $2.44 per gallon from the 40,000 gallon operation to $4.65 from the plant producing 6,000 gallons per year. Most of this difference was accounted for by a decline in fixed costs per unit of output with an increase in output. The fixed costs, which were $2.78 per gallon in the 6,000 gallon operation, decreased to 62 cents per gallon for the 40,000 gallon operation.

Conclusions

The cost of fuel ethanol as estimated in this study is considerably higher than the current prices of conventional fuels. In fact, the cost of ethanol from the most economical operation, at $2.44 per gallon, is more than twice that of diesel fuel at the time of this writing. Government subsidies of various forms are being provided to reduce the cost of ethanol to the producer. However, the purpose of this study was to ascertain the "real" costs of production irrespective of their incidence. Subsidies, if they are sufficiently large, could, of course, make ethanol production financially attractive to the individual.

The major components of the cost of producing fuel ethanol are plant amortization at $.53 per gallon, production plant costs at $.41 per gallon, substrate costs at $1.32 per gallon, and labor at $.52 per gallon. The total (i.e., $2.78) of the foregoing costs, which refer to the 40,000 gallon operation, is reduced by a feed credit of $.52 per gallon of ethanol. If the costs of production are to be reduced to competitive levels, the reductions will have to be achieved in the above areas.

Plant amortization costs could be reduced in two possible ways. If a plant of a given capacity could be assembled for less than the assumed amount, costs per gallon would be reduced. Alternatively, if more annual output could be produced with a given investment, the costs per gallon would decline as well. The impact of such cost reduction would be quite limited, however. For example, if investment costs were reduced by one-half, the savings would be only about 27 cents per gallon. The 40,000 gallon plant budgeted in this study will not be able to increase output significantly without the addition of more fermentation tanks, which would require a larger building and more supporting equipment. This study did not examine economies of size beyond the 40,000 gallon plant. However, a larger plant of this same design would likely not achieve much reduction in cost.

A limitation on plant size will be the amount of fuel the farm operation can utilize, since a producer will likely have difficulty marketing surplus output at a price which will cover his variable costs. Non-anhydrous ethanol is not suitable for blending with petroleum fuels. Furthermore, neighboring farmers are not likely to buy fuel ethanol as long as conventional fuels are available at a lower cost. Consequently, the individual farmer is limited in his ability to reduce fixed costs significantly by increasing output.

Nor are major reductions likely to be achieved in the cost of operating ethanol plants of a given design. Both the quantities required and the prices of inputs (i.e., yeasts, enzymes, fuel, etc.) are largely outside the control of the operator. All indications are that the prices of the inputs will continue to go up, not down. Some believe that major cost savings can be achieved by substituting a farm-produced fuel, such as crop residues or methane, for LP gas. However, an investigation of available technology indicated that such fuels would increase, not decrease, costs. But, even if operating costs were cut in half, the decrease in ethanol costs would be only $.13 per gallon.

Substrate costs are $1.32 per gallon. The cost of the ground corn is assumed to be $2.64 per bushel. A yield of 2.0 gallons of anhydrous equivalent ethanol per bushel is assumed. The substrate cost per gallon could be reduced if either the cost of grain were lower or the yield of ethanol higher. However, the cost of corn assumed at $2.50 per bushel appears to be below the cost of producing it. An increase in the price of corn to $3.00 per bushel would result in an increase in costs of 25 cents per gallon. Conversely, if corn were only $2.00 per bushel, the cost of ethanol would be reduced by 25 cents per gallon. Reductions in grinding costs would have only small cost impacts and are not foreseen in the future.

Much has been written about using farm-produced materials other than grain as feedstock for producing ethanol. Among crops suggested have been sweet sorghum, artichokes, and potatoes. It is true that any material containing starch or sugar can be used as a feedstock. Furthermore, cellulose, which is cheaper and more abundant, can, also, be converted to ethanol but currently only by methods which are impractical, especially in small plants. However, this analysis was limited to corn, a source of starch which is currently more abundant than any other in the United States.

Increases in the yield of ethanol per bushel of corn would reduce both the fixed and variable costs per unit of output. For example, an increase from 2.0 to 2.5 gallons of ethanol would reduce the cost of the feedstock to $1.06 per gallon from $1.32. However, yield increases of this magnitude in on-farm ethanol plants appear unlikely. Commercial plants, especially those using a wet milling process, approach and in some cases achieve yields of 2.5 gallons of ethanol per bushel of corn. However, no on-farm plants were located which were obtaining even 2.0 gallons on a sustained basis. Without a significant technological breakthrough, the average yield of ethanol from a small-scale plant will likely be below 2.0 gallons per bushel. Unfortunately, most of the recent technological advances are practical only in larger more sophisticated plants.

Reducing the amount of labor required per batch, the charge per hour, or the yield of alcohol per bushel would reduce the labor cost of the ethanol. The labor required per 40-bushel batch is assumed to be 8.7 hours at $4.80 per hour for a total labor cost of $41.76 per batch. Increasing yields to 2.5 gallons per bushel would decrease labor costs by 10 cents per gallon. As discussed above, this is unlikely. Reducing by half the hours required or the charge per hour would reduce costs by 26 cents per gallon for the 40,000 gallon plant. However, given the assumption that most of the plant maintenance and repair would be performed by the plant operator, a labor requirement of 8.7 hours per batch appears to be optimistic.

Labor requirements could be reduced if money was invested in additional automation. However, such a decision would not reduce costs but would simply shift them from variable to fixed. Given the volume of production in the plants budgeted in this study, additional automation did not appear to be cost effective. Obviously, any owner-operator could budget his labor at a cost lower than $4.80 per hour. But the time required is substantial. For the smaller plant about 31 hours are required per week, while 92 hours are required in the larger plant. Such a commitment of time will compete, not only with leisure but directly with other farm enterprises. To the extent that such labor is hired, responsible employees will not be available at a wage rate lower than that assumed.

The by-product feed credit is the last major item influencing costs. If the credit could be increased, the cost of the ethanol would decrease. The value assigned herein is the result of inserting the calculated nutrient analysis of wet stillage into a least-cost ration model on the AgNet system (See Appendix 3). The ration chosen was one for high-producing dairy animals. Lower producing dairy cows, beef animals, or swine would all yield a lower value. Stated differently, those who feed the stillage to livestock other than high-producing dairy cows will realize a return which is lower, and probably significantly so.

If the costs of the other feedstuffs change, the value of the stillage will likewise change. An increase in the prices of competing feeds would increase the value of the stillage. Conversely, a reduction in the price of livestock feed would reduce it. If large amounts of grain are diverted to ethanol in the future, grain prices will increase. The result will be higher costs for feedstocks and upward pressure on the value of stillage. Conversely, the resulting increase in DDGS on the market would tend to depress the price of protein feeds. The net effect on the value of stillage from these differing price movements is difficult to determine. In any case, the value of wet stillage is not likely to increase dramatically with increased grain prices; a claim made by ethanol advocates. Any increase in the value of stillage resulting from higher grain prices, will not likely offset the increased cost of feedstock for the still.

The above discussion indicates that without a major change in technology, the cost of on-farm production of fuel ethanol produced in on-farm plants is not likely to be lower than the costs arrived at in this study. To the contrary, any variations from these results in a farmer-owned and operated plant are more likely to be toward higher costs. The inevitable conclusion is that the cost per gallon of fuel ethanol produced in small-scale plants exceeds by some multiple the current price of petroleum-based fuels.

The comparison is even less favorable to ethanol in terms of energy content. The consensus of agricultural engineers, who were consulted, was that, in a spark ignition engine designed to burn ethanol, thermal efficiency might equal that achieved in a compression ignition engine burning diesel fuel. On the other hand, a gasoline engine modified to burn ethanol will likely achieve a thermal efficiency no better than was being achieved with gasoline. In terms of volumetric comparisons, a switch from gasoline to ethanol will result in approximately a 30 percent reduction in miles, or horsepower hours, per gallon of fuel.

The heavy work in U.S. agriculture is now performed predominantly by diesel engines. Based on the optimistic assumption that the ethanol will be used in engines which will achieve a thermal efficiency equal to that of diesel engines, a comparison of the work-value of ethanol versus diesel fuel can be based on the energy contained in the two fuels. Ethanol contains approximately 85,000 British Thermal Units (BTUs) per gallon; while diesel fuel contains about 140,000 BTUs per gallon. Assuming equal thermal efficiency, a gallon of ethanol would accomplish about 61% of the work of a gallon of diesel fuel. Since the value of a fuel is in the work that it can accomplish, ethanol is worth 0.61 times the price of diesel fuel. That is to say, if the price of diesel fuel is $1.00 per gallon, a gallon of ethanol (anhydrous equivalent) would be worth only 61 cents.

Alternatively, dividing the cost of ethanol by .61 gives the price that diesel fuel would have to reach before ethanol is competitive. For our smallest plant producing ethanol for $4.65 per gallon, diesel fuel would have to reach $7.66 per gallon if the ethanol is to be competitive. For the plant producing 40,000 gallons, the diesel equivalent cost of ethanol at $2.44 equals $4.00 per gallon.

The above discussion concerning the use of ethanol as a motor fuel still overstates its value since the above comparison makes no provision for conversion of engines to alcohol. U.S. farms are currently equipped to use petroleum based fuels; therefore, existing engines will need to be modified, or new engines purchased, if ethanol is to be used effectively. Ethanol has characteristics which make it unsuitable for diesel engines. Not only does ethanol lack the natural lubricants required by diesel engines, but its high octance rating virtually precludes compression ignition. On the other hand, use of a blend of ethanol and a petroleum based fuel does not achieve the independence which is cited as the principal advantage of the on-farm production of fuel alcohol.

Furthermore, as indicated above, only anhydrous ethanol can be mixed with petroleum based fuels. "Wet" alcohol can be burned with gasoline or diesel fuel only by introducing the fuels into the engine from separate tanks. Furthermore, an engine burning straight alcohol will require special provision for cold weather starting. In any case, the on-farm production of alcohol will likely be even less cost competitive if ethanol constitutes only a portion of the fuel used. The budgets presented in this report vary in cost per gallon of ethanol from $4.65 for an output of 6,000 gallons to $2.44 for a 40,000 gallon operation. The inference to be drawn is that costs of production are sensitive to the volume produced. Costs per gallon decline not only with increases in plant size but even more dramatically as the output of a given plant increases toward full capacity. Nor does the sale of surplus "wet" ethanol appear to be a viable option. Stated differently, the construction and operation of an on-farm plant to produce fuel ethanol for blending with other fuels, or for emergencies, appears to be even less attractive, economically, than does producing all of the liquid fuel for the farm.

Another consideration with respect to on-farm production of fuel alcohol is safety. The production of ethanol involves the handling of several potentially dangerous substances. Ethanol itself is explosive. Great care must be taken in the design, construction and operation of a plant to avoid the concentration of ethanol vapors or the generation of sparks. Further hazards are posed by acid and live steam. Both can cause severe burns if the operator of the plant is exposed to them. Most farmers have worked with neither and may tend to ignore the dangers. Safety training may be required to handle the above substances. But even the most skilled and careful plant operator will be exposed to severe hazards if the design and construction of the plant fail to meet safety standards.

Another product of ethanol production is carbon dioxide. Being heavier than air, carbon dioxide tends to settle in low lying areas. The plant must be adequately ventilated to prevent carbon dioxide suffocation. Animals in areas surrounding the plant will need to be watched on still days and possibly moved from areas of carbon dioxide concentration.

No attempt has been made in this study to examine costs of producing ethanol in intermediate or large-scale plants or to examine net energy balances. The costs of producing ethanol in plants of the size budgeted is obviously much higher than the current prices of conventional fuels. The decision to produce ethanol by any individual should be made with the costs in mind. Government subsidies, plus the value of an assured fuel supply, may persuade some individuals to produce fuel ethanol. However, as a matter of public policy, high costs are evidence of inefficient allocation of resources.[1/] Furthermore, unless the production of fuel alcohol results in a net gain in premium fuels,[2/] the impact on petroleum imports of a large, on-farm ethanol program will not be positive.

1/ Baumol, Wm. J. and Sue Anne Batey Blackman. "Unprofitable Energy is Squandered Energy," Challenge, July-August, 1980, pp. 28-35.

2/ Preimum fuels include gasoline, diesel fuel, LPG, fuel oils, jet fuel, plus natural gas and electricity. Expending a BTU of any of these fuels to gain one BTU in ethanol would not likely contribute to the solution of the energy problem.

In any case, the farmer who produces all of his liquid fuels will not thereby achieve energy independence. Liquid fuels consumed on farms constitute only a small fraction of the energy purchased by farmers. In fact, the single largest energy input on U.S. farms is not liquid fuel; it is nitrogen fertilizer.[3/] Other fertilizers and the various pesticides also represent major energy inputs. Furthermore, a vast amount of energy is embodied in the machinery and equipment which farmers use. All of these inputs are sensitive in price and availability to petroleum. This study did not address the issues of premium fuel substitution and energy balance; however, policy makers would do well to ponder all of their implications before making major commitments of resources.

One reason for the high cost of production of fuel ethanol in small-scale plants is their relatively low yield of ethanol per bushel. Low yields raise both fixed and variable costs, since most costs are the same per unit of substrate regardless of the yield. However, the economical production of fuel ethanol from grain by fermentation faces formidable obstacles in plants of any size. High cost is an inevitable consequence of a) the use of a feedstock which is produced and processed by energy-intensive methods and b) the inherent inefficiency of the conversion by fermentation of sugar to ethanol, which results in one third of the carbon atoms (i.e., the energy) being transposed into CO_2.

Logic would suggest that fuels can be economically produced on the farm only with a feedstock which is less costly and more abundant than starch (e.g., cellulose) and with a conversion process which is more energy efficient than fermentation.

In summary, the general conclusion to be drawn from this investigation is that fuel ethanol from grain shows little promise for making a significant contribution to the solution of the energy problem for reasons, including:

a) The feedstock is a commodity possessing great and growing utility in its present form;

b) Both the production of the feedstock and its conversion to ethanol are energy intensive and thus require large inputs of premium fuels;

3/ Pimentel, David et. al. "Food Production and the Energy Crisis," Science, November 2, 1972.

c) On a BTU basis, the cost of fuel alcohol is substantially greater than the current prices of petroleum based fuels. Furthermore, this adverse situation will not necessarily improve with an increase in the price of crude oil, natural gas or electricity; since the cost of producing ethanol will go up with the prices of energy.

d) The potential for producing liquid fuels from grain is overwhelmed by the magnitude of current consumption. For example, conversion of the entire U.S. corn crop to ethanol would yield an amount equal to only about 10 percent of the 1979 U.S. consumption of liquid fuels (i.e., 170 billion gallons);

e) Diversion of a major proportion of the U.S. grain crop to fuel ethanol would increase drastically the prices of livestock feed and human food and the ability of the U.S. to meet export demands. Incidentally, it would also increase dramatically, the cost of the feedstock for ethanol production. Conversely, the value of the feed by-product would likely decline as the market for high protein feedstuffs was glutted. Shifts of agricultural resources from grain to the production of other feed stocks would have similar impacts.

f) The soil and water resources of the U.S. are being rapidly depleted at present levels of production. Subjecting these resources to the additional stress associated with producing liquid fuels would surely bode ill for the future.

Not only does fuel ethanol face serious problems as a means to ameliorate the shortage of liquid fuels but, in addition, farm production of fuel ethanol is at a disadvantage as compared to large-scale commercial operations for reasons, as follows:

1) Farm-size plants of current design utilize relatively primitive technology. Furthermore, no standards of design or of construction are in force to protect those who make such an investment. But, in any case, technologically sophisticated small-scale plants constructed in conformance with standards of quality which would ensure efficiency, durability and reliability in operation would be prohibitively costly;

2) The ethanol produced in on-farm plants does not have access to the heavily subsidized market for ethanol used on the highways;

3) Small plants as compared to large scale plants will:

    a) Be unable to recover gluten meal, corn oil or other by-products;

    b) Achieve lower yields per unit of feedstock;

c) Expose the operators to the hazards of live steam, acids, carbon dioxide concentrations and potentially explosive ethanol fumes.

4) A final disadvantage of on-farm production of fuel ethanol is the incompatability of the current inventory of engines, with alcohol. Conversion of the tractors, combines, stationary engines, etc. to engines, which will burn alcohol effectively is a formidable and costly obstacle.

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APPENDIX 1

CAPITAL INVESTMENT (6,000 AND 12,000 GALLON PLANTS)

	Price/Unit	Total Costs
Building and Fixtures		
40' X 50' Building		$16,000
Insulation (924 ft.^{2})		1,840
20 footings for tanks		300
Ventilation System		
Acme Jet System		1,800
Exhaust Fans		1,500
Heating System		500
Subtotal (6,000 gallon plant)		$21,940
Substrate Storage		
Wooden Bin (200 bushel) & Measuring Box		$ 400
Substrate Handling Equipment		
3" 15 ft. auger and motor	$500	$ 500
Cooking and Fermentation Vats		
2 - 1500 gal. steel fermentation tanks	$600	$ 1,200
1 - 1500 gal. cooking tank	600	600
3 - Meters and agitators	350	1,050
3 - Steam rings	100	300
Subtotal		$ 3,150
Plumbing, Pumps, Liquid Distribution & Water Storage		
1 - Feed pump	$700	$ 700
1 - Feed pump motor	200	200
1 - Mass transfer pump	500	500
Plumbing and pipes for feed transfer		3,500
2 - Overhead water tanks - 2,000 gal.	950	1,900
Plumbing and valves for overhead tanks		1,000
Subtotal		$ 7,800

Stripping and Distillation Column Parts	$ 2,500
Heat Exchanger & Condenser	
1 - Mass heat exchanger	$ 4,500
1 - Condenser/Preheater	500
Subtotal	$ 5,000
Sealed Pre-denaturing Tank	$ 600
Storage for Denatured Alcohol	
4500 gal. Tank	$ 1,425
Yeast Culture Equipment	$ 150
Enzyme Storage Refrigerator - Used	$ 50
Stillage Extraction Equipment - Sump pump & piping	$ 100
Control Equipment	$ 500
Boiler & Supporting Equipment	$ 7,480
Water Treatment Unit (water softener)	$ 700
Steam Distribution System	$ 1,000
Subtotal	$31,355
Estimated Labor Cost to Assemble & Install Equipment	$20,900
TOTAL (6,000 gallon operation)	$74,195

The 12,000 gallon per year operation is identical except for additional ventilation capacity required for summer operations at a cost of $1,500.

TOTAL (12,000 gallon operation)	$75,695

CAPITAL INVESTMENT (20,000 AND 40,000 GALLON PLANTS)

	Price/Unit	Total Costs
Building and Fixtures		
40' X 50' Building		$16,000
Insulation (924 ft^2)		1,840
40 footings for tanks		600
Ventilation System		
Acme Fan Jet System		1,860
Exhaust Fans		1,500
Heating System		500
Subtotal (20,000 gallon operation)		$22,300
Substrate Storage		
1 - 300 Bushel Bulk Bin	$1,000	$ 1,000
1 - Bottom Scale	1,500	1,500
Subtotal		$ 2,500
Substrate Handling Equipment		
1 - 4" 15 ft. auger and motor	$ 500	$ 500
Cooking and Fermentation Vats		
7 - 1500 gal. steel fermentation tanks	$ 600	$ 4,200
1 - 1500 gal. cooking tank	600	600
8 - Motors and agitators	350	2,800
8 - Steam rings	100	800
Subtotal		$ 8,400
Plumbing, Pumps, Liquid Distribution, and Water Storage		
2 - Feed pumps	$ 700	$ 1,400
2 - Feed pump motors	200	400
2 - Mass transfer pumps	500	1,000
Plumbing and piping for feed transfer		6.000
2 - Overhead water tanks - 2,000 gal.	950	1,900
Plumbing and valves for overhead tanks		1,000
Subtotal		$11,700

Stripping and Distillation Column Parts	
Column materials	$ 2,500
Heat Exchangers and Condensers	
1 - Mass heat exchanger (cool mash)	$ 4,500
1 - Mass heat exchanger (cool fermentor)	2,500
1 - Condenser/preheater	500
Subtotal	$ 7,500
Sealed Pre-denaturing Tanks	$ 600
Storage for Denatured Alcohol	
8,200, 4,500, and 2,100 gallon tanks	$ 4,615
Metered Pump	$ 1,200
Yeast Culture Equipment	$ 300
Enzyme Storage - 2 Refrigerators - Used	$ 200
DDG Extraction Equipment - Sump pump and piping	$ 100
Control Equipment	$ 1,000
Boiler and Supporting Equipment	$ 7,480
Water Treatment Unit - Water Softener	$ 700
Steam Distribution System	$ 1,000
Subtotal	$50,295
Estimated Labor Cost to Assemble and Install Equipment	$33,500
TOTAL (20,000 gallon operation)	$106,095

The 40,000 gallon per year operation is identical to the 20,000 gallon operation except that more ventilation capacity is required for summer operations at a cost of $1,500.

TOTAL (40,000 gallon operation)	$107,535

APPENDIX 2

VARIABLE INPUTS

Variable inputs are defined as inputs which remain relatively constant per unit of output but vary during a production period with total output. Certain inputs were identified as inputs per bushel or ton of substrate used. Others were identified as inputs per gallon of output. Costs per bushel or ton are converted to cost per gallon by dividing the cost by the ethanol yield per bushel or ton. Following are the variable cost items identified in this study. These prices were obtained in late 1979. Most will have risen.

Yeast, enzymes, and chemicals	Quantity/batch (40 bushels)	Price/lb
Yeast inoculant	1 lb	$1.39

Yeast culture nutrients

Substance	Quantity/batch (40 bushels)	Price/kg (1000 gm)
Potassium phosphate monobasic	160 gm	$2.03
Epsom salts	40 gm	.87
Ammonium chloride	480 gm	2.35
Slake lime	800 gm	.15
Sugar	800 gm	.56

Enzymes

Substance	Quantity/batch (40 bushels)	Price/lb
GBFI - Dexlo XC	1.4 lb	$ .63
GBFI Enzyme Blend	3.7	1.52

pH control

Substance	Quantity/batch (40 bushels)	Price/lb
Propionic acid	1.6 lb	$ .335
Caustic soda	0.64 lb	.335

Boiler fuel - LP Gas

Price	$ .486/gal
Gross BTU's	94,500/gal
Boiler system efficiency	85%
Steam requirements per gallon of alcohol (1000 BTU's/lb of steam)	45,000 BTU's

Water softening salt

Salt requirements	3 lbs/1000 gal H_2O
Water requirements	16.0 gal/gal ethanol

Substrate $2.64/bu

Labor - 6,000 and 12,000 gallon operation

Labor will be required for the following activities. Breaking down to individual jobs is arbitrary because of overlapping of plant operations.

	Hours per batch
Feed preparation (set up, grind, haul, unload)	0.2
Heat, cook, add enzymes, cool substrate	a/
Fermentation monitoring	2.0
Disillation and stillage removal	6.0
Yeast preparation	0.5
Steam plant operation	a/
TOTAL HOURS PER BATCH	8.7

Labor - 20,000 and 40,000 gallon operation

Feed preparation (set up, grind, haul, unload)	0.2
Heat, cook, add enzymes, cool substrate	a/
Fermentation monitoring	2.0
Distillation and stillage removal	6.0

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a/ To be performed while monitoring distillation.

Yeast preparation	0.5
TOTAL HOURS PER BATCH	8.7

Utilities - Cost per Batch

Electricity (@ $.04/kwh)

Used	104 kwh/batch
Cost	$4.16/batch

Water (@ $.05/1000 gallons)

Used	1280 gal/batch
Cost	$ .06/batch

Item 8 - Feed By-Product Credit[a/]

Quantity of stillage produced per bushel of grain	17.4 lbs (dry weight)
Value of stillage from least cost ration information (shadow price)	$ .07/dry lb
Value of stillage discounted for extra cost of handling high moisture material	$ .06/dry lb

Interest on Working Capital - 6,000 Gallon Operation

Value of average alcohol inventories	
Average alcohol fuel inventory for year	2400 gal
Sum of costs (less by-product credit) on summary page except plant fixed costs and substrate cost per gallon ethanol	$1.21
Substrate cost per gallon ethanol	$1.32
Proportion of year alcohol will be held beyond the normal length of time grain is held	.5
Value of normal fuel inventories	
Average fuel inventory for year	300
Average cost of fuel	$ .909/gal
Annual interest rate of working capital	11%

[a/] See Appendix 5 for more detailed explanation of the stillage calculation.

Cost of average alcohol inventories

$1.21 cost/gal eth. (excluding amortized plant and substrate costs) x 2400 gal eth. inv. x 11% interest/yr = $319 interest on "other" costs

$1.32 substrate costs/gal eth. x 2400 gal av. eth. inv. x .5 frac. yr. eth. held x 11% interest/yr. = $174 interest on substrate cost

Total cost of fuel inventories = $493 interest cost eth. inv.

Reduced cost of conventional fuel inventories

$.909/gal fuel x 300 gal av. fuel inv. x 11% interest/yr = $ 30 interest on fuel inv.

Net interest on working capital

$493 interest cost on eth. inv.--

$ 30 interest on fuel inv. = $463 net interest on eth.

$463 net interest on eth. ÷ 6000 Total gal eth./yr = $.08/gal eth.

Interest on Working Capital - 12,000 Gallon Operation

Value of average alcohol inventories

Average inventory	2400 gal
Sum of costs (less by-product credit) on summary page except plant fixed costs and substrate cost per gallon ethanol	$ .88
Substrate cost per gallon ethanol	$1.32
Proportion on year alcohol will be held beyond the normal length of time grain is held	.5

Value of normal fuel inventories

Average fuel inventory for year	300
Average cost of fuel	$.909/gal
Annual interest rate on working capital	11% interest/yr

Cost of average alcohol inventories

$.88 cost/gal eth. (excluding amortized plant and substrate costs) x 2400 gal eth. inv. x 11% interest/yr = $232 interest on other costs

$1.32 substrate costs/gal eth. x 2400 gal av. eth. inv. x .5 frac. yr eth. held x 11% interest/yr = $174 interest on substrate cost

Total cost of fuel inventories $406 interest cost eth. inv.

Reduced cost of conventional fuel inventories

$.909/gal fuel x 300 gal av. fuel inv. x 11% interest/yr = $ 30 interest on fuel inv.

Net interest on working capital

$406 interest cost on eth. inv. -- $ 30 interest on fuel inv. = $376 net interest on eth.

$376 net interest on eth. ÷ 12,000 total gal eth./yr = $.03/gal eth.

Interest on Working Capital - 20,000 gallon operation

Value of average alcohol inventories

Average inventory	8,000 gal

Sum of costs (less by-product credit) on summary page except plant fixed costs and substrate cost per gallon ethanol	$ .78
Substrate cost per gallon ethanol	$1.32
Proportion of year alcohol will be held beyond the normal length of time grain is held	1/2

Value of normal fuel inventories

Average fuel inventory for year	900
Average cost of fuel	$.909

Annual interest rate on working capital	11%/yr

Cost of average alcohol inventories

$.78 cost/gal eth. (excluding amortized plant and substrate costs) x 8,000 gal eth. inv. x 11% interest/yr = $686 interest on "other" costs

$1.32 substrate costs/gal eth. x 8,000 gal av. eth. inv. x .5 frac. yr eth. held x 11% interest/yr = $581 interest on substrate cost

Total cost of other fuel inventories = $1267 interest cost eth. inv.

Reduced cost of conventional fuel inventories

$.909/gal fuel x 900 gal av. fuel inv. x 11% interest/yr = $ 90 interest on fuel inv.

Net interest on working capital

$1267 interest cost on eth. inv. -- $ 90 interest on fuel inv. = $1177 net interest on eth.

$1177 net interest on eth. ÷ 20,000 total gal eth./yr = $ .06/gal eth.

Interest on Working Capital - 40,000 gallon plant

Value of average alcohol inventories

Average alcohol fuel inventory for year	8,000 gal
Sum of costs (less by-product credit) on summary page except plant fixed costs and substrate cost per gallon ethanol	$ .65
Substrate cost per gallon ethanol	$1.32
Proportion of year alcohol will be held beyond the normal length of time grain is held	.5

Value of normal fuel inventories

Average fuel inventory for year	900
Average cost of fuel	$.909

Annual interest rate on working capital 11%

Cost of average alcohol inventories

$ .65 cost/gal eth. (excluding amortized plant

and substrate costs) x 8,000 gal eth. inv. x

11% interest/yr = $ 572 interest on "other" costs

$1.32 substrate costs/gal eth. x 8,000 gal

av. eth. inv. x .5 frac. yr. eth. held x

11% interest/yr = $ 581 interest on substrate cost

Total cost of other fuel inventories = $1153 interest cost eth. inv.

Reduced cost of conventional fuel inventories

$.909/gal fuel x 900 gal av. fuel inv. x

11% interest/yr = $ 90 interest on fuel inv.

Net interest on working capital

$1153 interest cost on eth. inv. --

$ 90 interest on fuel inv.	= $1063 net interest on eth.
$1063 net interest on eth. ÷ 40,000 total gal eth./yr	= $ .03/gal eth.

Appendix 3

STILLAGE EVALUATION

The stillage is valued through the use of a computerized ration formulation model. The model has been placed on the AgNet system and is accessible by remote terminal throughout Nebraska, Iowa, North Dakota, South Dakota, Wyoming, Montana, and other states. The model, which computes least-cost rations for various classes of livestock, was developed by animal scientists and agricultural economists. The user can insert feedstuffs specific to his situation and the computer will specify the lowest cost ration to fulfill the nutritional requirements of the designated animals. The nutrient analysis of a feedstuff, not on the basic data file, can be inserted and the feedstuff be evaluated. A high cost is placed on the feedstuff to insure that it will not enter the solution. The printout then indicates the price at which the feed would enter the solution and in what amounts. This "shadow price" is the value of the feedstuff in relation to the other feedstuffs available at the prices specified.

Before the wet stillage could be evaluated, its nutrient analysis had to be determined. The nutrient analysis of stillage is affected by variations in the proportions of the starch which are converted to ethanol. The published nutrient analysis for the feed by-product of alcohol plants refers to DDG from large plants with ethanol yields of approximately 2.5 gallons of ethanol per bushel of corn. The assumed yield for the plants in this study is 2.0 gallons per bushel, resulting in stillage with a larger proportion of starch. The assumption was made that the same proportion of the protein would remain in solution as in the by-product of large plants. Guyer and Klopfenstein[1] indicated that about 40 percent of the protein would be in the solubles and 60 percent in the DDG portion. All of the unconverted starch, about eight pounds per bushel, is assumed to remain in the solids portion.

Based on these assumptions and interpolating from the nutrient analysis of commercial DDG and of corn, the wet solids from the model plants contain 18.6 percent crude protein, on a dry basis, with 17.4 pounds of dry matter per bushel of grain. The portion retained for feeding is assumed to be 82.5 percent moisture. The solubles contained in the liquid portion (the 82.5% moisture) are included in the 17.4 pounds of feed. The dry weight of solubles fed amounts to 5 percent of the 82.5 percent liquid portion. The following table contains the assumed nutrient analysis of the wet stillage.

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[1] Guyer, Paul G. and Terry Klopfenstein. "Distillers Feeds for Livestock." Agricultural Notebook - Livestock Letter. (Cooperation Extension Service - University of Nebraska - Lincoln) 1979.

Table 1. Nutrient Analysis of DDG and Corn and the Assumed Nutrient Analysis of Wet Stillage.[a/]

Feedstuff	Crude Protein %	NEG Mcal/16	TDN %	CA %	P %	K %	Fiber %
DDG	29.7	.600	84.0	.100	.430	.18	12.80
Wet Stillage	18.6	.639	87.9	.055	.368	.25	6.83
Corn	10.0	.670	91.0	.020	.320	.31	2.20

[a/] The nutrient analysis for DDG and corn were extracted from Terry Klopfenstein and Paul Guyer. "Distillers Feeds for Livestock." Agricultural Notebook - Livestock Letter Cooperative Extension Service. University of Nebraska at Lincoln, Lincoln, Nebraska. May 8, 1979. The nutrient analyses of the wet stillage is interpolated from the analysis of DDG and corn.

The above data were inserted into the model specifying high producing dairy cows. This enterprise was chosen because a) the form of the protein is better for ruminants as compared to swine or poultry, b) diary cows require large quantities of bulk and of water, and c) personnel must be present day in and day out throughout the year as is also true of the ethanol plant.

Assumptions concerning the availability and prices of feedstuffs were entered into the computer, as follows: corn at $2.50 per bushel; soybean meal (solvent extracted) at $220 per ton; alfalfa hay at $40.000 per ton; limestone at $40 per ton; phosphorus dicalcium at $205 per ton; trace mineralized salt at $35 per ton; vitamin A at $100 per hundred weight; corn silage at $21 per ton; corn molasses at $98 per ton; and phosphorus monosodium at $550 per ton. From these data the computer model specified a least cost-ration, as follows: 51.92% corn, 9.65% soybean meal, 37.48% alfalfa hay, 0.06% limestone, 0.4% phosphorus dicalcium, 0.4% trace mineral salt, and 1.0% Vitamin A. The model further indicated that the stillage would enter at a price of $20.80 per ton, wet basis, $138.67 ton dry basis, or about $.07 per pound of dry matter. When inserted at this value, about 8 pounds of stillage, dry basis, would be fed per cow, per day. Corn, soybean meal, and alfalfa hay were all reduced. At this rate, one bushel of corn would provide slightly more than enough stillage for two cows for one day. The 6,000 and 12,000 gallon plants consume 120 bushels per week which would provide the required amount for thirty-four cows. The 20,000 and 40,000 gallon plants would process 400 bushel of corn per week and provide enough stillage for 114 cows.

APPENDIX 4

ABBREVIATED AMORTIZATION TABLES

Table 1. Present Value of a Uniform Series Factors.

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

$$Vo = A\,[\text{Table 1 Factor}]i,n$$

Vo = Present value at series

A = Annuity amount

i = Interest or discount rate per time period

n = Time period

				i				
n	8	9	10	11	12	14	16	18
5	3.993	3.890	3.791	3.696	3.605	3.433	3.274	3.127
10	6.710	6.418	6.145	5.889	5.650	5.216	4.833	4.494
15	8.559	8.061	7.606	7.191	6.811	6.142	5.575	5.092
20	9.818	9.129	8.514	7.963	7.469	6.623	5.929	4.353

Table 2. Present Value of a Single Payment.

$$Vo = Pn\ (1 + i)^{-n}$$

$$Vo = Pn\ (\text{Table Factor})i,n$$

Vo = Present value

Pn = Future payment

i = Interest or discount rate per time period

n = Time period

				i				
n	i	9	10	11	12	14	16	18
5	.681	.650	.621	.593	.567	.519	.476	.437
10	.463	.422	.386	.352	.322	.270	.227	.191
15	.315	.275	.239	.209	.183	.140	.108	.084
20	.215	.078	.149	.124	.104	.073	.051	.037