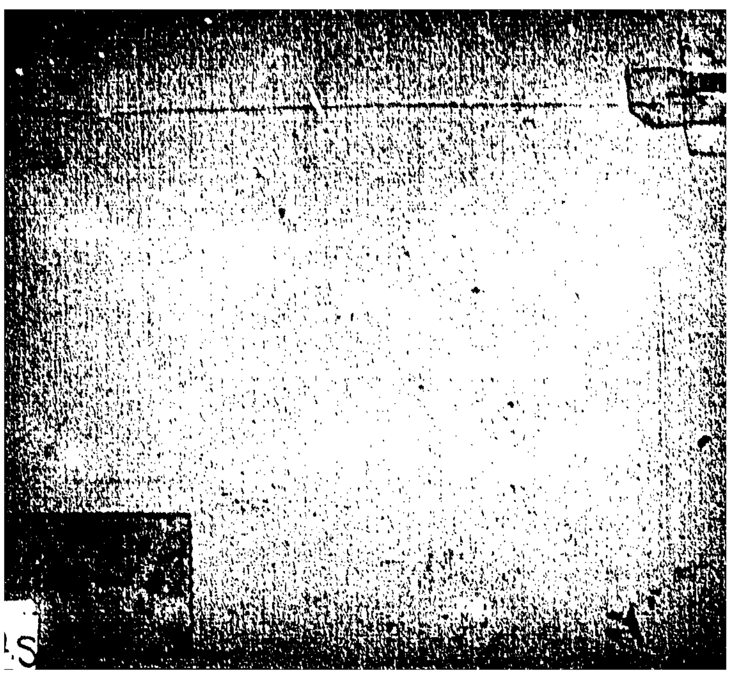

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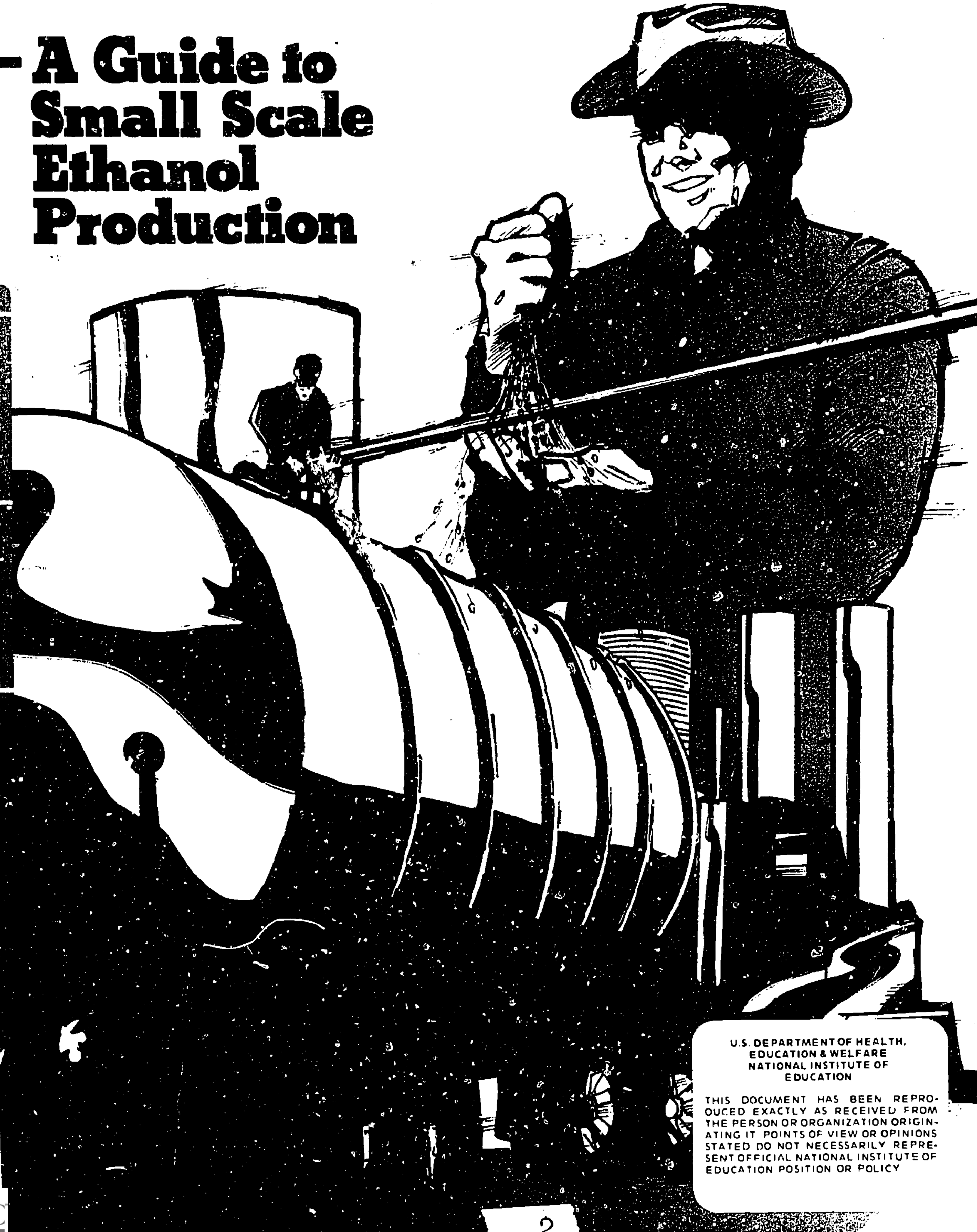
ABSTRACT

Ethanol and blends of ethanol and gasoline (such as gasohol) offer a near-term fuel alternative to oil. The focus of this handbook is upon the small-scale production of ethanol using farm crops as the source of raw materials. Provided are chapters on ethanol production procedures, feedstocks, plant design, and financial planning. Also presented are decision and planning worksheets and a sample business plan for use in determining whether or not to go into ethanol production. Emphasis is on providing the facts necessary to make informed judgments rather than recommending particular production processes. (Author/WB)

Fuel from Farms

– A Guide to Small Scale Ethanol Production



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FUEL FROM FARMS

A Guide to Small-Scale Ethanol Production

A Product of the
Solar Energy Information Data Bank

Solar Energy Research Institute
Operated for the U.S. Department of Energy by the
Midwest Research Institute

Under Contract No. EG-77-C-01-4042

February 1980

Department of Energy
Washington, D.C. 20545

Farms and businesses all across the nation can take part in one of the most exciting endeavors of this new decade. We are in the midst of a transition from an economy that is dependent on oil to alternative sources of fuels. Ethanol and blends of ethanol and gasoline, such as gasohol, offer a near-term alternative. The Administration's recently announced gasohol program will spur the investments that we together must make for a more secure energy future. We will create new markets for our farmers. We will no longer have to throw away waste materials which can be turned into profitable essential fuels.

A part of our effort to increase the production of ethanol will stress dissemination of technically-sound information on the production and use of ethanol. The Department of Energy and the Solar Energy Research Institute is providing current information on ethanol production and uses in the future. This guide to small-scale ethanol production is the beginning of a series of publications for alcohol production.

You can obtain additional copies of "Fuel From Farms" from:

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T. E. Stelson,
Assistant Secretary
Conservation and Solar Energy

TES/dje

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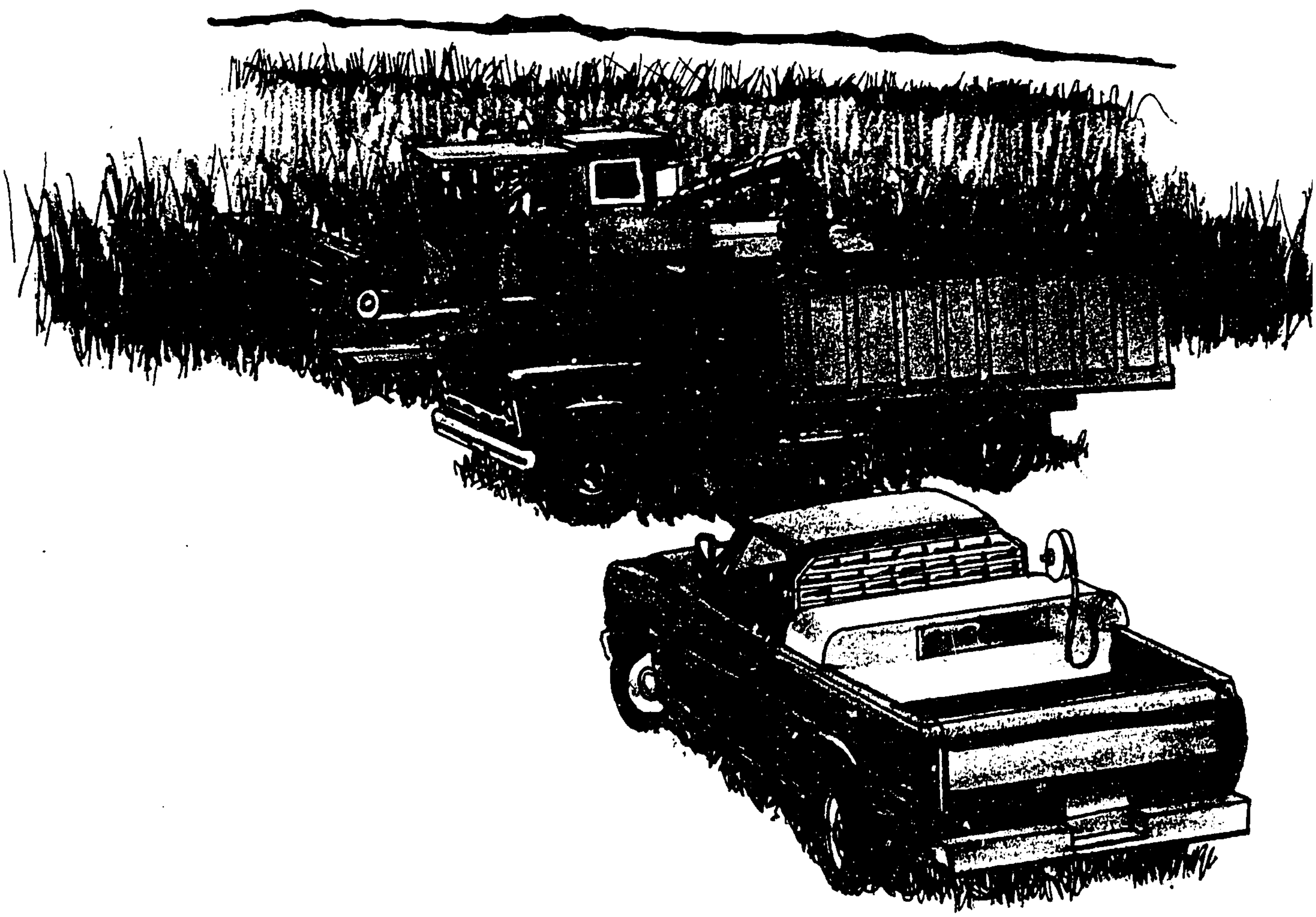
CHAPTER I

Introduction



CHAPTER I
Introduction

OBJECTIVE

The expanding support for gasohol in this country over the last several years provides an opportunity to directly reduce U.S. oil imports in the very near future. Interest is evident by the many requests for information about gasohol that are being received throughout the federal government daily. This guide has been prepared to meet the challenge of filling the information void on fermentation ethanol in a balanced, reasoned way, with emphasis on small-scale production of fermentation ethanol using farm crops as the source of raw materials. It is addressed not only to those in the U.S. farming community who may wish to consider the production of ethanol as part of their normal farming operations, but also to owners of small businesses, investors, and entrepreneurs.

This guide presents the current status of on-farm fermentation ethanol production as well as an overview of some of the technical and economic factors. Tools such as decision and planning worksheets and a sample business plan for use in exploring whether or not to go into ethanol production are given. Specifics in production including information on the raw materials, system components, and operational requirements are also provided. Recommendation of any particular process is deliberately avoided because the choice must be tailored to the needs and resources of each individual producer. The emphasis is on providing the facts necessary to make informed judgments.

PERSPECTIVE

Foreign crude oil imports currently provide the raw material for production of half of the liquid fuels consumed in the United States and represent a cash outflow of almost $8 million per hour. Recent events have dramatically illustrated the substantial economic cost, instability, and economic vulnerability of such imports. Ethanol is a liquid fuel that can substitute domestic renewable resources for petroleum products now and increasingly in the next few years.

Fermentation ethanol is becoming the first nonpetroleum fuel to attain widespread use in the United States. This trend is apparent from the rapid increase in the sale of gasohol, a blend of 10% agriculturally derived anhydrous ethanol and 90% unleaded gasoline. As of late 1979, the market had expanded to more than 2,000 outlets in 35 states. Gasohol can be readily substituted for unleaded gasoline in current vehicles with no engine adjustments and little or no change in engine performance.

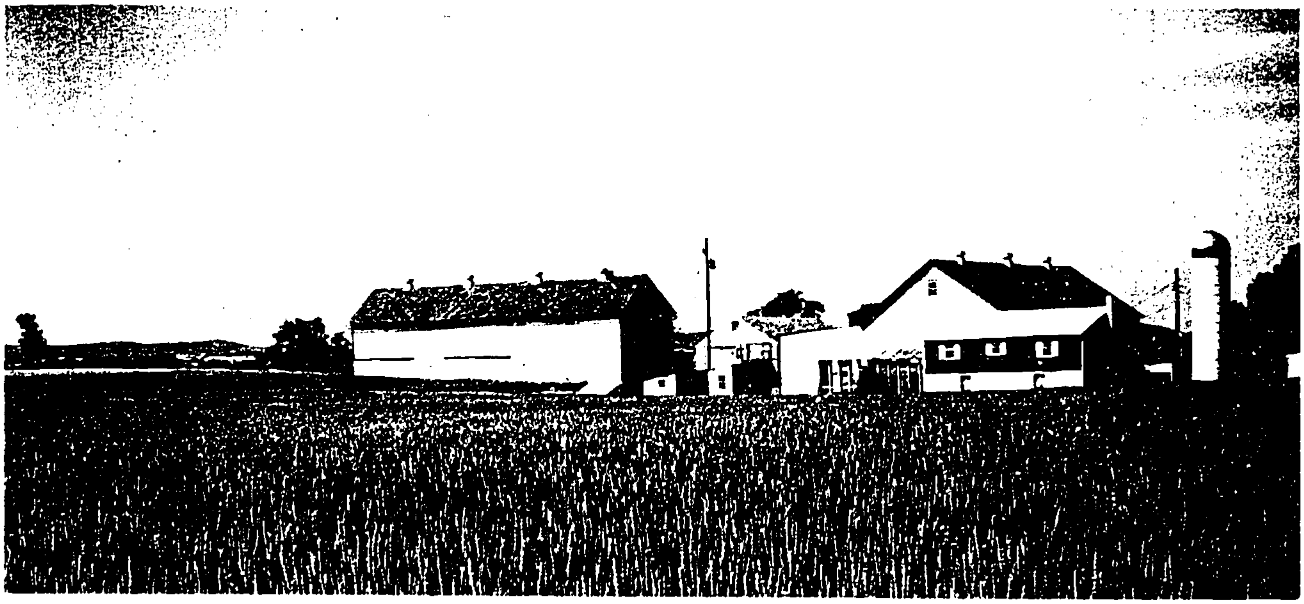
The petrochemical market for fermentation ethanol, while considerably smaller than the automotive fuel market, is also substantial. Thirty percent of the bulk of industrial-grade ethanol is produced from a petroleum derivative and hence is also a potential candidate for displacement by fermentation ethanol.

The production of ethanol from grain leaves behind a protein-rich stillage. This stillage, used in conjunction with straw, permits reduction in the use of hay and grain, and becomes an excellent, nutritive source of animal feed. Dried stillage, in turn, can also be exported as feed with practically no loss in commercial value.

The supply of ethanol is still limited. Essentially, all of the ethanol used in gasohol is currently obtained from a few producers, in spite of the expanding market. However, the production intended for automotive uses is increasing. In early 1979, production of ethanol for gasohol was at a rate of 30 million gallons annually. It is expected that by the end of 1980 this will increase quite significantly.

Existing and proposed federal and state incentives for fermentation ethanol production and use have contributed to the rapid expansion of the gasohol market. In addition, a broad spectrum of options is currently being pursued at the federal level to help accelerate the commercialization of gasohol by stimulating both its production and uses. Maximizing ethanol production will require a mix of various sized ethanol plants. Because of the lag time involved in building and operating larger facilities, it is critical to provide basic information to individuals interested in constructing small-scale facilities—since they can be built most quickly.

The production of fermentation ethanol is based on established technology, and a variety of raw materials is available from the agricultural sector to more than meet projected demands. Fermentation ethanol can be produced from such crops as corn, wheat, sugarcane,



Small-Scale Ethanol Production can be Readily Incorporated into Farm Operations

potatoes, cassava, beets, and Jerusalem artichokes; from agricultural byproducts and wastes; and from cellulose. In short, whatever can be broken down to sugars can become a primary material for fermentation. Thus, the variety of raw materials is quite large. These crops as well as distressed grains are ideal for the production of fermentation ethanol and do not affect the availability of food supplies.

The United States has the potential for growing grains and other crops well in excess of the requirements for domestic and export markets. Economic factors have consequently played a major role in the institution of "set-aside land" and "land diversion" programs by the U.S. Department of Agriculture (USDA). However, growing grain or other crops on this land for fuel production would not detract from the production of food. Rather, if properly utilized, it would constitute a resource that would otherwise have been left idle. Furthermore, the crops grown on this land can still be held in reserve for emergency food, should that become necessary. In 1978, for example, the USDA has certified that the amount of cropland left fallow was 13.4 million acres under the set-aside program and an additional 5.3 million acres under the diversion program. If this acreage had been cultivated with corn for ethanol production, nearly 3.03 billion gallons of ethanol and 10 million tons of distillers' dried grains (DDG) could have been produced. (This assumes a modest average yield of 65 bushels of corn per acre per year with an average production of 2.5 gallons of 200-proof ethanol and 17 pounds of DDG per bushel of corn.) This is only ethanol produced from land left idle through two specific farm programs. The production of fermentation ethanol is not limited by the extent of this land, and additional unused land as well as some land currently under cultivation can be used for crops for production of fermentation ethanol. All this makes the production of ethanol even more promising, and a conservative estimate for the potential displacement of petroleum is at least several billion gallons per year in the near term.

Belt tightening alone will not help the United States solve the present economic difficulties. Farmers, like everyone else, do not like austerity programs and would rather increase our national wealth. This can be achieved by increasing productivity—the production of more goods and services from every barrel of oil we use and development of new sources of energy.

Clearly, the agricultural sector has a role whose full potential is just beginning to be realized. A farm-based fermentation ethanol industry can provide a decentralized system of fuel production and a measure of energy self-sufficiency for the farm community. This can be accomplished as an integral part of normal farming operations following sound agricultural practices.

The technology for ethanol production has existed for centuries. In the early 1900's, Henry Ford and others in the U.S. auto industry used ethanol as the fuel for automobiles. Ultimately, it was replaced by gasoline, which was much cheaper. Today, the tables appear to be turning once again, this time in favor of fuel derived from renewable domestic resources. There are, however, several underlying issues related to fermentation ethanol production that must be examined.

ISSUES

In addition to the need to increase the number of ethanol production facilities, there is the concern about the impact of ethanol production on agriculture. The production of more ethanol than is obtainable from surplus and distressed crops will require cultivation of land that is currently fallow and shifts to specialized high-yield crops. The switch to such crops may allow a decrease in use of fertilizers, pesticides, and herbicides, whose production and transport require petroleum fuels and natural gas. This diversification of crops itself offers specific advantages to the farmer, not least of which may be modifications of agricultural practice and new patterns of crop rotation to improve soil fertility. Nongrain forage crops need less fertilizer, herbicides, and pesticides than high-yield grain crops. As commercial processes become available for the small-scale conversion of these crops to ethanol, the opportunity will exist to decrease demands on the soil to achieve production of equivalent value to current crops.

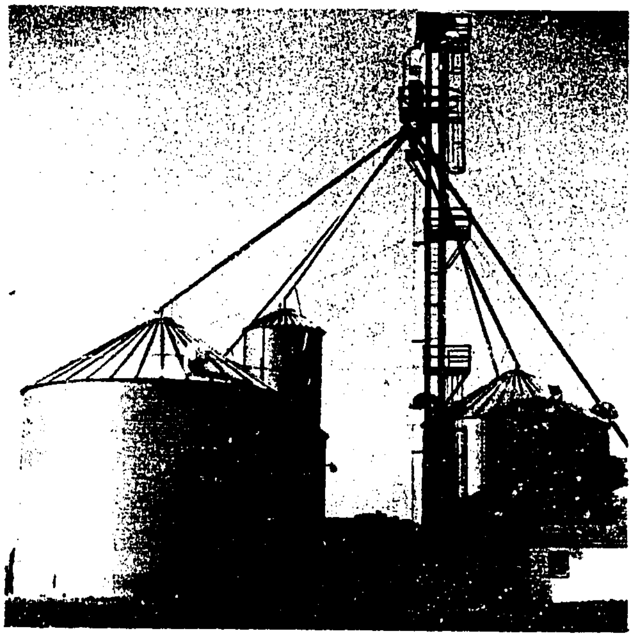
The energy balance of ethanol production and use is a controversial subject. Whether one achieves a net energy gain or loss in ethanol production depends upon where the energy boundaries are drawn and the assumptions used. Examples of alternative means of determining the energy balance in ethanol production are given in Appendix D.

Conversion of crops with significant human food value to fuel is not desirable. Fortunately, production of fermentation ethanol does not make this an "either-or" consideration. Much of the cereal grain (including most of the corn) currently produced in the United States is used as animal feed. While fermentation of cereal grains to produce ethanol uses most of the carbohydrates, almost all of the protein is recovered in the stillage coproduct. This stillage can be fed directly to animals as a high-protein source, and other nutritional requirements can be filled using forages which have no value as human food. This consideration, along with the use of spoiled perishable crops, distressed crops, and marginal crops, provides a feedstock base for ethanol production that requires no displacement of crops for human food.

Since stillage is considered an animal feed replacement for soybean meal (on a protein equivalence basis), there is legitimate concern about its impact on the soybean meal market. However, this concern has to be viewed in the proper perspective. First, the use of soybean meal and cotton seed meal for animal feed was developed after World War II. Their use changed the entire animal feed pattern in the United States and, in the process, displaced grains such as corn, oats, wheat, barley, and high-quality hay. Second, from the general viewpoint of the farm community, agricultural products must be able to compete for markets on an equal footing. Consequently, if stillage proves to be economically and nutritively more attractive than soybean meal, markets for it must be allowed to develop normally. One can thus predict a healthy readjustment of farm production to a new set of conditions that will develop with the introduction of fermentation ethanol.

Another issue is anhydrous ethanol versus hydrated ethanol production. Anhydrous ethanol is more costly and energy intensive to produce than lower proof ethanol. However, if the ethanol is to be sold to blenders for use in gasohol, the ability to produce

There Is Sufficient Land Available to Produce the Quantity of Crops Needed to Achieve Ethanol Production Goals



Small-Scale Ethanol Production can Take Advantage of the Types of Crop Storage and Handling Equipment Already in use on the Farm

anhydrous ethanol is mandatory. Hydrated ethanol may be produced for on-farm use or for use in topping cycles.

A final but important issue of concern is the economics of small- and large-scale production of fermentation ethanol. In most production processes, substantial economies-of-scale are realized with higher plant capacity. However, in the case of on-farm fermentation ethanol production, certain economies-of-scale are also present for small-scale production (e.g., lower transportation and capital costs) which may balance the economic advantages of large-scale plants. As a result, small-scale production of ethanol may possibly be achieved with product costs comparable to those from larger plants. Thus, there appears to be a future role for both small- and large-scale plants for the production of fermentation ethanol.

GUIDE TO THE DOCUMENT

A detailed consideration of the several factors briefly discussed above is presented in the six chapters and appendices that follow.

A decision process to determine the feasibility of on-farm production of ethanol is developed in Chapter II, with emphasis on the market for ethanol and what must be done to participate in it profitably. The sequential steps involved in this process are presented in planning and decision worksheets.

Ethanol production operations are described in Chapter III to indicate how the conversion of agricultural products proceeds through the various stages. Feedstock considerations are discussed in Chapter IV with particular attention to alternate crops, their ethanol yield potentials, and overall implications of their respective agricultural requirements. Ethanol plant design considerations are treated in detail in Chapter V. They include (1) farm-related objectives and integration of ethanol production with normal farming operations; (2) plant design criteria and functional specifications; and (3) energy, labor needs, process control, and safety aspects, and the inherent tradeoffs between them. The information developed is then applied to the design of a representative, small-scale fermentation ethanol production plant, with an output of 25 gallons of anhydrous ethanol per hour. All major operational features are addressed, including the requirements for system control, record keeping, and maintenance. This representative plant is intended to serve as a model from which an actual facility can be designed, built, and operated.

Chapter VI follows with a detailed preparation of a business plan for building the 25-gallon-per-hour facility. The business plan draws on information developed in Chapter V. Its purpose is to determine the financial obligations of the farm owner and the profitability of the enterprise, both of which are essential to obtain necessary financing for construction and operation. Alternative sources of financing available to the small-scale farmer are described and their special requirements are identified. As in Chapter V, the material in Chapter VI is intended to serve as a basis from which an actual business plan can be prepared.

The appendices complete the handbook. They provide a description of current regulations and legislation at the federal and state levels concerning fermentation ethanol production; information on plant licensing and bonding requirements enforced by the Bureau of Alcohol, Tobacco, and Firearms; discussion of the environmental considerations that apply to on-farm production of ethanol; reference data and charts; lists of resources, both people and information; a bibliography; and a glossary.

CHAPTER II

Decision to Produce

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CHAPTER II

Decision To Produce

Expanding farm operations to include a fermentation ethanol plant is ultimately a personal decision. Information can be collected and planning tools used to provide a foundation for such a decision. Market uses and assessment for fuel ethanol and stillage as coproducts, production potential, equipment selection, and financial requirements are the four major areas to be considered in this chapter, which, with succeeding chapters as building blocks, is intended to set up the tools for the decision-making process.

Market values can be estimated for all the products and used as a basis for evaluating the profit potential, which can then be examined in relation to the complete farm operation. Direct considerations affecting production potential, such as how much feedstocks can be grown and how much ethanol can be produced, are also examined. The decision and planning worksheets at the end of this chapter can be used as a step-by-step tool for reaching a decision on whether or not to develop a small-scale, on-farm fermentation ethanol plant.

In addition to the direct factors examined in the worksheets there will be intangible considerations, such as a desire for on-farm fuel self-sufficiency.

With Proper Modification, Straight Ethanol can be Used in Either Gasoline- or Diesel-Powered Farm Equipment

BENEFITS

There are three areas in which there are benefits to the farm economy from small-scale, on-farm, ethanol production. These are direct sales, on-farm uses, and indirect farm benefits.

Farm-produced ethanol sold for profit provides an alternative market for farm commodities. It can provide a "shock absorber" for excess production and a "fall back position" if unforeseen events adversely affect crop or yields.

Farming, perhaps more than any other single occupation, offers the opportunity for self-reliance. The on-farm production of ethanol expands this opportunity. Ethanol can be used in farm equipment as a blend with gasoline in spark ignition engines, as anhydrous or hydrated ethanol fuels in modified spark ignition engines, as a blend with diesel fuel in diesel engines, and as a dual-carbureted mixture with water in diesel turbochargers to enhance efficiency. Protein coproducts, such as stillage, can be fed to farm animals as a replacement for other protein sources. Cellulosic coproducts, if sufficiently dry, can be burned as fuel.

Farm overproduction is generally planned to meet anticipated demand in the event of possible reductions in crop yield. However, the cumulative result of consistent overproduction in the absence of alternative markets is depressed commodity prices. Consequently, the financial health of many farms depends on the opening of new markets. Fermentation ethanol production provides several alternative markets for a broad variety of farm commodities.

MARKETS AND USES

Ethanol

The use of ethanol for fuel in internal combustion engines is not a new concept. Engines built around the turn of the century used ethanol for fuel. Henry Ford offered automobiles capable of operating on either ethanol or gasoline [1]. With the development of equipment capable of economically extracting and refining petroleum early in this century, gasoline became the more practical fuel and further development of fuel-grade ethanol was shelved. Now that the production from domestic petroleum reserves is becoming more costly and difficult to develop and foreign oil is at a premium, the nation is looking for ethanol to displace some petroleum-based fuels and chemicals.

The forms in which ethanol can be used for fuel are as

- various ethanol-gasoline blends,
- hydrated (lower proof) ethanol,
- straight anhydrous ethanol, and
- dual-carbureted diesel fuel supplement.

Anhydrous Ethanol can be Blended With Gasoline for Direct Use in Unmodified Vehicles

Ethanol-Gasoline Blends. The market for gasohol (a blend of 90% unleaded gasoline and 10% agriculturally derived anhydrous ethanol) is already well established in many parts of the country. It is expected that by the end of 1981 as much as 500 million gallons of ethanol production capacity could be made available to make gasohol, and that within 5 years this quantity could increase three to ten times.

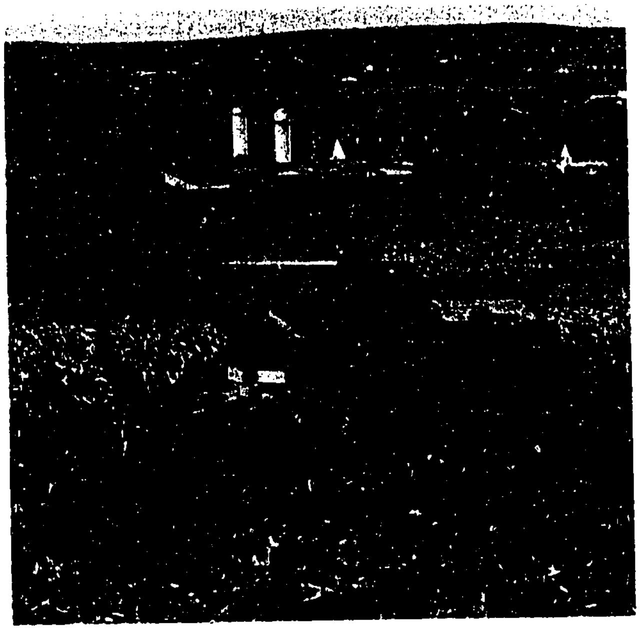
Hydrated Ethanol. Hydrated ethanol can be burned efficiently in spark-ignited internal combustion engines with minor alterations to the engine. Regular motor vehicle engines have been successfully modified to run on to ethanol. The jet size in the carburetor needs to be enlarged slightly when converting from a gasoline to an ethanol-powered engine because ethanol contains less useful thermal energy per unit volume than gasoline. Accordingly, more ethanol than gasoline must be introduced into an engine to generate the equivalent amount of energy. With most engines, it is also necessary to modify the intake manifold to insure proper vaporization of the ethanol so that all cylinders will be operating with equal air-fuel mixtures. There are many possible methods for doing this, such as installing preheaters in the fuel system or enlarging the heat stove on the exhaust manifold, with accompanying adjustment of the heat stove control gate for the higher temperature requirement. However, none of these systems are commercially available. However, problems associated with the burning characteristics of the ethanol-water mixture can complicate performance and become a serious impairment as the concentration of water increases.

Anhydrous Ethanol. Anhydrous ethanol can be burned directly in spark-ignition engines using essentially the same engine modifications discussed above for the use of hydrated ethanol. However, hydrated ethanol is less costly and it is not likely that anhydrous ethanol would find extensive use as motor fuel. Its primary use is likely to be as an additive to gasoline to produce gasohol.

In the United States, gasohol usage has been demonstrated in a large number of tests to be a motor fuel essentially equivalent to gasoline. Gasohol does have less total thermal energy per unit volume than gasoline, however, no significant decrease in terms of "miles per gallon" results from the use of gasohol.

The addition of ethanol to gasoline increases the octane rating of the mixture because anhydrous ethanol is a high-octane fuel. In the past, the octane of fuels was increased by adding tetraethyllead. Because the lead compounds have significant adverse impacts on the environment, the conversion to unleaded gasoline was mandated. The changes in refinery operations that are required to produce fuel of the same octane without lead reduce the quantity of fuel that can be produced from a barrel of crude oil. This is because the chemical constituency of the gasoline is altered by reforming lower hydrocarbons to increase the percentage of octane-boosting aromatic compounds. This reforming process consumes additional energy in the refining process—energy directly lost from every barrel processed. The addition of ethanol to gasoline effectively gives the required octane boost and the reforming requirement is correspondingly reduced. This means that every barrel of gasohol produced decreases crude oil demand not only by the quantity of gasoline directly replaced by ethanol, but also by the crude oil saved due to the value of ethanol as an octane enhancer [2].

The use of a mixture of hydrated ethanol and unleaded gasoline can lead to complications. Mixtures of water, ethanol, and gasoline can encounter problems when the three components do not remain in solution. Depending upon the amount of water, the characteristics of the gasoline, and the temperature, two distinct phases can



Corn Stover can be Burned to Provide the Heat Needed for Ethanol Production

separate out. When this separation occurs, the upper phase (layer) is comprised of gasoline and the lower phase (layer) is comprised of water and most of the ethanol. Because the air-fuel requirements are different for the ethanol and gasoline fuels, vehicle operations will not be satisfactory if the fuels separate. Heating and agitating these two phases will cause them to go back into solution, but subsequent cooling will result in phase separation again.

Data from tests on gasohol used in vehicles in Brazil and domestically in Nebraska, Iowa, Indiana, and other states indicate no adverse effects on engine life.

Dual-Carbureted Diesel Fuel Supplement. Diesel engines can operate on separately carbureted ethanol and diesel fuel. When low-quality diesel fuel is used, the amount of ethanol injected is generally less than 25%. When the intent is to reduce "diesel smoke" and increase power, the amount of ethanol used can range as high as 50% [3].

Industrial Chemical Feedstocks. The chemical industry consumes large quantities of ethanol either as a basic feedstock or for use as a solvent. Most of the ethanol currently used by industry is produced from petroleum- or natural gas-derived ethylene. Thus, the cost of ethylene conversion to ethanol is a direct function of petroleum and natural gas costs. As petroleum-derived ethanol costs continue to increase, industrial consumers will look for less expensive sources of ethanol. The current selling price of ethanol produced in this manner is in excess of $1.50 per gallon [4]. These markets are highly localized and generally far removed from rural areas.

The largest industrial chemical markets in the United States are for acetic acid and ethylene because of their wide use in the production of polymers. Acetates (acetic acid polymers) constitute the raw material for synthetic fabrics, plastics, and an enormous variety of common products. Ethanol can be fermented directly to acetic acid (this is what happens when wine turns to vinegar). Acetic acid is also a byproduct of ethanol fermentation. Hence, consideration may be given to recovery of this material.

The pharmaceutical industry also consumes large quantities of ethanol for use as solvent. The quality control requirements for this market are extremely stringent and the costs of producing a pure product (not just anhydrous, but free of fusel oils and other contaminants) is quite high.

Fermentation ethanol has replaced a significant portion of petroleum-derived ethanol in India and Brazil [5, 6]. In fact, ethylene is produced from fermentation ethanol in these countries. Similar programs are being developed in the Philippines, South Africa, Australia, and other countries, and it is reasonable to assume that such a development could also occur in the United States.

Other Uses. Other possible uses of ethanol are as fuel for

- crop drying,
- general heating, and
- electricity generation with small generators.

Coproducts

Stillage can be fed to farm animals as a protein supplement either whole (as produced), wet, solid (screened), or dry. The stillage from cereal grains ranges from 26% to 32% protein on a dry basis. The basic limitation on the amount that can be fed at any one time to an animal is palatability (acid concentration caused by drying makes the taste very acrid). Mature cattle can consume about 7 pounds of dry stillage per day or, roughly, the stillage resulting from the production of 1 gallon of ethanol. The feeding of whole stillage is limited by the normal daily water intake of the animal and the requirements for metabolizable energy and forage fiber. The feeding value to swine and poultry is somewhat limited. Wet stillage cannot be stored for long periods of time, and the lack of locally available herds of animals to consume it may lower its value. Stillage from grains contaminated with aflatoxins cannot be used as animal feed.

The cellulosic coproducts may be directly fermented to produce methane gas or dried for use as boiler fuel.

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Carbon dioxide (CO_2) produced by fermentation can be compressed and sold to users of refrigerants, soft drink bottlers, and others. It also has many agricultural applications which are beyond the scope of this handbook.

MARKET ASSESSMENT

Before a decision to produce can be made, it is necessary to accurately determine if markets for the ethanol and coproducts exist close enough to allow for economical distribution. The size of the market is defined by the quantities of ethanol and coproducts that can be used directly on the farm and/or sold. The ethanol on-farm use potential can be determined from the consumption of gasoline and diesel fuel in current farming operations. Then, a decision must be made on the degree of modification that is acceptable for farm equipment. If none is acceptable, the on-farm use will range from 10% to 20% of the total gasoline consumption. If direct modification to spark ignition equipment is acceptable, the on-farm potential use can be 110% to 120% of current gasoline consumption. If the risks associated with attempting undemonstrated technology are considered acceptable, the ethanol replacement of diesel fuel will be roughly 50% of current diesel fuel consumption [3].

The sale of ethanol off the farm will be dependent upon local conditions and upon the type of Bureau of Alcohol, Tobacco, and Firearms (BATF) license obtained. (Currently, a commercial license from BATF is required for off-farm sale of ethanol.) Market estimates should be based on actual letters of intent to purchase, not an intuitive guess of local consumption.

The on-farm use of stillage must be calculated on the basis of the number of animals that are normally kept and the quantity of stillage they can consume.

The potential for sale of stillage must be computed on the basis of letters of intent to purchase, not just on the existence of a local feedlot. The value of stillage will never exceed the directly corresponding cost of protein from other sources.

Direct on-farm use of carbon dioxide is limited; its principal value may come from sales. If Jerusalem artichokes, sorghum, or sugarcane are used, the bagasse and fiber that remain after the sugar is removed may be sufficient to supply the entire energy requirements of the ethanol plant. This value should be calculated in terms of the next less expensive source of fuel.

PRODUCTION POTENTIAL

Feedstocks

The mix of feedstocks determine in part the actual production potential. Chapter IV discusses the use and production of the various feedstocks individually and in

Stillage can be Used as a Protein Supplement When Mixed With the Proper Quantities of Grain and Forage

combination. The guidance offered in that chapter will help define the sizing of the plant from the viewpoint of output once the potential of the available feedstocks is determined. Additional feedstocks may also be purchased and combined with products available on-site.

Water

Significant amounts of water are used in the ethanol production process (about 16 gallons of water per gallon of ethanol produced). This demand includes requirements for generating steam, cooling, and preparing mashes. Also, it may be desirable to grow a crop not normally produced in the area. If additional irrigation water is necessary for this crop, the increment must be included, but it is likely that stillage liquids can be directly applied to fulfill this need.

Heat Sources

Heat is required in the conversion of feedstocks to ethanol, primarily in cooking, distillation, and stillage drying. An accurate assessment must be made to determine the type and quantity of available heat sources. Waste materials can contribute as energy sources and, from a national energy perspective, the use of petroleum fuels is not desirable. In some cases, other renewable sources of energy such as methane, solar, wind, and geothermal may be used as supplements.

EQUIPMENT SELECTION

The determination of the best equipment that can be obtained to fill the defined production needs is based on the operation's financial constraints and the labor and/or product compromises that can be made. All the options must be considered in relation to each other rather than independently.

The following variables related to equipment selection affect the decision to produce.

Labor Requirements

The availability of labor determines the schedule of plant operations and the degree of automation required. Labor availability is determined from normal farming routine and the disruptions which are tolerable.

Investment/Financing

Financing is a pivotal factor in the decision to produce. The options chosen depend initially upon capital and operating costs (which are in turn dependent upon plant size), and on individual financial situations. The potential income from the operation is the second line of consideration. Though no less important than the first, an inability to qualify for capital financing makes consideration of succeeding concerns a futile exercise.

Maintenance

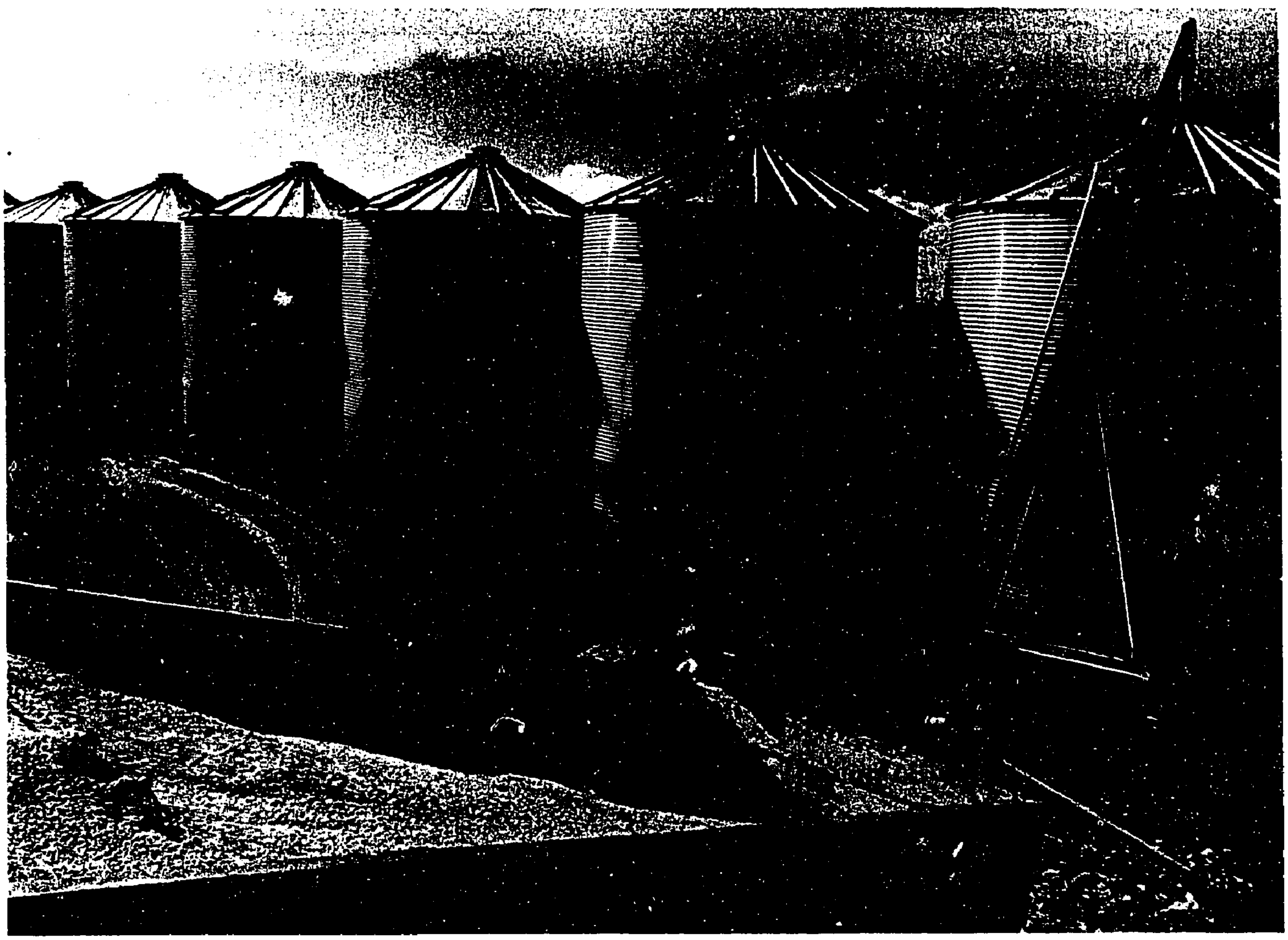
Equipment maintenance varies in relation to the type of component and its use. In general, it can be assumed that the highest quality equipment will cost the most. Critical components should be identified and investments concentrated there. Noncritical or easily replaceable components can be less expensive. Routine maintenance should not interfere with production schedules.

Regulations

State and federal environmental protection standards must be observed. In addition, the Bureau of Alcohol, Tobacco, and Firearms (BATF) bonding requirements and regulations must be met. (See Appendix B for more information.)

Intended Use

Equipment must be selected that is capable of producing the quality, quantity, and form of coproducts dictated by the intended market.



Ethanol Feedstocks can be Stored in Conventional Facilities

Form of Coproducts

The form and amounts of coproducts will dictate the type and size of equipment. If stillage is to be sold in wet form, the only required equipment may be a storage tank. If stillage is to be dried, then screens, driers, and additional dry storage space will be necessary. If carbon dioxide is to be used or collected and sold, equipment for this will be needed.

Safety

Ethanol is extremely flammable and must be handled accordingly. Ignition sources must be isolated from all possible ethanol leaks. This isolation requirement affects either plant layout or equipment selection. The proper handling of acids and bases mandates particular types of construction materials.

Heat Sources

The type or types of fuels available to the operation will dictate the type of equipment necessary to convert this fuel into the required heat source.

Feedstock Mix

The desired feedstock mix will define the feed preparation equipment necessary (e.g., the production of ethanol from corn requires different front-end processing than sugar beets). Since it may be desirable to process more than one feedstock concurrently, additional equipment may be required in the processing step.

FINANCIAL REQUIREMENTS

Considerations to Proceed

Once the considerations for equipment selection are completed, the capital and operating costs may be roughly computed.

The capital cost considerations are:

- equipment,
- real estate and buildings,
- permits and licenses, and
- availability of financing.

The operating costs are:

- labor,
- cost of money,
- insurance,
- chemicals, enzymes, additives,

Agricultural Residue can be Collected in Large Round Bales for Storage

- fuel,
- feedstocks,
- costs of delivery, and
- bonds.

These considerations are then compared to the specific financial situtation of the individual. If the results of this comparison are not acceptable, then other options in equipment specifications and plant size must be considered. If all possibilities result in an unfavorable position, the decision to produce is no. If a favorable set of conditions and specifications can be devised, detailed design considerations should be examined (see Chapter V, Plant Design) and an appropriate organization and financial plan developed (see Chapter VI, Business Plan).

DECISION AND PLANNING WORKSHEETS

The following questions are based on the considerations involved in deciding to proceed with development of a small-scale fermentation ethanol plant. Questions 1-28 are concerned with determining the potential market and production capability; questions 9, 20, and 29-47 examine plant size by comparing proposed income and savings with current earnings; questions 48-53 look at plant costs; questions 54-69 relate to financial and organizational requirements; and questions 71-85 examine financing options.

The final decision to produce ethanol is the result of examining all associated concerns at successively greater levels of detail. Initially a basic determination of feasibility must be made and its results are more a "decision to proceed with further investigation" than an ultimate choice to build a plant or not. This initial evaluation of feasibility is performed by examining: (1) the total market (including on-farm uses and benefits) for the ethanol and coproducts; (2) the actual production potential; (3) the approximate costs for building and operating a plant of the size that appropriately fits the potential market and the production potential; (4) the potential for revenues, savings, or indirect benefits; and (5) personal financial position with respect to the requirements for this plant. There are several points during the course of this evaluation that result in a negative answer. This does not necessarily mean that all approaches are infeasible. Retracing a few steps and adjusting conditions may establish favorable conditions; however, adjustments must be realistic, not overly optimistic. Similarly, completion of the exercise with a positive answer is no guarantee of success, it is merely a positive preliminary investigation. The real work begins with specifics.

Market Assessment

1. List equipment that runs on gasoline and estimate annual consumption for each.

	Equipment	Fuel Consumption	
a.	______	______	gal/yr
b.	______	______	gal/yr
c.	______	______	gal/yr
d.	______	______	gal/yr
e.	______	______	gal/yr
	TOTAL	______	gal/yr

2. List the equipment from Question 1 that you intend to run on a 10%-EtOH/90%-gasoline blend.

	Equipment	Fuel Consumption	
a.	______	______	gal/yr
b.	______	______	gal/yr
c.	______	______	gal/yr
d.	______	______	gal/yr
e.	______	______	gal/yr
	TOTAL	______	gal/yr

(Throughout these worksheets ethanol is abbreviated EtOH)

3. Take the total from Question 2 and multiply by 10% to obtain the quantity of EtOH to supply your own gasohol needs.

______ × 0.1 = ______ gal EtOH/yr

4. List the equipment from Question 1 that you are willing to modify for straight EtOH fuel.

	Equipment	Fuel Consumption	
a.	______________	______________	gal/yr
b.	______________	______________	gal/yr
c.	______________	______________	gal/yr
d.	______________	______________	gal/yr
e.	______________	______________	gal/yr
	TOTAL	______________	gal/yr

5. Take the total from Question 4 and multiply by 120% to obtain the quantity of EtOH for use as straight fuel in spark-ignition engines.

______________ gal/yr × 1.2 = ______________ gal EtOH/yr

6. List your pieces of equipment that operate on diesel fuel.

	Equipment	Diesel Fuel Consumption	
a.	______________	______________	gal/yr
b.	______________	______________	gal/yr
c.	______________	______________	gal/yr
d.	______________	______________	gal/yr
e.	______________	______________	gal/yr
	TOTAL	______________	gal/yr

7. List the equipment from Question 6 that you will convert to dual-injection system for 50% EtOH/50% diesel fuel blend.

	Equipment	Diesel Fuel Consumption	
a.	______________	______________	gal/yr
b.	______________	______________	gal/yr
c.	______________	______________	gal/yr
d.	______________	______________	gal/yr
e.	______________	______________	gal/yr
	TOTAL	______________	gal/yr

8. Take the total from Question 7 and multiply by 0.5 to obtain the quantity of EtOH required for dual-injection system equipment.

_____________ gal/yr ×0.5 = _____________ gal EtOH/yr

9. Total the answers from Questions 3, 5, and 8 to determine your total annual on-farm EtOH consumption potential.

_________ gal EtOH/yr + _________ gal EtOH/yr + _________ gal EtOH/yr = _________ gal EtOH/yr

10. List the number of cattle you own that you intend to feed stillage.

a. _____________ Feeder Calves

_____________ Mature Cattle

A mature cow can consume the stillage from 1 gallon of ethanol production in 1 day. A feeder calf can consume the stillage from 0.7 gallon of ethanol production in 1 day. Multiply the number of feeder calves by 0.7. Add this product to the number of mature cattle to obtain the daily maximum EtOH production rate for which stillage can be consumed by cattle.

b. _________ Feeder Calves × 0.7 + _________ Mature Cattle = _________ gal/day

11. List the number of cattle that neighbors and/or neighboring feedlots own which they will commit to feed your stillage at full ration.

_____________ Feeder Calves

_____________ Mature Cattle

_________ Feeder Calves × 0.7 + _________ Mature Cattle = _________ gal/day

12. Total the answers from Questions 10 and 11 to determine the equivalent daily EtOH production rate for which the stillage can be consumed by cattle.

_____________ gal/day + _____________ gal/day = _____________ gal/day

13. Determine the number of pigs you own that you can feed stillage.

a. _____________ Pigs

Determine the number of pigs owned by neighbors or nearby pig feeders that can be committed to feeding your stillage at full ration.

b. _____________ Neighbor Pigs

Total the results from a and b.

a + b. _____________________ Total Pigs

14. Multiply total from Question 13 by 0.4 to obtain equivalent daily EtOH production for which stillage can be consumed by pigs.

_______________ Pigs × 0.4 = _______________ gal/day

15. Repeat the exercise in Question 13 for sheep.

a. _______________ Sheep Owned

b. _______________ Neighbors Sheep

a + b. _______________ Total Sheep

16. Multiply total from Question 15 by the quantity of linseed meal normally fed every day to sheep in order to obtain the equivalent daily EtOH production rate for which stillage can be consumed by sheep.

_______________ Sheep × _______________ = gal/day

17. Repeat the excercise in Question 13 for poultry. Poultry can consume less than 0.05 lb of distillers' dried grains per day. This corresponds to about 0.07 gallons of whole stillage per day. Unless the poultry operation is very large, it is doubtful that this market can make any real contribution to consumption.

a. _______________ Poultry Owned

b. _______________ Neighbor's Poultry

a + b. _______________ Total Poultry

18. Take total from Question 17 and multiply by 0.05 to obtain the equivalent daily EtOH production rate for which stillage can be consumed by poultry.

_______________ Poultry × 0.05 gal/day = _______________ gal/day

19. Total the answers from Questions 11, 12, 14, 16, and 18 to obtain the total equivalent daily EtOH production rate for which stillage can be consumed by local livestock.

_____ gal/day + _____ gal/day + _____ gal/day + _____ gal/day + _____ gal/day = _____ gal/day

20. Multiply the total from Question 19 by 365 to obtain the total annual EtOH production for which the stillage will be consumed.

_______________ gal/day × 365 = _______________ gal/yr

Compare the answer from Question 20 to the answer from Question 9. If the answer from Question 20 is larger than the answer from Question 9, all of the stillage produced can be consumed by local livestock. This is the first production-limiting consideration. If the answer to Question 20 is smaller than the answer for Question 11, a choice must be made between limiting production to the number indicated by Question 20 or purchasing stillage processing equipment.

21. Survey the local EtOH purchase market to determine the quantity of EtOH that they will commit to purchase.

	High Proof		Anhydrous	
a. Dealers	______	gal/yr	______	gal/yr
b. Local Dist.	______	gal/yr	______	gal/yr
c. Regional Dist.	______	gal/yr	______	gal/yr
d. Other Farmers	______	gal/yr	______	gal/yr
e. Trans. Fleets	______	gal/yr	______	gal/yr
f. Fuel Blenders	______	gal/yr	______	gal/yr
TOTAL	______	gal/yr	______	gal/yr

22. Combine the answers from Questions 9 and 21 to determine annual market for EtOH.

______ gal/yr + ______ gal/yr = ______ gal/yr

This is the ethanol market potential. It is not necessarily an appropriate plant size.

Production Potential

23. Which of the following potential EtOH feedstocks do you now grow?

	Acres	Yield/Acre	Annual Production	
a. Corn	______	______	______	bu/yr
b. Wheat	______	______	______	bu/yr
c. Rye	______	______	______	bu/yr
d. Barley	______	______	______	bu/yr
e. Rice	______	______	______	bu/yr
f. Potatoes	______	______	______	cwt/yr
g. Sugar Beets	______	______	______	tons/yr
h. Sugarcane	______	______	______	tons/yr
i. Sweet Sorghum	______	______	______	tons/yr

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24. Do you have additional uncultivated land on which to plant more of any of these crops?

	Anticipated Acres	Potential Yield/Acre	Additional Annual Production	
a. Corn	______	______	______	bu/yr
b. Wheat	______	______	______	bu/yr
c. Rye	______	______	______	bu/yr
d. Barley	______	______	______	bu/yr
e. Rice	______	______	______	bu/yr
f. Potatoes	______	______	______	cwt/yr
g. Sugar Beets	______	______	______	tons/yr
h. Sugarcane	______	______	______	tons/yr
i. Sweet Sorghum	______	______	______	tons/yr

25. Can you shift land from production of any of the crops not mentioned in Question 24 to increase production of one that is? If so, calculate the potential increase as in Question 24.

Crop	Anticipated Acres	Potential Yield/Acre	Additional Annual Production
______	______	______	______
______	______	______	______

26. Add the annual production values separately for each crop from Questions 22, 23, and 24. (This procedure can be used for other crops; however, reliable data for other crops are not available at this time.)

	Cereal Grains (combine totals) bu/yr	Potatoes cwt/yr	Sugar Beets ton/yr
a.	______	______	______
b.	______	______	______
c.	______	______	______
TOTAL	______	______	______
	Column I	Column II	Column III

27. Multiply the Question 26 answers from:

a. Column I by 2.5 to obtain annual potential EtOH production from cereal grains;

_______________ bu/yr × 2.5 gal/bu = _______________ gal EtOH/yr

b. Column II by 1.4 gal/cwt to obtain annual potential EtOH production from potatoes;

_______________ cwt/yr × 1.4 gal/cwt = _______________ gal EtOH/yr

c. Column III by 20 gal/ton to obtain annual potential EtOH production for sugar beets.

_______________ ton/yr × 20 gal/ton = _______________ gal EtOH/yr

28. Total the answers from Question 27a, 27b, and 27c to determine total *potential* production capability. (This is not necessarily the plant size to select, as the following series of questions demonstrates.)

_________ gal/yr + _________ gal/yr + _________ gal/yr = _________ gal/yr

If the answer to Question 28 is greater than the answer to Question 22, the *maximum* size of the plant would be the value from Question 22.

Plant Size

Neither the size of the market nor the production potential are sufficient to determine the appropriate plant size although they do provide an upper limit. A good starting point is to fill your own fuel needs (answer to Question 9) and not exceed local stillage consumption potential (answer to Question 20). Since the latter is usually larger and the equipment for treatment of stillage introduces a significant additional cost, the value from Question 20 is a good starting point. Now the approximate revenues and savings must be compared to current earnings from the proposed ethanol feedstock to determine if there is any gain in value by building an ethanol plant. Assume all feedstock costs are charged to production of EtOH.

Fuel Savings

29. Multiply the total of Questions 3 and 5 by the current price you pay for gasoline in $/gal.

(_________ gal/yr + _________ gal/yr) × _________ $/gal = _________ $/yr

This is the savings from replacing gasoline with EtOH.

30. Multiply the answer from Question 8 by the current price you pay for diesel fuel in $/gal.

_______________ gal/yr × _______________ $/yr = _______________ $/yr

This is the savings from replacing diesel fuel with EtOH.

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31. Total Questions 29 and 30 to obtain the fuel savings.

_______________ \$/yr + _______________ \$/yr = _______________ \$/yr

Feed Savings

32. Total the answers from Questions 10b, 14, 16, and 18.

_______ gal/day + _______ gal/day + _______ gal/day + _______ gal/day = _______ gal/day

33. Total the answers from Questions 11, 14, 16, and 18.

_______ gal/day + _______ gal/day + _______ gal/day + _______ gal/day = _______ gal/day

34. Multiply the answer to Question 32 by 6.8 to obtain the dry mass of high-protein material represented by the whole stillage fed (if using cereal grain feedstock).

___________ gal/day × 6.8 lb dry mass/gal EtOH = ___________ lb dry mass/day

35. Multiply the answer to Question 34 by the protein fraction (e.g., 0.28 for corn) of the stillage on a dry basis.

_____________ lb dry mass/day × _____________ = _____________ lb protein/day
(protein fraction)

36. a. Determine the cost (in \$/lb protein) of the next less expensive protein supplement and multiply this number by the answer to Question 35 (answer this question only if you buy protein supplement).

___________ \$/lb protein × ___________ lb protein/day = ___________ \$/day

b. Multiply the answer to Question 36a by 365 (or the number of days per year you keep animals on protein supplement) to obtain annual savings in protein supplement.

______________________ \$/day × 365 days/yr = ______________________ \$/yr

Production Savings

37. a. Determine the cost of production of high-protein feeds on your farm in \$/lb dry mass and multiply by the protein fraction of each to obtain your actual cost of producing protein for feeding on-farm.

_____________ \$/lb dry mass × _____________ = _____________ \$/lb protein
(protein fraction)

b. Multiply the answer to Question 37a by the answer to Question 35 (or by the amount of protein you actually produce on-farm: quantity in lbs times protein fraction, whichever is smaller) to obtain potential protein.

__________ \$/lb protein × __________ lb protein/day = __________ \$/day

c. Multiply the answer to Question 37b by the number of days you keep animals on protein supplement during the year up to 365.

__________ \$/day × __________ days/yr = __________ \$/yr

38. Total the answers from Questions 36b and 37c.

__________ \$/yr + __________ \$/yr = __________ \$/yr

This is the total animal feed savings you will realize each year.

Revenues

39. a. Multiply the answer from Question 28 by the reasonable market value of the stillage you produce.

__________ gal/day × __________ \$/gal = __________ \$/day

b. Multiply the answer obtained in Question 39a by the number of days during the year that this quantity of stillage can be marketed, up to 365.

__________ \$/day × __________ days/yr = __________ \$/yr

This is the total stillage sales you will realize each year.

40. Total the answers from Questions 38 and 39b.

__________ \$/yr + __________ \$/yr = __________ \$/yr

This is the total market value of the stillage you will produce.

41. Subtract the answer to Question 9 from the answer to Question 20 to obtain the EtOH production potential that remains for sale.

__________ gal/yr − __________ gal/yr = __________ gal/yr

42. Multiply the answer from Question 41 by the current market value for ethanol.

__________ gal/yr × __________ \$/gal = __________ \$/yr

This is the annual ethanol sales potential.

43. Total the answers from Questions 31, 38, 40, and 42 to obtain the total revenues and savings from this production rate.

__________ \$/yr + __________ \$/yr + __________ \$/yr + __________ \$/yr = __________ \$/yr

44. Divide the answer to Question 20 by:

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a. 2.5 gal/bu if the feedstock to be used is cereal grain.

______________ gal/yr ÷ 2.5 gal/bu = ______________ bu/yr

b. 1.4 gal/cwt if the feedstock to be used is potatoes.

______________ gal/yr ÷ 1.4 gal/cwt = ______________ cwt/yr

c. 20 gal/ton if the feedstock to be used is sugar beets.

______________ gal/yr ÷ 20 gal/ton = ______________ tons/yr

45. Multiply:

a. The answer from Question 44a by the appropriate market value for cereal grains to obtain the potential earnings for direct marketing with EtOH production;

______ bu/yr × ______ \$/bu = ______ \$/yr

b. The answer from Question 44b by the appropriate market value for potatoes;

______ cwt/yr × ______ \$/cwt = ______ \$/yr

c. The answer from Question 44c by the appropriate market value for sugar beets.

______ tons/yr × ______ \$/ton = ______ \$/yr

46. Total the answers from Questions 45a, 45b, and 45c to obtain the potential earnings from directly marketing crops without making EtOH.

______ \$/yr + ______ \$/yr + ______ \$/yr = ______ \$/yr

Compare the answers from Questions 46 and 43. If Question 46 is as large, or nearly as large as the answer from Question 43, the construction of an ethanol plant of this size cannot be justified on a purely economic basis. Consider scaling down to a size that fills your own fuel needs and recompute Questions 29 through 46. If Question 43 is considerably larger (2 to 3 times) than Question 46, you can consider increasing your plant size within the bounds of the answers to Question 22 (market) and Question 28 (production potential). Care must be taken to assess local competition and market share as you expand plant size.

If a market share exists or if there is good reason to believe that you can acquire a share by superior techniques, the initial plant sizing must accurately reflect this realistic market share.

47. a. Multiply the initial plant production capacity (in gallons EtOH/hr) by 16 gallons of water per gallon EtOH production capacity.

______ gal EtOH/hr × 16 gal H_2O/gal EtOH = ______ gal H_2O/hr.

b. Can the answer to Question 47 be realistically achieved in your area? If yes, no adjustment to chosen plant size needs to be made to account for water availability. If no, reduce plant size to realistically reflect available water.

Approximate Costs of Plant

The cost of the equipment you choose will be a function of the labor available, the maintenance required, the heat source selected, and the type of operating mode.

Labor Requirements

How much time during the normal farming routine can you dedicate to running the ethanol plant?

48. a. Do you have any hired help or other adult family members, and if so, how much time can he/she dedicate to running the ethanol plant?

    b. Can you or your family or help dedicate time at periodic intervals to operating the ethanol plant?

If labor is limited, a high degree of automatic control is indicated.

Maintenance

49. What are your maintenance capabilities and equipment?

Heat Source

Determine the least expensive heat source available.

50. Select a plant design that accomplishes your determined production rate and fits your production schedule.

51. List all of the plant components and their costs

    a) storage bins $ ______

    b) grinding mill $ ______

    c) meal hopper $ ______

    d) cookers $ ______

    e) fermenters $ ______

    f) distillation columns $ ______

    g) storage tanks (product and coproduct) $ ______

    h) pumps $ ______

    i) controllers $ ______

    j) pipes and valves $ ______

    k) metering controls $ ______

    l) microprocessors $ ______

    m) safety valves $ ______

32

n) heat exchangers $ ______

o) instrumentation $ ______

p) insulation $ ______

q) boiler $ ______

r) fuel handling equipment $ ______

s) feedstocks handling equipment $ ______

t) storage tanks (stillage) $ ______

u) stillage treatment equipment (screen, dryers, etc.) $ ______

v) CO_2 handling equipment $ ______

w) ethanol dehydration equipment $ ______

TOTAL $ ______

52. Determine operating requirements for cost.

Plant capacity = ______ gallons of anhydrous ethanol per hour.

Production = ______ gallons per hour × hours of operation per year = ______ gal/yr.

Feed materials = Production ______ gal/yr ÷ ______ gal/bu = ______ bu/yr.

	$/yr	$/gal
a. Operating Costs		
Feed materials		
Grain ($/bu ÷ gal anhydrous ethanol/bu = $/gal.)	______	______
or ($/bu × bu/yr = $/yr.)	______	______
Supplies		
Enzymes	______	______
Other	______	______
Fuel for plant operation	______	______
Waste disposal	______	______
Operating labor (operating crew × hrs of operation per year × $/hr = $/year)	______	______
Total Operating Costs	______	______

b. Maintenance Costs

Routine scheduled maintenance		
Labor (Maintenance crew staff × hrs/yr × $/hr)		
Supplies and replacement parts		
Maintenance equipment rental		
Unscheduled Maintenance (Estimated)		
Labor		
Supplies		
Maintenance equipment		
Total Maintenance Costs		

c. Capital or Investment Costs

Plant equipment costs		
Land		
Inventory		
Grain		
Supplies		
Ethanol		
Spare parts		
Total		
Taxes		
Insurance		
Depreciation		
Interest on loan or mortgage		
Total Capital or Investment Costs		
TOTAL COSTS (Totals of a, b and c)		

Financial Requirements

53. Capital Costs

Item	Cost Estimate	Considerations
Real estate		

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Item	Cost Estimate	Considerations
Buildings	______	______
Equipment	______	______
Business formation	______	______
Equipment installation	______	______
Licensing costs	______	______

54. Operating Costs

Item	Cost Estimate	Considerations
Labor	______	______
Maintenance	______	______
Taxes	______	______
Supplies	______	Includes raw materials, additives, enzymes, yeast, and water.
Delivery	______	______
Expenses	______	Includes electricity and fuel(s).
Insurance	______	______
Interest on debt	______	Includes interest on long- and short-term loans.
Bonding	______	______

55. Start-Up Working Capital

Item	Cost Estimate	Considerations
Mortgage	______	Principle payments only, for first few months.
Cash to carry accounts receivable for 60 days	______	______
Cash to carry a finished goods inventory for 30 days	______	______
Cash to carry a raw material inventory for 30 days	______	______

56. Working Capital

Item	Cost Estimate	Considerations
Mortgage	________	Principle payments only.

Assets (Total Net Worth)

57. List all items owned by the business entity operating the ethanol plant.

Item	Value
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________

Organizational Form

58. Are you willing to assume the costs and risks of running your own EtOH production facility? ________

59. Are you capable of handling the additional taxes and debts for which you will be personally liable as a single proprietor? ________
Includes interest on long- and short-term loans.

60. Is your farm operation large enough or are your potential markets solid enough to handle an EtOH production facility as a single proprietor? ________

61. Is your credit alone sufficient to provide grounds for capitalizing a single proprietorship? ________

62. Will a partner(s) enhance your financial position or supply needed additional skills? ________

63. a. Do you need a partner to get enough feedstock for your EtOH production facility? ________

b. Are you willing to assume liabilities for product and partner? ________

64. Is your intended production going to be of such a scale as to far exceed the needs for your own farm or several neighboring farms? ________

65. Do you need to incorporate in order to obtain adequate funding? ________

66. Will incorporation reduce your personal tax burden? ________

67. Do you wish to assume product liability personally? ________

68. How many farmers in your area would want to join a cooperative? ________

69. Do you plan to operate in a centralized location to produce EtOH for all the members? ________

70. Is your main reason for producing EtOH to service the needs of the cooperative members, others, or to realize a significant profit? ________

Financing

If you are considering borrowing money, you should have a clear idea of what your chances will be beforehand. The following questions will tell you whether debt financing is a feasible approach to your funding problem.

71. a. How much money do you already owe? ________________________

b. What are your monthly payments? ________________________

72. How much capital will you have to come up with yourself in order to secure a loan? ____________

73. Have you recently been refused credit? ________

74. a. How high are the interest rates going to be? ________

b. Can you cover them with your projected cash flow? ________

75. If the loan must be secured or collateralized, do you have sufficient assets to cover your debt? ________

If you are already carrying a heavy debt load and/or your credit rating is low, your chances of obtaining additional debt financing is low and perhaps you should consider some other type of financing. Insufficient collateral, exorbitant interest rates, and low projected cash flow are also negative indicators for debt financing.

The choice between debt and equity financing will be one of the most important decisions you will have to face since it will affect how much control you will ultimately have over your operation. The following questions deal with this issue, as well as the comparative cost of the two major types of financing.

76. How much equity do you already have? ________________________

77. Do you want to maintain complete ownership and control of your enterprise? ________

78. Are you willing to share ownership and/or control if it does not entail more than a minority share? ________

79. Will the cost of selling the stock (broker's fee, bookkeeper, etc.) be more than the interest you would have to pay on a loan? ______

If you are reluctant to relinquish any control over your operation, you would probably be better off seeking a loan. On the other hand, if your chances of obtaining a loan are slim, you might have to trade off some personal equity in return for a better borrowing position.

80. Do you have other funds or materials to match with federal funds? (It is usually helpful.) ______

81. Do you live in a geographical area that qualifies for special funds? ______
82. Will you need continued federal support at the end of your grant period? ______

83. Are you going to apply for grant funds as an individual, as a nonprofit corporation, or as a profit corporation? ______

84. Are you a private nonprofit corporation? ______

85. Is there something special about your alcohol facility that would make it attractive to certain foundations? ______

You should now have a good idea as to where you are going to seek your initial funding. Remember that most new businesses start up with a combination of funding sources. It is important to maintain a balance that will give you not only sufficient funding when you need it, but also the amount of control over your operation that you would like to have.

Completion of these worksheets can lead to an initial decision on the feasibility to proceed. However, this should not be construed as a final decision, but rather a step in that process.

If the financial requirements are greater than the capability to obtain financing, it does not necessarily mean the entire concept will not work. Rather, the organizational form can be reexamined and/or the production base expanded in order to increase financing capability.

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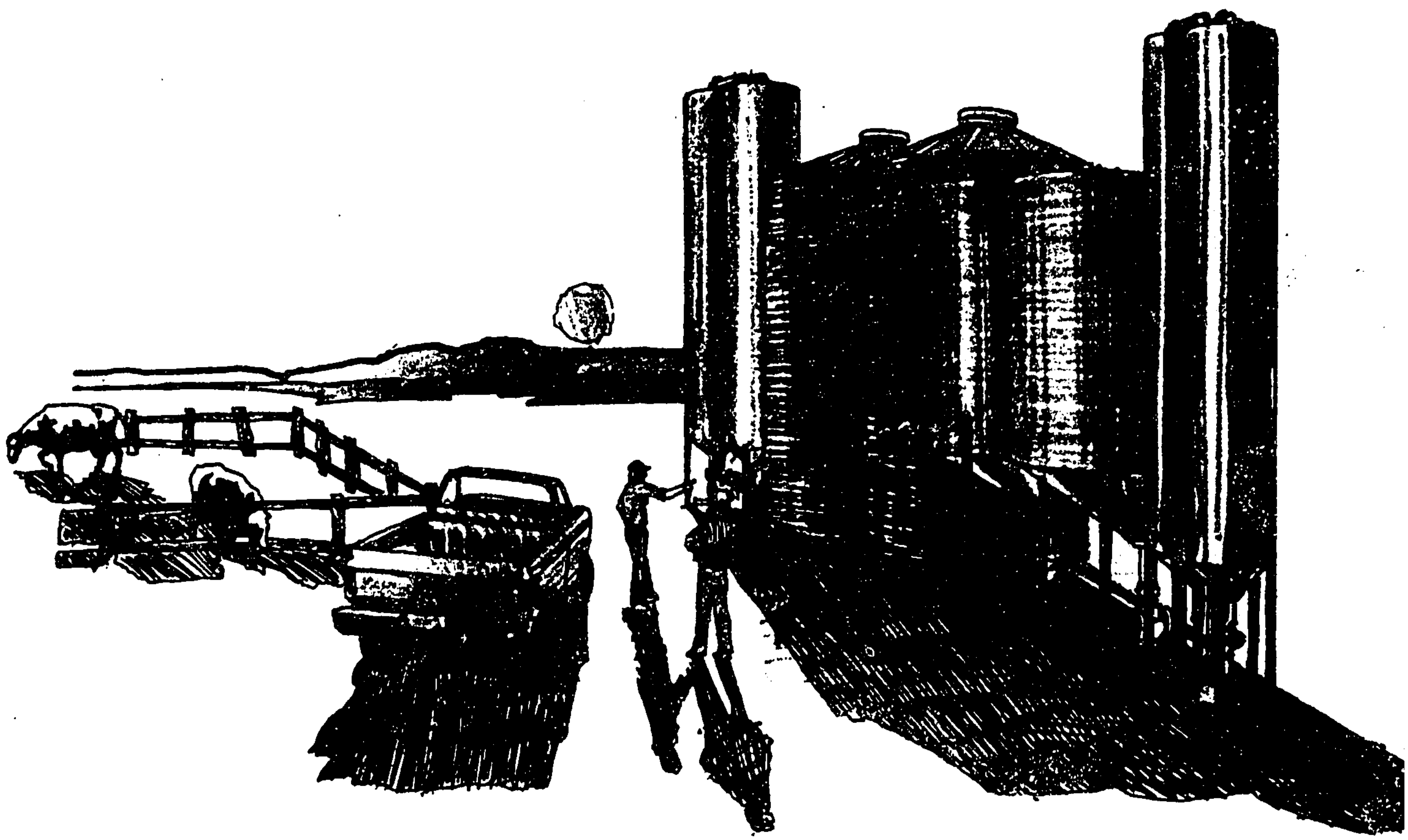
CHAPTER III

Basic Ethanol Production



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CHAPTER III

Basic Ethanol Production

The production of ethanol is an established process. It involves some of the knowledge and skill used in normal farm operations, especially the cultivation of plants. It is also a mix of technologies which includes microbiology, chemistry, and engineering. Basically, fermentation is a process in which microorganisms such as yeasts convert simple sugars to ethanol and carbon dioxide. Some plants directly yield simple sugars; others produce starch or cellulose that must be converted to sugar. The sugar obtained must be fermented and the beer produced must then be distilled to obtain fuel-grade ethanol. Each step is discussed individually. A basic flow diagram of ethanol production is shown in Figure III-1.

PREPARATION OF FEEDSTOCKS

Feedstocks can be selected from among many plants that either produce simple sugars directly or produce starch and cellulose. The broad category of plants which this includes means there is considerable diversity in the initial processing, but some features are universal:

- simple sugars must be extracted from the plants that directly produce them;
- starch and cellulose must be reduced from their complex form to basic glucose; and
- stones and metallic particles must be removed.

The last feature must be taken care of first. Destoning equipment and magnetic separators can be used to remove stones and metallic particles. Root crops require other approaches since mechanical harvesters don't differentiate between rocks and potatoes or beets of the same size. Water jets or flumes may be needed to accomplish this.

The simple sugars from such plants as sugarcane, sugar beets, or sorghum can be obtained by crushing or pressing the material. The low sugar bagasse and pulp which remain after pressing can be leached with water to remove residual sugars. The fibrous cellulosic material theoretically could be treated chemically or enzymatically to produce more sugar. However, no commercially available process currently exists.

Commonly used starchy feedstocks are grains and potatoes. Starch is roughly 20% amylose (a water-soluble carbohydrate) and 80% amylopectin (which is not soluble in water). These molecules are linked together by means of a bond that can be broken with relative ease. Cellulose, which is also made up of glucose, differs from starch mainly in the bond between glucose units.

Starch must be broken down because yeast can only act on simple sugars to produce ethanol. This process requires that the material be broken mechanically into the smallest practical size by milling or grinding, thereby breaking the starch walls to make all of the material available to the water. From this mixture, a slurry can be prepared and it can be heated to temperatures high enough to break the cell walls of the starch. This produces complex sugars which can be further reduced by enzymes to the desired sugar product.

Conversion of Starches by Enzymatic Hydrolysis

Consider the preparation of starch from grain as an example of enzymatic hydrolysis. The intent is to produce a 14% to 20% sugar solution with water and whole grain. Grain is a good source of carbohydrate, but to gain access to the carbohydrate, the grain must be ground. A rule of thumb is to operate grinders so that the resulting meal can pass a 20-mesh screen. This assures that the carbohydrate is accessible and the solids can be removed with a finer screen if desired. If the grain is not ground finely enough, the resultant lumpy material is not readily accessible for enzymatic conversion to sugar. The next step is to prepare a slurry by mixing the meal directly with water. Stirring should be adequate to prevent the formation of lumps and enhance enzyme contact with the starch (thus speeding liquefaction).

High-temperature and high-pressure processes may require a full time operator, thus making it difficult to integrate into farming operations. Therefore, when deciding which enzyme to purchase, consideration should be given to selecting one that is active at moderate temperature, i.e., 200° F (93° C), near-ambient pressure, and nearly neutral pH. The acidity of the slurry can be adjusted by addition of dilute basic solution (e.g., sodium hydroxide) if the pH is too low and addition of concentrated sulfuric acid or lactic acid if the pH is too high.

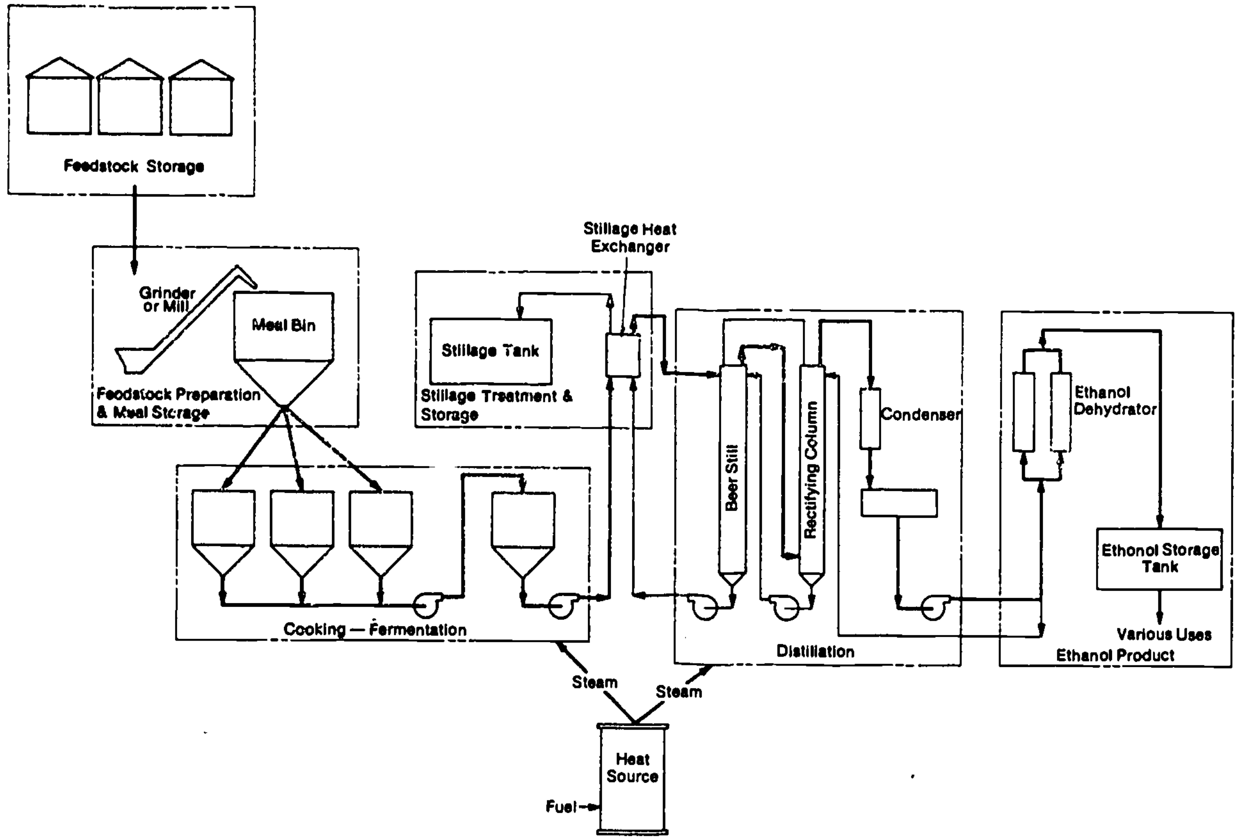


Figure III-1. Ethanol Pr ı c .or Flow Diagram

The enzyme should be added to the slurry in the proper proportion to the quantity of starch to be converted. If not, liquefaction ends up incomplete or takes too long to complete for practical operations. Enzymes vary in activity but thermophyllic bacterial amylases, which are commercially available, can be added at rates slightly greater than ¾ ounce per bushel of meal. Rapid dispersion of the dry enzyme is best accomplished by mixing a premeasured quantity with a small volume of warm water prior to addition to the slurry. Liquefaction should be conducted in the specific temperature range and pH suggested by the supplier of the specific enzyme used.

After the enzyme is added, the grain mash is heated to break the cell walls of the starch. However, the enzyme must be added before the temperature is raised because once the cell walls rupture, a gel forms and it becomes almost impossible to accomplish good mixing of the enzyme with the starch. The rupture of cell walls, which is caused by heating in hot water, is called gelatinization because the slurry (which is a suspension of basically insoluble material in water) is converted to a high-viscosity solution. Under slow cooking conditions and normal atmospheric pressure, gelatinization can be expected to occur around 140° F (60° C).

The temperature is then raised to the optimal functional range for the enzyme and held for a period of time sufficient to completely convert the starch to soluble dextrins (polymeric sugars). There are commercially available enzymes that are most active around 200° F (93° C) and require a hold time of 2½ hours if the proper proportion of enzyme is used. When this step is complete, the slurry has been converted to an aqueous solution of dextrins. Care must be taken to assure that the starch conversion step is complete because the conditions for the glucose-producing enzyme (glucoamylase), which is introduced in the next step, are significantly different from those for liquefaction.

The next step, saccharification, is the conversion of dextrins to simple sugars, i.e., glucose. The mash temperature is dropped to the active range of the glucoamylase, the enzyme used for saccharification, and the pH of the solution is adjusted to optimize conversion activity. The pH is a critical factor because the enzymatic activity virtually ceases when the pH is above 6.5. Glucoamylase is added in the proportion required to convert the amount of sugar available. Again, depending upon the variety selected and its activity, the actual required quantity of enzyme varies.

After the enzyme is added, the temperature of the mash must neither exceed 140° F (60° C) nor drop below 122° F (50° C) during the saccharification step or the enzyme activity is greatly reduced. The mash, as in the prior step, must be stirred continuously to assure intimate contact of enzyme and dextrin. The mash should be held at the proper temperature and pH until conversion of the dextrin to glucose is complete.

FERMENTATION

Fermentation is the conversion of an organic material from one chemical form to another using enzymes produced by living microorganisms. In general, these bacteria are classified according to their tolerance of oxygen. Those that use oxygen are called aerobic and those that do not are called anaerobic. Those that start with oxygen but continue to thrive after all of the available oxygen is consumed are called facultative organisms. The yeast used to produce ethanol is an example of this type of facultative anaerobe. The breakdown of glucose to ethanol involves a complex sequence of chemical reactions which can be summarized as:

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \longrightarrow \underset{\text{(ethanol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2} + \text{heat}$$

Actual yields of ethanol generally fall short of predicted theoretical yields because about 5% of the sugar is used by the yeast to produce new cells and minor products such as glycerols, acetic acid, lactic acid, and fusel oils.

Yeasts are the microorganisms responsible for producing the enzymes which convert sugar to ethanol. Yeasts are single-cell fungi widely distributed in nature, commonly found in wood, dirt, plant matter, and on the surface of fruits and flowers. They are spread by wind and insects. Yeasts used in ethanol productions are members of the genus *Saccharomyces*. These yeasts are sensitive to a wide variety of variables that potentially affect ethanol production. However, pH and temperature are the most influential of these variables. *Saccharomyces* are most effective in pH ranges between 3.0 and 5.0 and temperatures between 80° F (27° C) and 90° F (35° C). The length of time required to convert a mash to ethanol is dependent on the number of yeast cells per quantity of sugar. The greater the number initially added, the faster the job is complete. However, there is a point of diminishing returns.

Yeast strains, nutritional requirements, sugar concentration, temperature, infections, and pH influence yeast efficiency. They are described as follows:

Yeast Strains

Yeasts are divided informally into top and bottom yeasts according to the location in the mash in which most of the fermentation takes place. The top yeasts, *Saccharomyces cerevisiae,* produce carbon dioxide and ethanol vigorously and tend to cluster on the surface of the mash. Producers of distilled spirits generally use top yeasts of high activity to maximize ethanol yield in the shortest time; producers of beer tend to use bottom yeasts which produce lower ethanol yields and require longer times to complete fermentation. Under normal brewing conditions, top yeasts tend to flocculate (aggregate together into clusters) and to separate out from the solution when fermentation is complete. The various strains of yeast differ considerably in their tendency to flocculate. Those strains with an excessive tendency toward premature flocculation tend to cut short fermentation and thus reduce ethanol yield. This phenomenon, however, is not singularly a trait of the yeast. Fermentation conditions can be an influencing factor. The cause of premature flocculation seems to be a function of the pH of the mash and the number of free calcium ions in solution. Hydrated lime, which is sometimes used to adjust pH, contains calcium and may be a contributory factor.

Nutritional Requirements

Yeasts are plants, despite the fact that they contain no chlorophyll. As such, their nutritional requirements must be met or they cannot produce ethanol as fast as desired. Like the other living things that a farmer cultivates and nurtures, an energy source such as carbohydrate must be provided for metabolism. Amino acids must be provided in the proper proportion and major chemical elements such as carbon, nitrogen, phosphorus, and others must be available to promote cell growth. Some species flourish without vitamin supplements, but in most cases cell growth is enhanced when B-vitamins are available. Carbon is provided by the many carbonaceous substances in the mash.

The nitrogen requirement varies somewhat with the strain of yeast used. In general, it should be supplied in the form of ammonia, ammonium salts, amino acids, peptides, or urea. Care should be taken to sterilize farm sources of urea to prevent contamination of the mash with undesired microbial strains. Since only a few species of yeasts can assimilate nitrogen from nitrates, this is not a recommended source of nitrogen. Ammonia is usually the preferred nitrogen form, but in its absence, the yeast can break up amino acids to obtain it. The separation of solids from the solution prior to fermentation removes the bulk of the protein and, hence, the amine source would be removed also. If this option is exercised, an ammonia supplement must be provided or yeast populations will not propagate at the desired rates and fermentation will take an excessive amount of time to complete. However, excessive amounts of ammonia in solution must be avoided because it can be lethal to the yeast.

Although the exact mineral requirements of yeasts cannot be specified because of their short-term evolutionary capability, phosphorus and potassium can be identified as elements of prime importance. Care should be taken not to introduce excessive trace minerals, because those which the yeast cannot use increase the osmotic pressure in the system. (Osmotic pressure is due to the physical imbalance in concentration of chemicals on either side of a membrane. Since yeasts are cellular organisms, they are enclosed by a cell wall. An excessively high osmotic pressure can cause the rupture of the cell wall which in turn kills the yeast.)

Sugar Concentration

There are two basic concerns that govern the sugar concentration of the mash: (1) excessively high sugar concentrations can inhibit the growth of yeast cells in the initial stages of fermentation, and (2) high ethanol concentrations are lethal to yeast. If the concentration of ethanol in the solution reaches levels high enough to kill yeast before all the sugar is consumed, the quantity of sugar that remains is wasted. The latter concern is the governing control. Yeast growth problems can be overcome by using large inoculations to start fermentation. *Saccharomyces* strains can utilize effectively all of the sugar in solutions that are 16% to 22% sugar while producing a beer that ranges from 8% to 12% ethanol by volume.

Temperature

Fermentation is strongly influenced by temperature, because the yeast performs best in a specific temperature range. The rate of fermentation increases with temperature in the temperature range between 80° F (27° C) and 95° F (35° C). Above 95° F (35° C), the rate of fermentation gradually drops off, and ceases altogether at temperatures above 109° F (43° C). The actual temperature effects vary with different yeast strains and typical operating conditions are generally closer to 80° F (27° C) than 95° F (35° C). This choice is usually made to reduce ethanol losses by evaporation from the beer. For every 9° F (5° C) increase in temperature, the ethanol evaporation rate increases 1.5 times. Since scrubbing equipment is required to recover the ethanol lost by evaporation and the cost justification is minimal on a small scale, the lower fermentation temperature offers advantages of simplicity.

The fermentation reaction gives off energy as it proceeds (about 500 Btu per pound of ethanol produced). There will be a normal heat loss from the fermentation tank as long as the temperature outside the tank is less than that inside. Depending upon the location of the plant, this will depend on how much colder the outside air is than the inside air and upon the design of the fermenter. In general, this temperature difference will not be sufficient to take away as much heat as is generated by the reaction except during the colder times of the year. Thus, the fermenters must be equipped with active cooling systems, such as cooling coils and external jackets, to circulate air or water for convective cooling.

Infections

Unwanted microbial contaminants can be a major cause of reductions in ethanol yield. Contaminants consume sugar that would otherwise be available for ethanol production and produce enzymes that modify fermentation conditions, thus yielding a drastically different set of products. Although infection must be high before appreciable quantities of sugar are consumed, the rate at which many bacteria multiply exceeds yeast propagation. Therefore, even low initial levels of infection can greatly impair fermentation. In a sense, the start of fermentation is a race among the microorganisms present to see who can consume the most. The objective is the selective culture of a preferred organism. This means providing the conditions that are most favorable to the desired microorganism. As mentioned previously, high initial sugar concentrations inhibit propagation of *Saccharomyces cerevisiae* because it is not an osmophylic yeast (i.e., it cannot stand the high osmotic pressure caused by the high concentration of sugar in the solution). This immediately gives an advantage to any osmophylic bacteria present.

Unwanted microbes can be controlled by using commercially available antiseptics. These antiseptics are the same as those used to control infections in humans, but are less expensive because they are manufactured for industrial use.

DISTILLATION

The purpose of the distillation process is to separate ethanol from the ethanol-water mixture. There are many means of separating liquids comprised of two or more components in solution. In general, for solutions comprised of components of significantly different boiling temperatures, distillation has proved to be the most easily operated and thermally efficient separation technique.

At atmospheric pressure, water boils around 212° F (100° C) and ethanol boils around 172° F (77.7° C). It is this difference in boiling temperature that allows for distillative separation of ethanol-water mixtures. If a pan of an ethanol and water solution is heated on the stove, more ethanol molecules leave the pan than water molecules. If the vapor leaving the pan is caught and condensed, the concentration of ethanol in the condensed liquid will be higher than in the original solution, and the solution remaining in the pan will be lower in ethanol concentration. If the condensate from this step is again heated and the vapors condensed, the con-

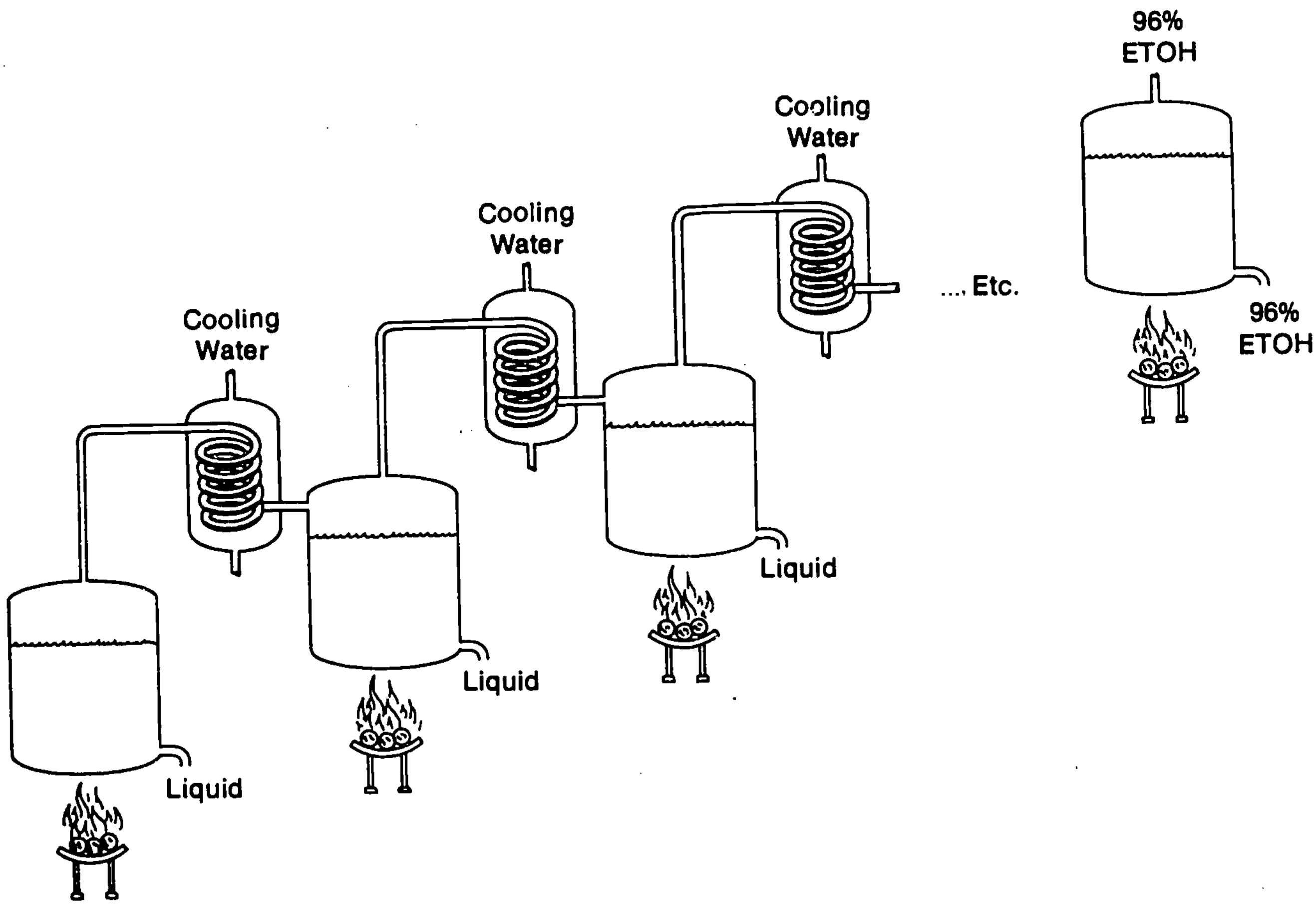


Figure III-2. Basic Process of Successive Distillation to Increase Concentration of Ethanol

centration of ethanol in the condensate will again be higher. This process could be repeated until most of the ethanol was concentrated in one phase. Unfortunately, a constant boiling mixture (azeotrope) forms at about 96% ethanol. This means that when a pan containing a 96%-ethanol solution is heated, the ratio of ethanol molecules to water molecules in the condensate remains constant. Therefore, no concentration enhancement is achieved beyond this point by the distillation method.

The system shown in Figure III-2 is capable of producing 96%-pure ethanol, but the amount of final product will be quite small. At the same time there will be a large number of products of intermediate ethanol-water compositions that have not been brought to the required product purity. If, instead of discarding all the intermediate concentrations of ethanol and water, they were recycled to a point in the system where the concentration was the same, we could retain all the ethanol in the system. Then, if all of these steps were incorporated into one vessel, the result would be a distillation column. The advantages of this system are that no intermediate product is discarded and only one external heating and one external cooling device are required. Condensation at one stage is affected when vapors contact a cooler stage above it, and evaporation is affected when liquid contacts a heating stage below. Heat for the system is provided at the bottom of the distillation column; cooling is provided by a condenser at the top where the condensed product is returned in a process called reflux. It is important to note that without this reflux the system would return to a composition similar to the mixture in the first pan that was heated on the stove.

The example distillation sieve tray column given in Figure III-3 is the most common single-vessel device for carrying out distillation. The liquid flows down the tower under the force of gravity while the vapor flows upward under the force of a slight pressure drop.

The portion of the column above the feed is called the rectifying or enrichment section. The upper section serves primarily to remove the component with the lower vapor pressure (water) from the upflowing vapor, thereby enriching the ethanol concentration. The portion of the column below the feed, called the stripping section, serves primarily to remove or strip the ethanol from the down-flowing liquid.

Figure III-4 is an enlarged illustration of a sieve tray. In order to achieve good mixing between phases and to provide the necessary disengagement of vapor and liquid between stages, the liquid is retained on each plate

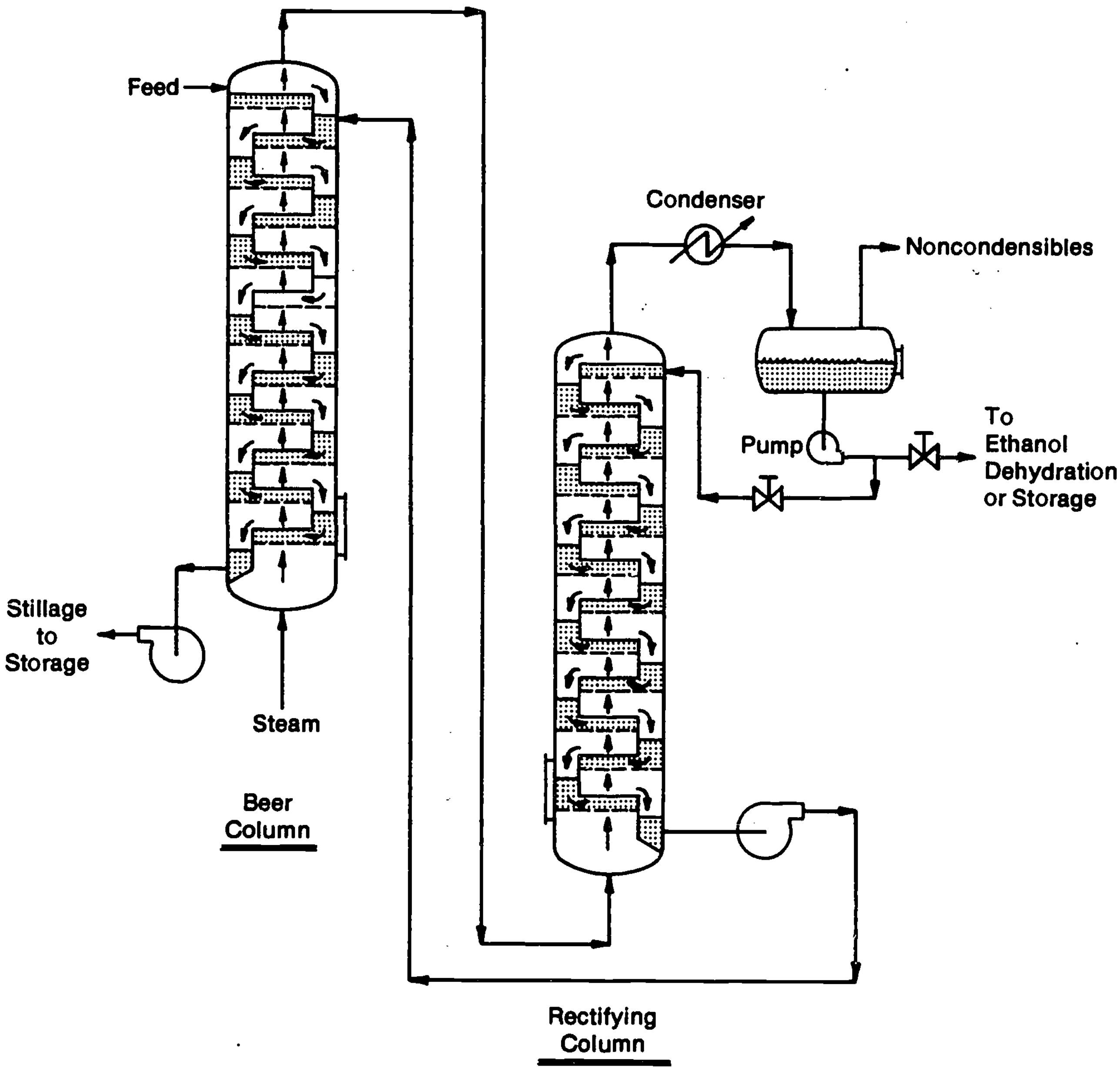


Figure III-3. Schematic Diagram of Sieve Tray Distillation of Ethanol

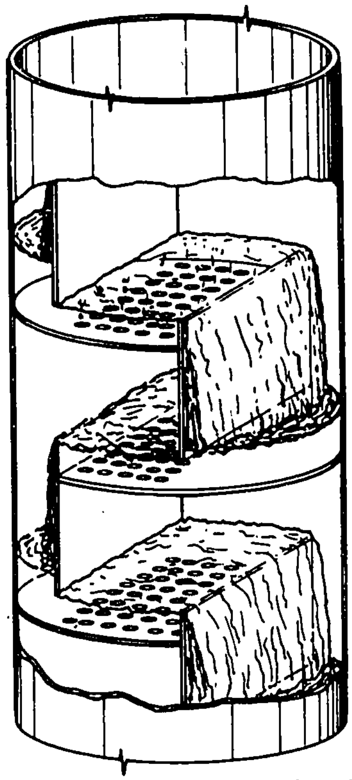


Figure III-4. Enlarged Illustration of Sieve Tray

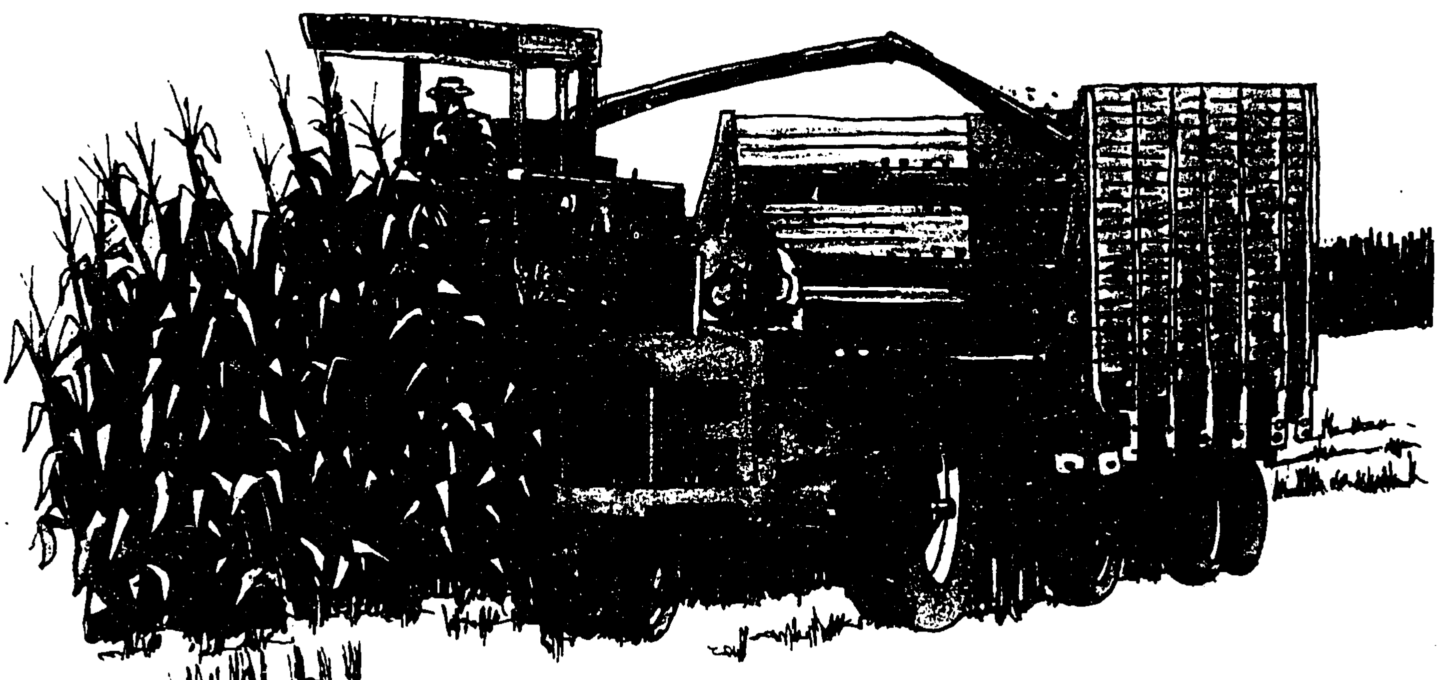
by a weir (a dam that regulates flow) over which the solution flows. The effluent liquid then flows down the downcomer to the next stage. The downcomer provides sufficient volume and residence time to allow the vapor-liquid separation.

It is possible to use several devices other than sieve tray columns to achieve the counter-current flow required for ethanol-water distillation. A packed column is frequently used to effect the necessary vapor-liquid contacting. The packed column is filled with solid material shaped to provide a large surface area for contact. Counter-current liquid and vapor flows proceed in the same way described for the sieve tray column.

Production of fuel-grade ethanol is a practical operation to include in farm activities. Texts in microbiology and organic chemistry portray it as a complex procedure, but this is not necessarily true. Fermentation is affected by a variety of conditions. The more care used in producing optimum conditions, the greater the ethanol yield. Distillation can range from the simple to the complex. Fortunately, the middle line works quite satisfactorily for on-farm ethanol production.

CHAPTER IV

Feedstocks



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CHAPTER IV
Feedstocks

The previous chapter discussed the basic process for fermenting sugar into ethanol. The purposes of this chapter are (1) to describe the types of agricultural crops and crop residues that make up the feedstocks used in the production of ethanol; (2) to provide data on the yield of the three principal coproducts derived from fermentation of these feedstocks; and (3) to present agronomic and feedstock considerations of ethanol production.

TYPES OF FEEDSTOCKS

Biological production of ethanol is accomplished by yeast through fermentation of six-carbon sugar units (principally glucose). All agricultural crops and crop residues contain six-carbon sugars, or compounds of these sugars, and therefore can be used in the production of ethanol. Three different arrangements of the basic sugar units are possible, as seen in the three different types of agricultural feedstocks available for fermentation: sugar crops, starch crops, and lignocellulosic residues. The starch crops and lignocellulosic residues contain six-carbon sugar compounds which must be broken down into simple six-carbon sugar units before fermentation can take place.

Sugar Crops

In sugar crops, the majority of the six-carbon sugar units occur individually or in bonded pairs. Once a sugar crop has been crushed to remove the sugar, no additional processing is needed prior to fermentation since the six-carbon sugar units are already in a form that the yeast can use. This fact is both an advantage and a disadvantage. Preparation of the feedstock for fermentation involves comparatively low equipment, labor, and energy costs, since the only major steps involved are milling and extraction of the sugar. However, sugar crops tend to spoil easily. Numerous types of microorganisms (including the type of yeast that produces ethanol) thrive on these crops during storage because of their high moisture and sugar content. Therefore, steps must be taken during storage to slow the loss of sugar. The only proven storage method is evaporation of water from the sugar solution—an effective, but costly method in terms of equipment (evaporators) and energy. Sterilization of the juice by use of heat, chemicals, or ultrafiltration to remove microbes is currently under investigation [1].

The two sugar crops that have been cultivated in the United States for many years at a commercial level of production are sugarcane and sugar beets. Other alternative sugar crops that can be cultivated in the United States include sweet sorghum, Jerusalem artichokes, fodder beets, and fruits.

Sugarcane. Sugarcane is considered a favorable feedstock because of its high yield of sugar per acre (as high as 50 tons per acre per year) and a correspondingly high yield of crop residue, known as bagasse, that can be used as a fuel for production of process heat. The major drawback with this feedstock is the limited availability of land suitable for economical cultivation. Presently, only four states (Florida, Louisiana, Texas, and Hawaii) cultivate sugarcane.

Sugar Beets. Sugar beets are a much more versatile crop than sugarcane. They are presently grown in 19 states, and the potential for cultivation in other parts of the country is high because sugar beets tolerate a wide range of climatic and soil conditions. An important advantage of sugar beets is the comparatively high yield of crop coproducts: beet pulp and beet tops. Beet pulp, the por-

Sugar Beets are a Good Ethanol Feedstock

Sweet Sorghum Yields Grain and Sugar, Both of Which can be Used as Ethanol Feedstocks

tion of the root that remains after the sugar has been removed, is bulky and palatable and may be fed in either wet or dry form. Beet tops have alternative uses that include leaving them on the field for organic material (fertilizer) and as cover to lessen soil erosion.

Widespread expansion of sugar beet cultivation is limited to some extent by the necessity to rotate with nonroot crops, in order to lower losses caused by a buildup of nematodes, a parasitic worm that attacks root systems. A general guideline of one beet crop per 4-year period should be followed. None of the sugar beet crop coproducts are suitable for use as a boiler fuel.

Interest in ethanol production from agricultural crops has prompted research on the development of sugar crops that have not been cultivated on a widespread commercial basis in this country. Three of the principal crops now under investigation are sweet sorghum, Jerusalem artichokes, and fodder beets.

Sweet Sorghum. Sweet sorghum is a name given to varieties of a species of sorghum: *Sorghum bicolor.* This crop has been cultivated on a small scale in the past for production of table syrup, but other varieties can be grown for production of sugar. The most common types of sorghum species are those used for production of grain.

There are two advantages of sweet sorghum over sugarcane: its great tolerance to a wide range of climatic and soil conditions, and its relatively high yield of ethanol per acre. In addition, the plant can be harvested in three ways: (1) the whole plant can be harvested and stored in its entirety; (2) it can be cut into short lengths (about 4 inches long) when juice extraction is carried out immediately; and (3) it can be harvested and chopped for ensilage. Since many varieties of sweet sorghum bear significant quantities of grain (milo), the harvesting procedure will have to take this fact into account.

The leaves and fibrous residue of sweet sorghum contain large quantities of protein, making the residue from the extraction of juice or from fermentation a valuable livestock feed. The fibrous residue can also be used as boiler feed.

Jerusalem Artichokes. The Jerusalem artichoke has shown excellent potential as an alternative sugar crop. A member of the sunflower family, this crop is native to North America and well-adapted to northern climates [2]. Like the sugar beet, the Jerusalem artichoke produces sugar in the top growth and stores it in the roots and tuber. It can grow in a variety of soils, and it is not demanding of soil fertility. The Jerusalem artichoke is a perennial; small tubers left in the field will produce the next season's crop, so no plowing or seeding is necessary.

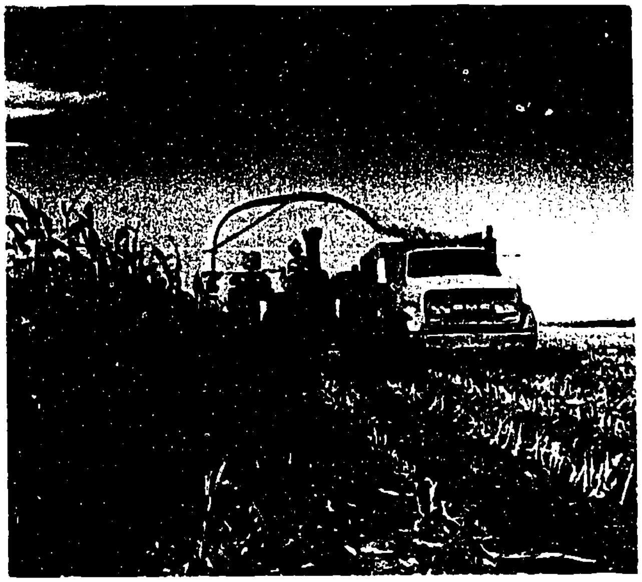
Although the Jerusalem artichoke traditionally has been grown for the tuber, an alternative to harvesting the tuber does exist. It has been noted that the majority of the sugar produced in the leaves does not enter the tuber until the plant has nearly reached the end of its productive life [3]. Thus, it may be possible to harvest the Jerusalem artichoke when the sugar content in the stalk reaches a maximum, thereby avoiding harvesting the tuber. In this case, the harvesting equipment and procedures are essentially the same as for harvesting sweet sorghum or corn for ensilage.

Fodder Beets. Another promising sugar crop which is presently being developed in New Zealand is the fodder beet. The fodder beet is a high yielding forage crop obtained by crossing two other beet species, sugar beets and mangolds. It is similar in most agronomic respects to sugar beets. The attraction of this crop lies in its higher yield of fermentable sugars per acre relative to sugar beets and its comparatively high resistance to loss of fermentable sugars during storage [4]. Culture of fodder beets is also less demanding than sugar beets.

Fruit Crops. Fruit crops (e.g., grapes, apricots, peaches, and pears) are another type of feedstock in the sugar crop category. Typically, fruit crops such as grapes are used as the feedstock in wine production. These crops are not likely to be used as feedstocks for production of fuel-grade ethanol because of their high market value for direct human consumption. However, the coproducts of processing fruit crops are likely to be used as feedstocks because fermentation is an economical method for reducing the potential environmental impact of untreated wastes containing fermentable sugars.

Starch Crops

In starch crops, most of the six-carbon sugar units are linked together in long, branched chains (called starch). Yeast cannot use these chains to produce ethanol. The starch chains must be broken down into individual six-



Corn Is one of the Most Popular Ethanol Feedstocks, In Part Due to Its Relatively Low Cost of Production

carbon units or groups of two units. The starch conversion process, described in the previous chapter, is relatively simple because the bonds in the starch chain can be broken in an inexpensive manner by the use of heat and enzymes, or by a mild acid solution.

From the standpoint of ethanol production, the long, branched chain arrangement of six-carbon sugar units in starch crops has advantages and disadvantages. The principal disadvantage is the additional equipment, labor, and energy costs associated with breaking down the chain so that the individual sugar units can be used by the yeast. However, this cost is not very large in relation to all of the other costs involved in ethanol production. The principal advantage in starch crops is the relative ease with which these crops can be stored, with minimal loss of the fermentable portion. Ease of storage is related to the fact that a conversion step is needed prior to fermentation: many microorganisms, including yeast, can utilize individual or small groups of sugar units, but not long chains. Some microorganisms present in the environment produce the enzymes needed to break up the chains, but unless certain conditions (such as moisture, temperature, and pH) are just right, the rate of conversion is very slow. When crops and other feeds are dried to about 12% moisture—the percentage at which most microorganisms cannot survive—the deterioration of starch and other valuable components (for example, protein and fats) is minimal. There are basically two subcategories of starch crops: grains (e.g., corn, sorghum, wheat, and barley) and tubers (e.g., potatoes and sweet potatoes). The production of beverage-grade ethanol from both types of starch crops is a well established practice.

Much of the current agronomic research on optimizing the production of ethanol and livestock feed from agricultural crops is focused on unconventional sugar crops such as sweet sorghum. However, opportunities also exist for selecting new varieties of grains and tubers that produce more ethanol per acre. For example, when selecting a wheat variety, protein content is usually emphasized. However, for ethanol production, high starch content is desired. It is well known that wheat varieties with lower protein content and higher starch content usually produce more grain per acre and, consequently, produce more ethanol per acre.

Crop Residue

The "backbone" of sugar and starch crops—the stalks and leaves—is composed mainly of cellulose. The individual six-carbon sugar units in cellulose are linked together in extremely long chains by a stronger chemical bond than exists in starch. As with starch, cellulose must be broken down into sugar units before it can be used by yeast to make ethanol. However, the breaking of the cellulose bonds is much more complex and costly than the breaking of the starch bonds. Breaking the cellulose into individual sugar units is complicated by the presence of lignin, a complex compound surrounding cellulose, which is even more resistant than cellulose to enzymatic or acidic pretreatment. Because of the high cost of converting liquefied cellulose into fermentable sugars, agricultural residues (as well as other crops having a high percentage of cellulose) are not yet a practical feedstock source for small ethanol plants. Current research may result in feasible cellulosic conversion processes in the future.

Forage Crops

Forage crops (e.g., forage sorghum, Sudan grass) hold promise for ethanol production because, in their early stage of growth, there is very little lignin and the conversion of the cellulose to sugars is more efficient. In addition, the proportion of carbohydrates in the form of cellulose is less than in the mature plant. Since forage crops achieve maximum growth in a relatively short period, they can be harvested as many as four times in one growing season [5]. For this reason, forage crops cut as green chop may have the highest yield of dry material of any storage crop. In addition to cellulose, forage crops contain significant quantities of starch and fermentable sugars which can also be converted to ethanol. The residues from fermentation containing nonfermentable sugars, protein, and other components may be used for livestock feed.

The principal characteristics of the feedstock types considered in this section are summarized in Table IV-1.

COPRODUCT YIELDS

Ethanol

The yield of ethanol from agricultural crops can be

TABLE IV-1. SUMMARY OF FEEDSTOCK CHARACTERISTICS

Type of Feedstock	Processing Needed Prior to Fermentation	Principal Advantage(s)	Principal Disadvantage(s)
Sugar Crops (e.g., sugar beets, sweet sorghum, sugarcane, fodder beet, Jerusalem artichoke)	Milling to extract sugar.	1. Preparation is minimal. 2. High yields of ethanol per acre. 3. Crop coproducts have value as fuel, livestock feed, or soil amendment.	1. Storage may result in loss of sugar. 2. Cultivation practices are not wide-spread, especially with "nonconventional" crops.
Starch Crops: Grains (e.g., corn, wheat, sorghum, barley) Tubers (e.g., potatoes, sweet potatoes)	Milling, liquefaction, and saccharification.	1. Storage techniques are well developed. 2. Cultivation practices are widespread with grains. 3. Livestock coproduct is relatively high in protein.	1. Preparation involves additional equipment, labor, and energy costs. 2. DDG from aflatoxin-contaminated grain is not suitable as animal feed.
Cellulosic: Crop Residues (e.g., corn stover, wheat straw) Forages (e.g., alfalfa, Sudan grass, forage sorghum	Milling and hydrolysis of the linkages.	1. Use involves no integration with the livestock feed market. 2. Availability is widespread.	1. No commercially cost-effective process exists for hydrolysis of the linkages.

estimated if the amount of fermentable components—sugar, starch, and cellulose—is known prior to fermentation. If the yield is predicted based on percentages at the time of harvest, then the loss of fermentable solids during storage must be taken into account. This factor can be significant in the case of sugar crops, as discussed earlier.

The potential yield of ethanol is roughly one-half pound of ethanol for each pound of sugar. However, not all of the carbohydrate is made available to the yeasts as fermentable sugars, nor do the yeasts convert all of the fermentable sugars to ethanol. Thus, for estimating purposes, the yield of ethanol is roughly one gallon for each 15 pounds of sugar or starch in the crop at the time the material is actually fermented. Because of the many variables in the conversion of liquefied cellulose to fermentable sugar, it is difficult to estimate active ethanol yields from cellulose.

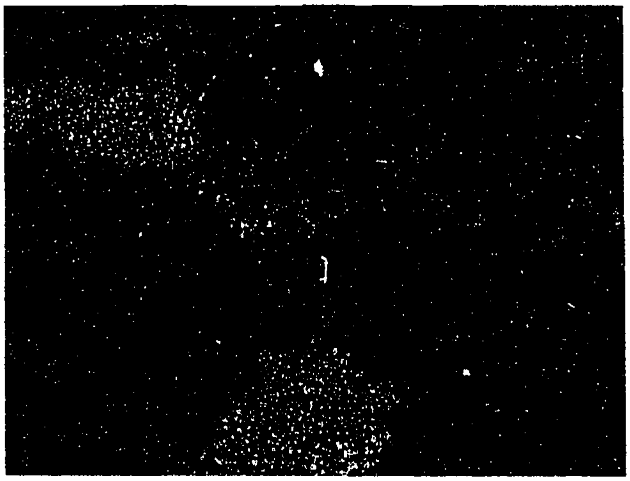
Carbon Dioxide

The fermentation of six-carbon sugars by yeast results in the formation of carbon dioxide as well as ethanol. For every pound of ethanol produced, 0.957 pound of carbon dioxide is formed; stated another way, for every 1 gallon of ethanol produced, 6.33 pounds of carbon dioxide are formed. This ratio is fixed; it is derived from the chemical equation:

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \longrightarrow \underset{\text{(ethanol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2} + \text{heat}$$

Other Coproducts

The conversion and fermentation of agricultural crops yield products in addition to ethanol and carbon dioxide. For example, even if pure glucose is fermented, some yeast will be grown, and they would represent a coproduct. These coproducts have considerable eco-



Wheat, Like the Other Cereal Grains, Produces High Ethanol Yields and the Chaff can be Burned for Process Heat

Chopped Forage Crops May Represent Significant Ethanol Production Potential as Technology for Their Use Improves

nomic value, but, since they are excellent cultures for microbial contaminants, they may represent a pollutant if dumped onto the land. Therefore, it becomes doubly important that these coproducts be put to good use.

Sugar crops, after the sugar has been extracted, yield plant residues which consist mostly of cellulose, unextracted sugar, and protein. Some of this material can be used as livestock feed, although the quantity and quality will vary widely with the particular crop. If the crop is of low feeding value, it may be used as fuel for the ethanol plant. This is commonplace when sugarcane is the feedstock.

Sweet sorghum may yield significant quantities of grain (milo), and the plant residue is suitable for silage, which is comparable to corn or sorghum silage except that it has a lower energy value for feeding. Sugar beet pulp from the production of sugar has always been used for livestock feed, as have the tops. Jerusalem artichokes, grown in the Soviet Union on a very large scale, are ensiled and fed to cattle, so the plant residue in this case would be suitable for silage. All of these residues can supply significant amounts of protein and roughage to ruminants.

It is evident that all silage production has the potential for the production of significant quantities of ethanol without affecting the present uses or agricultural markets. By planting silage crops of high sugar content and extracting a part of the sugar for the production of ethanol, the ensiled residue satisfies the existing demand for silage.

Starch feedstock consists mostly of grains and, to a smaller extent, root crops such as potatoes (white or sweet). The production of nonfermentable material in these root crops is much less than in grains, and the use of the residue is similar.

In the case of grains, it is commonplace to cook, ferment, and distill a mash containing the whole grain. The nonfermentable portion then appears in the stillage (the liquid drawn off the bottom of the beer column after stripping off the ethanol). About three-quarters of the nonfermentable material is in suspension in the form of solids ranging from very coarse to very fine texture, and the remainder is in solution in the water. The suspended material may be separated from the liquid and dried. The coarser solids, in this case, are distillers' light grains. The soluble portion may be concentrated to a syrup with from 25% to 45% solids, called distillers' solubles. When dried together with the coarser material, the product is called distillers' dark grains. These nonfermentable solids derived from grain are valuable as high-protein supplements for ruminants in particular. However, if very large quantities of grain are fermented, the great quantity supplied may exceed the demand and lower the prices. Fortunately, the potential demand exceeds the present usage as a protein supplement, since feeding experience has shown that these coproducts can substitute for a significant part of the grain. When the liquid stillage is fed either as it comes from the still or somewhat concentrated, it is especially valuable, since it permits the substitution of straw for a significant proportion of the hay (e.g., alfalfa) normally fed to ruminants.

The nonfermentable portion of the grain can also be used as human food. In the wet milling industry, the grain components are normally separated and the oil is extracted. The starch may be processed for a number of uses, or it may be used as feedstock for ethanol production. The gluten (the principal portion of the protein in the grain) may be separated and processed for sale as, for example, vital gluten (from wheat) or corn gluten. As another option, the solids may be sent through the fermenters and the beer still to appear as distillers' grains.

Grain processing as practiced in large plants is not feasible for small plants. However, a simple form of processing to produce human food may be feasible. Wheat can be simply processed to separate the starch from the combined germ, gluten, and fiber. They form a cohesive, doughy mass which has long been used as a base for meat-analogs. This material can also be incorporated into bread dough to enhance its nutritional value by increasing the protein, fiber, and vitamin (germ) content.

Work at the University of Wisconsin has resulted in the development of a simple, practical processing machine that extracts about 60% of the protein from forage crops in the form of a leaf juice [6]. The protein in the juice can be separated in a dry form to be used as a very high quality human food. The fibrous residue is then in good condition to be hydrolyzed to fermentable sugars. Most of the plant sugars are in the leaf juice and, after separation of the protein, are ready for fermentation. Forage crops have the potential for producing large amounts of ethanol per acre together with large amounts of human-food-grade protein. The protein production potential is conservatively 1,000 pounds per acre, equivalent to 140 bushels per acre of 12%-protein wheat [7].

Representative feedstock composition and coproduct yields are given in Table IV-2. Appendix D provides additional information in the table comparing raw materials for ethanol production. As discussed earlier, these data cannot be applied to specific analyses without giving consideration to the variable nature of the composition of the feedstock and the yield per acre of the crop.

TABLE IV-2. REPRESENTATIVE YIELDS OF SOME MAJOR DOMESTIC FEEDSTOCKS

Crop	Ethanol Yield
Cereal grains	2.5 gal/bu
Potatoes	1.4 gal/cwt
Sugar beets	20 gal/ton

AGRONOMIC CONSIDERATIONS

A simple comparison of potential ethanol yield per acre of various crops will not rank the crops in terms of economic value for production of ethanol. The crops vary considerably in their demands on the soil, demands for water, need for fertilization, susceptibility to disease or insect damage, etc. These factors critically influence the economics of producing a crop. Fortunately, forage crops which have the potential for producing large amounts of ethanol per acre have specific agronomic advantages relative to some of the principal grain crops (e.g., corn).

The nonfruiting crops, including forage crops, some varieties of high-sugar sorghum, and Jerusalem artichokes, are less susceptible to catastrophic loss (e.g., due to hail, frost, insects, disease, etc.), and, in fact, are less likely to suffer significant loss of production due to adverse circumstances of any sort than are fruiting crops such as grains. Furthermore, forage crops and Jerusalem artichokes are less demanding in their culture than almost any grain. Their cost of culture is usually lower than for grains on the same farm, and they have great potential for planting on marginal land.

FEEDSTOCK CONSIDERATIONS

It is apparent from the foregoing discussion that the selection of feedstocks for ethanol production will vary from region to region, and even from farm to farm. The results of development work now being carried out will influence choices but, most significantly, the additional choices open to farmers resulting from the opportunity to produce feedstocks for ethanol production from a large variety of crops will alter the patterns of farming. It is not possible to predict what new patterns will evolve. However, it is clear that there will be benefits from the creation of choices in the form of new markets for existing crops and alternative crops for existing markets.

In the near future, ethanol is likely to be produced primarily from grain. However, the development of processes for the effective use of other crops should yield results in the near term which could bring about a rapid increase in the use of nongrain feedstocks.

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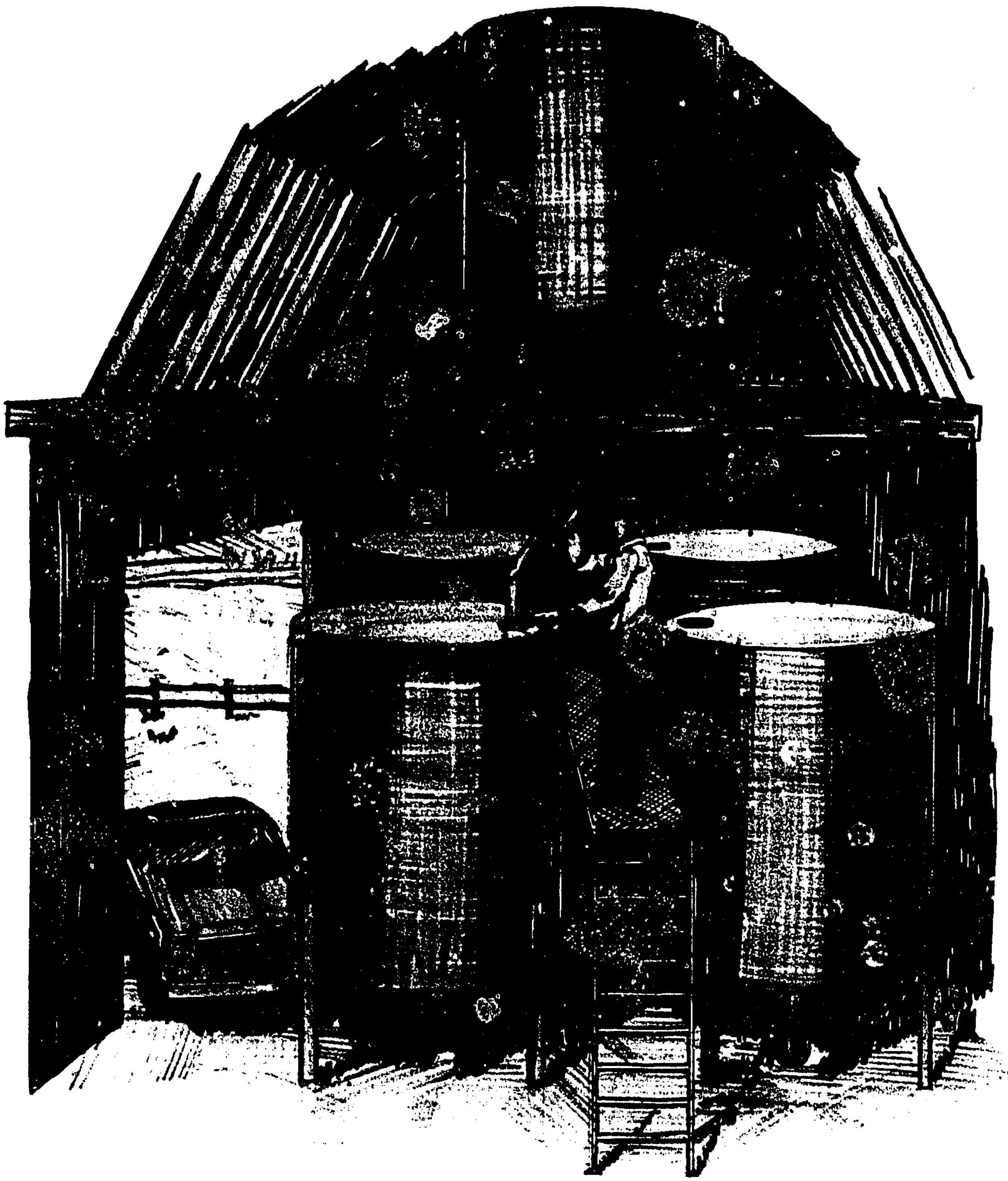
CHAPTER V

Plant Design



CHAPTER V

PLANT DESIGN

The criteria affecting the decision to produce ethanol and establishing a production facility can be categorized into two groups: fixed and variable. The fixed criteria are basically how much ethanol and coproducts can be produced and sold. These issues were discussed in Chapter II. This chapter is concerned with the second set of criteria and their effect on plant design.

Plant design is delineated through established procedures which are complex and interrelated. The essential elements, however, are described here.

The first step is to define a set of criteria which affect plant design. These criteria (not necessarily in order of importance) are:

- amount of labor that can be dedicated to operating a plant;
- size of initial investment and operating cost that can be managed in relation to the specific financial situation and/or business organization;
- ability to maintain equipment both in terms of time to do it and anticipated expense;
- federal, state, and local regulations on environmental discharges, transportation of product, licensing, etc;
- intended use (on-farm use and/or sales) of chemicals;
- desired form of coproducts;
- safety factors;
- availability and expense of heat source; and
- desired flexibility in operation and feedstocks.

The second step is to relate these criteria to the plant as a whole in order to set up a framework or context for plant operations. The third step is complex and involves relating the individual systems or components of production to this framework and to other connected systems within the plant. Finally, once the major systems have been defined, process control systems can be integrated where necessary. This design process leads to specifying equipment for the individual systems and process control.

After the process is discussed from overall plant considerations through individual system considerations to process control, a representative ethanol plant is described. It is an example to illustrate ethanol production technology and not a state-of-the-art or recommended design.

OVERALL PLANT CONSIDERATIONS

Before individual systems and their resulting equipment specifications are examined, the criteria listed above are examined in relation to the overall plant. This establishes a set of constraints against which individual systems can be correlated.

Required Labor

The expense the operation can bear for labor must be considered. To some extent the latter concern is modified by the size of plant selected (the expense for labor is less per gallon the more gallons produced). If it is possible to accomplish the required tasks within the context of daily farming activities, additional outside labor will not be required. A plant operated primarily by one person should, in general, require attention only twice—or at most three times—a day. If possible, the time required at each visit should not exceed 2 hours. The labor availability directly affects the amount and type of control and instrumentation that the plant requires, but it is not the sole defining criteria for plant specification.

Maintenance

The plant should be relatively easy to maintain and not require extensive expertise or expensive equipment.

Feedstocks

The process should use crop material in the form in which it is usually or most economically stored (e.g., forage crops should be stored as ensilage).

Use

The choice of whether to produce anhydrous or lower-proof ethanol depends upon the intended use or market and may also have seasonal dependencies. Use of lower-proof ethanols in spark-ignition tractors and trucks poses no major problems during summertime (or other

Labor Requirements for Ethanol Production can be a Par' · 'he Normal Farm Work Routine

periods of moderate ambient temperature). Any engine equipped for dual injection does not require anhydrous ethanol during moderate seasons (or in moderate climates). If the ethanol is to be sold to blenders for use as gasohol, the capability to produce anhydrous ethanol may be mandatory.

Heat Source

Agricultural residues, coal, waste wood, municipal waste, producer gas, geothermal water, solar, and wind are the preferred possibilities for heat sources. Examples of these considerations are shown in Table V-1. Each poses separate requirements on the boiler selected, the type and amount of instrumentation necessary to fulfill tending (labor) criteria, and the cash flow necessary to purchase the necessary quantity (if not produced on-farm). This last consideration is modified by approaches that minimize the total plant energy demand.

Safety

An ethanol plant poses several specific hazards. Some of these are enumerated in Table V-2 along with options for properly addressing them.

Coproduct Form and Generation

Sale or use of the coproducts of ethanol production is an important factor in overall profitability. Markets must be carefully weighed to assure that competitive influences do not diminish the value of the coproduct that results from the selected system. In some areas, it is conceivable that the local demand can consume the coproduct produced by many closely located small plants; in other areas, the local market may only be able to absorb the coproducts from one plant. If the latter situation occurs, this either depresses the local coproduct market value or encourages the purchase of equipment to modify coproduct form or type so that it can be transported to different markets.

Flexibility in Operation and Feedstocks

Plant profitability should not hinge on the basis of theoretical maximum capacity. Over a period of time, any of a myriad of unforeseen possibilities can interrupt operations and depress yields. Market (or redundant commodity) variables or farm operation considerations may indicate a need to switch feedstocks. Therefore, the equipment for preparation and conversion should be capable of handling cereal grain and at least one of the following:

- ensiled forage material;
- starchy roots and tubers; or
- sugar beets, or other storable, high-sugar-content plant parts.

Compliance with Environmental Regulations and Guidelines

Liquid and gaseous effluents should be handled in compliance with appropriate regulations and standards.

Initial Investment and Operating Costs

All of the preceding criteria impact capital or operating costs. Each criterion can influence production rates

TABLE V-1. HEAT SOURCE SELECTION CONSIDERATIONS

Heat Source	Heating Value (dry basis)	Form	Special Equipment Req'd	Boiler Types	Source	Particular Advantages	Particular Disadvantages
Agriculture Residuals	3,000-8,000 Btu/lb	Solid	Handling and feeding eqpmt.; collection eqpmt.	Batch burner-fire tube; fluidized bed	Farm	Inexpensive; produced on-farm	Low bulk density; requires very large storage area
Coal	9,000-12,000 Btu/lb	Solid	High sulfur coal requires stack scrubber	Conventional grate-fire tube; fluidized bed	Mines	Widely available demonstrated technology for combustion	Potentially expensive; no assured availability; pollution problems
Waste Wood	5,000-12,000 Btu/lb	Solid	Chipper or log feeder	Conventional fluidized bed	Forests	Clean burning; inexpensive where available	Not uniformly available
Municipal Solid Waste	8,000 Btu/lb	Solid	Sorting eqpmt.	Fluidized bed or conventional fire tube	Cities	Inexpensive	Not widely available in rural areas
Pyrolysis Gas		Gas	Pyrolyzer-fluidized bed	Conventional gas-boiler	Carbonaceous materials	Can use conventional gas-fired boilers	Requires additional piece of equipment
Geothermal	N.A.	Steam/ hot water	Heat exchanger	Heat exchanger water tube	Geothermal source	Fuel cost is zero	Capital costs for well and heat exchanger can be extremely high
Solar	N.A.	Radiation	Collectors, concentrators, storage batteries, or systems	Water tube	Sun	Fuel cost is zero	Capital costs can be high for required equipment
Wind	N.A.	Kinetic energy	Turbines, storage batteries, or systems	Electric	Indirect solar	Fuel cost is zero	Capital costs can be high for required equipment

which, in turn, change the income potential of the plant. An optimum investment situation is reached only through repeated iterations to balance equipment requirements against cost in order to achieve favorable earnings.

INDIVIDUAL SYSTEM CONSIDERATIONS

Design considerations define separate specific jobs which require different tools or equipment. Each step depends upon the criteria involved and influences related steps. Each of the components and systems of the plant must be examined with respect to these criteria Figure V-1 diagrams anhydrous ethanol production. The typical plant that produces anhydrous ethanol contains the following systems and/or components: feedstock handling and storage, conversion of carbohydrates to simple sugars, fermentation, distillation, drying ethanol, and stillage processing.

Feedstock Handling and Storage

Grain. A small plant should be able to use cereal grains. Since grains are commonly stored on farms in large quantity, and since grain-growing farms have the basic equipment for moving the grain out of storage, handling should not be excessively time-consuming. The increasing popularity of storing grain at high moisture content provides advantages since harvesting can be done earlier and grain drying can be avoided. When stored as whole grain, the handling requirements are identical to those of dry grain. If the grain is ground and stored in a bunker, the handling involves additional labor since it must be removed from the bunker and loaded into a grainery from which it can be fed by an auger into the cooker. This operation probably could be performed once each week, so the grains need not be ground daily as with whole grain.

Roots and tubers. Potatoes, sugar beets, fodder beets, and Jerusalem artichokes are generally stored whole in cool, dry locations to inhibit spontaneous fermentation by the bacteria present. The juice from the last three can be extracted but it can only be stored for long periods of time at very high sugar concentrations. This requires expensive evaporation equipment and large storage tanks.

Equipment for Handling and Storage of Crop Residues is Currently Available from Farm Equipment Manufacturers

TABLE V-2. ETHANOL PLANT HAZARDS

Hazards	Precautions
1. Overpressurization; explosion of boiler	• Regularly maintained/checked safety boiler "pop" valves set to relieve when pressure exceeds the maximum safe pressure of the boiler or delivery lines. • Strict adherence to boiler manufacturer's operating procedure. • If boiler pressure exceeds 20 psi, acquire ASME boiler operator certification. Continuous operator attendance required during boiler operation.
2. Scalding from steam gasket leaks	• Place baffles around flanges to direct steam jets away from operating areas. • (Option) Use welded joints in all steam delivery lines.
3. Contact burns from steam lines	• Insulate all steam delivery lines.
4. Ignition of ethanol leaks/fumes or grain dust	• If electric pump motors are used, use fully enclosed explosion-proof motors. • (Option) Use hydraulic pump drives; main hydraulic pump and reservoir should be physically isolated from ethanol tanks, dehydration section, distillation columns, condenser. • Fully ground all equipment to prevent static electricity build-up. • Never smoke or strike matches around ethanol tanks, dehydration section, distillation columns, condenser. • Never use metal grinders, cutting torches, welders, etc. around systems or equipment containing ethanol. Flush and vent all vessels prior to performing any of these operations.
5. Handling acids/bases	• Never breathe the fumes of concentrated acids or bases. • Never store concentrated acids in carbon steel containers. • Mix or dilute acids and bases slowly—allow heat of mixing to dissipate. • Immediately flush skin exposed to acid or base with copious quantities of water.

Hazards	Precautions
	• Wear goggles whenever handling concentrated acids or bases; flush eyes with water and immediately call physician if any gets in eyes.
	• Do not store acids or bases overhead work areas or equipment.
	• Do not carry acids or bases in open buckets.
	• Select proper materials of construction for all acid or base storage containers, delivery aides, valves, etc.
6. Suffocation	• Never enter the fermenters, beer well, or stillage tank unless they are properly vented.

Belt conveyers will suffice for handling these root crops and tubers. Cleaning equipment should be provided to prevent dirt and rocks from building up in the fermentation plant.

Sugar Crops. Stalks from sugarcane, sweet sorghum, and Jerusalem artichokes cannot be stored for long periods of time at high moisture content. Drying generally causes some loss of sugar. Field drying has not been successful in warm climates for sugarcane and sweet sorghum. Work is being conducted in field drying for sweet sorghum in cooler climates; results are encouraging though no conclusions can be drawn yet.

Canes or stalks are generally baled and the cut ends and cuts from leaf stripping are seared to prevent loss of juice.

A large volume of material is required to produce a relatively small amount of sugar, thus a large amount of storage space is necessary. Handling is accomplished with loaders or bale movers.

Conversion of Carbohydrates to Simple Sugars

Processing options available for converting carbohydrates to simple sugars are:

- enzymatic versus acid hydrolysis;
- high-temperature versus low-temperature cooking;
- continuous versus batch processing; and
- separation versus nonseparation of fermentable nonsolids.

Enzymatic versus acid hydrolysis. Enzymatic hydrolysis of the starch to sugar is carried out while cooling the cooked meal to fermentation temperature. The saccharifying enzyme is added at about 130° F, and this temperature is maintained for about 30 minutes to allow nearly complete hydrolysis following which the mash is cooled to fermentation temperature. A high-activity enzyme is added prior to cooking so that the starch is quickly converted to soluble polymeric sugars. The saccharifying enzyme reduces these sugars to monomeric sugars. Temperature and pH must be controlled within specific limits or enzyme activity decreases and cooking time is lengthened. Thus the

Crops for Ethanol Production fit Well into Normal Rotation Practices

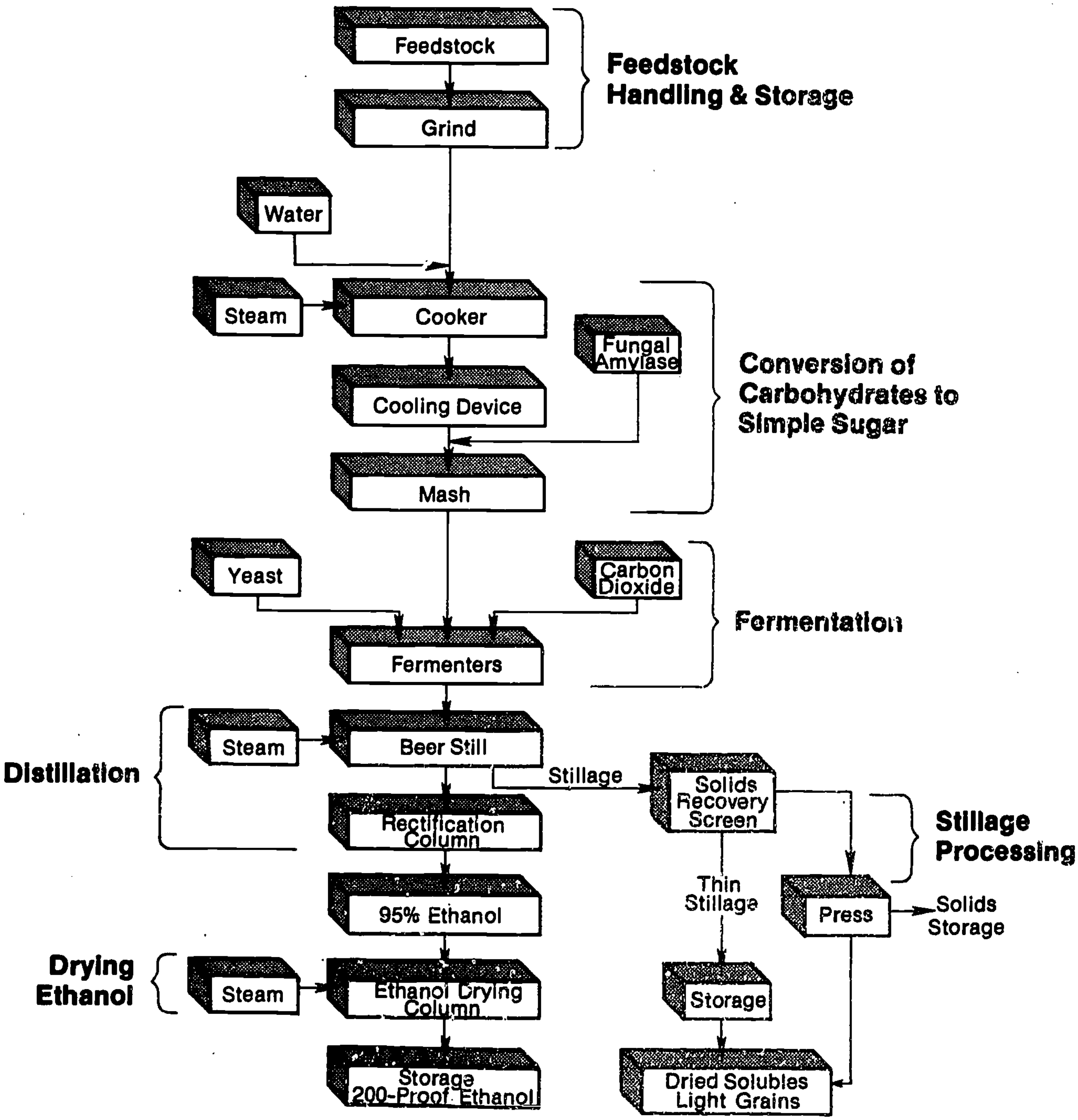


Figure V-1. Anhydrous Ethanol Production Flow Chart equipment for heating and cooling and the addition of acid or base are necessary.

Acid hydrolysis of starch is accomplished by directly contacting starch with dilute acid to break the polymer bonds. This process hydrolyzes the starch very rapidly at cooking temperatures and reduces the time needed for cooking. Since the resulting pH is lower than desired for fermentation, it may be increased after fermentation is complete by neutralizing some of the acid with either powdered limestone or ammonium hydroxide. It also may be desirable to add a small amount of glucoamylase enzyme after pH correction in order to convert the remaining dextrins.

High-temperature versus low-temperature cooking. Grain must be cooked to rupture the starch granules and to make the starch accessible to the hydrolysis agent. Cooking time and temperature are related in an inverse ratio; high temperatures shorten cooking time. Industry practice is to heat the meal-water mixture by injecting steam directly rather than by heat transfer through the wall of the vessel. The latter procedure runs the risk of causing the meal to stick to the wall; the subsequent scorching or burning would necessitate a shutdown to clean the surface.

High-temperature cooking implies a high-pressure boiler. Because regulations may require an operator in constant attendance for a high-pressure boiler operation, the actual production gain attributable to the high temperature must be weighed against the cost of the operator. If there are other supporting rationale for having the operator, the entire cost does not have to be offset by the production gain.

Continuous versus batch processes. Cooking can be accomplished with continuous or batch processes. Batch cooking can be done in the fermenter itself or in a separate vessel. When cooking is done in the fermenter, less pumping is needed and the fermenter is automatically sterilized before fermenting each batch. There is one less vessel, but the fermenters are slightly larger than those used when cooking is done in a separate vessel. It is necessary to have cooling coils and an agitator in each fermenter. If cooking is done in a separate vessel, there are advantages to selecting a continuous cooker. The continuous cooker is smaller than the fermenter, and continuous cooking and hydrolysis lend themselves very well to automatic, unattended operation. Energy consumption is less because it is easier to use counterflow heat exchangers to heat the water for mixing the meal while cooling the cooked meal. The load on the boiler with a continuous cooker is constant. Constant boiler load can be achieved with a batch cooker by having a separate vessel for preheating the water, but this increases the cost when using enzymes.

Continuous cooking offers a high-speed, high-yield choice that does not require constant attention. Cooking at atmospheric pressure with a temperature a little over 200° F yields a good conversion ratio of starch to sugar, and no high-pressure piping or pumps are required.

Separation versus nonseparation of nonfermentable solids. The hydrolyzed mash contains solids and dissolved proteins as well as sugar. There are some advantages to separating the solids before fermenting the mash, and such a step is necessary for continuous fermentation. Batch fermentation requires separation of the solids if the yeast is to be recycled. If the solids are separated at this point, the beer column will require cleaning much less frequently, thus increasing the feasibility of a packed beer column rather than plates. The sugars that cling to the solids are removed with the solids. If not recovered, the sugar contained on the solids would represent a loss of 20% of the ethanol. Washing the solids with the mash water is a way of recovering most of the sugar.

Fermentation

Continuous fermentation. The advantage of continuous fermentation of clarified beer is the ability to use high concentrations of yeast (this is possible because the yeast does not leave the fermenter). The high concentration of yeast results in rapid fermentation and, correspondingly, a smaller fermenter can be used. However, infection with undesired microorganisms can be troublesome because large volumes of mash can be ruined before the problem becomes apparent.

Batch fermentation. Fermentation time periods similar to those possible with continuous processes can be attained by using high concentrations of yeast in batch fermentation. The high yeast concentrations are economically feasible when the yeast is recycled. Batch fermentations of unclarified mash are routinely accomplished in less than 30 hours. High conversion efficiency is attained as sugar is converted to 10%-alcohol beer without yeast recycle. Further reductions in fermentation require very large quantities of yeast. The increases attained in ethanol production must be weighed against the additional costs of the equipment and time to culture large yeast populations for inoculation.

Specifications of the fermentation tank. The configuration of the fermentation tank has very little influence on system performance. In general, the proportions of the tank should not be extreme. Commonly, tanks are upright cylinders with the height somewhat greater than the diameter. The bottom may be flat (but sloped for drainage) or conical. The construction materials may be carbon steel (commonplace), stainless steel, copper, wood, fiberglass, reinforced plastic, or concrete coated on the inside with sprayed-on vinyl. Usually, the tanks are covered to permit collection of the CO_2 evolved during fermentation so that the ethanol which evaporates with it can be recovered.

Many potential feedstocks are characterized by relatively large amounts of fibrous material. Fermentation of sugar-rich material such as sugar beets, sweet sorghum, Jerusalem artichokes, and sugarcane as chips is not a demonstrated technology and it has many inherent problems. Typically, the weight of the nonfermentable solids is equal or somewhat greater than the weight of fermentable material. This is in contrast to grain mashers which contain roughly twice as much fermentable material as nonfermentable material in the mash. The volume occupied by the nonfermentable solids reduces the effective capacity of the fermenter. This means that larger fermenters must be constructed to equal the production rates from grain fermenters. Furthermore, the high volume of nonfermentable material limits sugar concentrations and, hence, the beer produced is generally lower in concentration (6% versus 10%) than that obtained from grain mashes. This fact increases the energy spent in distillation.

Since the nonfermentable solid chips are of larger size, it is unlikely that the beer containing the solids could be run through the beer column. It may be necessary to separate the solids from the beer after fermentation because of the potential for plugging the still. The separation can be easily accomplished, but a significant proportion of the ethanol (about 20%) would be carried away by the dewatering solids. If recovery is attempted by "washing out," the ethanol will be much more dilute than the beer. Since much less water is added to these feedstocks than to grain (the feedstock contains large amounts of water), only part of the dilute ethanol solution from the washing out can be recycled through the fermenter. The rest would be mixed with the beer, reducing the concentration of ethanol in the beer which, in turn, increases the energy required for distillation. Another approach is to evaporate the ethanol from the residue. By indirectly heating the residue, the resulting ethanol-water vapor mixture can be introduced into the beer column at the appropriate point. This results in a slight increase in energy consumption for distillation.

The fermenter for high-bulk feedstocks differs somewhat from that used for mash. The large volume of insoluble residue increases the demands on the removal pump and pipe plugging is more probable. Agitators must be sized to be self-cleaning and must prevent massive settling. High-speed and high-power agitators must be used to accomplish this.

The equipment for separating the fibrous residue from the beer when fermenting sugar crops could be used also to clarify the grain mash prior to fermentation. This would make possible yeast recyle in batch fermentation of grain.

Temperature control. Since there is some heat generated during fermentation, care must be taken to ensure that the temperature does not rise too high and kill the yeast. In fermenters the size of those for on-farm plants, the heat loss through the metal fermenter walls is sufficient to keep the temperature from rising too high when the outside air is cooler than the fermenter. Active cooling must be provided during the periods when the temperature differential cannot remove the heat that is generated. The maximum heat generation and heat loss must be estimated for the particular fermenter to assure that water cooling provisions are adequate.

Distillation

Preheater. The beer is preheated by the hot stillage from the bottom of the beer column before being introduced into the top of the beer column. This requires a heat exchanger. The stillage is acidic and hot so copper or stainless steel tubing should be used to minimize corrosion to ensure a reasonable life. Because the solids are proteinaceous, the same protein build-up that plugs the beer still over a period of time can be expected on the stillage side of the heat exchanger. This mandates accessibility for cleaning.

Beer column requirements. The beer column must accept a beer with a high solids content if the beer is not clarified. Not only are there solids in suspension, but also some of the protein tends to build up a rather rubbery coating on all internal surfaces. Plate columns offer the advantage of relatively greater cleaning ease when compared to packed columns. Even if the beer is clarified, there will be a gradual build-up of protein on the inner surfaces. This coating must be removed periodically. If the plates can be removed easily, this cleaning may be done outside of the column. Otherwise, a caustic solution run through the column will clean it.

The relatively low pH and high temperature of the beer column will corrode mild steel internals, and the use of stainless steel or copper will greatly prolong the life expectancy of the plates in particular. Nevertheless, many on-farm plants are being constructed with mild steel plates and columns in the interest of low first cost and ease of fabrication with limited shop equipment. Only experience will indicate the life expectancy of mild steel beer columns.

Introducing steam into the bottom of the beer column rather than condensing steam in an indirect heat exchanger in the base of the column is a common practice. The latter procedure is inherently less efficient but does not increase the total volume of water in the stillage as does the former. Indirect heating coils also tend to suffer from scale buildup.

Rectifying column. The rectifying column does not have to handle liquids with high solids content and there is no protein buildup, thus a packed column suffers no inherent disadvantage and enjoys the advantage in operating stability. The packing can be a noncorroding material such as ceramic or glass.

General considerations. Plate spacing in the large columns of commercial distilleries is large enough to permit access to clean the column. The small columns of on-farm plants do not require such large spacing. The shorter columns can be installed in farm buildings of standard eave height and are much easier to work on.

All items of equipment and lines which are at a significantly higher temperature than ambient should be insulated, including the preheated beer line, the columns, the stillage line, etc. Such insulation is more significant for energy conservation in small plants than for large plants.

Drying Ethanol

Addition of a third liquid to the azeotrope. Ethanol can be dehydrated by adding a third liquid such as gasoline to the 190-proof constant boiling azeotrope. This liquid changes the boiling characteristics of the mixture and further separation to anhydrous ethanol can be accomplished in a reflux still. Benzene is used in industry as a third liquid, but it is very hazardous for on-farm use. Gasoline is a suitable alternative liquid and does not pose the same health hazards as benzene, but it fractionates in a distillation column because gasoline is a mixture of many organic substances. This is potentially an expensive way to break the azeotrope unless the internal reflux is very high, thereby minimizing the loss of gasoline from the column. Whatever is choosen for the third liquid, it is basically recirculated continually in the reflux section of the drying column, and thus only very small fractions of makeup are required. The additional expense for equipment and energy must be weighed carefully against alternative drying methods or product value in uses that do not require anhydrous ethanol.

Molecular sieve. The removal of the final 4% to 6% water has also been accomplished on a limited basis using a desiccant (such as synthetic zeolite) commonly known as a molecular sieve. A molecular sieve selectively absorbs water because the pores of the material are smaller than the ethanol molecules but larger than the water molecules. The sieve material is packed into two columns. The ethanol—in either vapor or liquid form—is passed through one column until the material in that column can no longer absorb water. Then the flow is switched to the second column, while hot (450° F) and preferably nonoxidizing gas is passed through the first column to evaporate the water. Carbon dioxide from the fermenters would be suitable for this. Then the flow is automatically switched back to the other column. The total energy requirement for regeneration may be significant (the heat of absorption for some synthetic zeolites is as high as 2,500 Btu/lb). Sieve material is available from the molecular sieve manufacturers listed in Appendix E, but columns of the size required must be fabricated. The molecular sieve material will probably serve for 2,000 cycles or more before significant deterioration occurs.

Selective absorption. Another very promising (though undemonstrated) approach to dehydration of ethanol has been suggested by Ladisch [1]. Various forms of starch (including cracked corn) and cellulose selectively absorb water from ethanol-water vapor. In the case of grains, this opens the possibility that the feedstock could be used to dehydrate the ethanol and, consequently, regeneration would not be required. More investigation and development of this approach is needed.

Stillage Processing

The stillage can be a valuable coproduct of ethanol production. The stillage from cereal grains can be used as a high-protein component in animal feed rations, particularly for ruminants such as steers or dairy cows. Small on-farm plants may be able to directly use the whole stillage as it is produced since the number of cattle needed to consume the stillage is not large (about one head per gallon of ethanol production per day).

Solids separation. The solids can be separated from the water to reduce volume (and hence shipping charges) and to increase storage life. Because the solids contain residual sugars, microbial contaminants rapidly spoil stillage if it is stored wet in warm surroundings. The separation of the solids can be done easily by flowing the stillage over an inclined, curved screen consisting of a number of closely-spaced transverse bars. The solids slide down the surface of the screen, and the liquid flows through the spaces between the bars. The solids come off the screen with about 85% water content, dripping wet. They can drop off the screen into the hopper of a dewatering press which they leave at about 65% water content. Although the solids are still damp, no more water can be easily extracted. The liquid from the screen and dewatering press contains a significant proportion of dissolved proteins and carbohydrates.

Transporting solids. The liquid from the screen and dewatering press still contains a significant proportion of dissolved proteins and carbohydrates. If these damp solids are packed in airtight containers in CO_2 atmosphere, they may be shipped moderate distances and stored for a short time before microbes cause major spoilage. This treatment would enable the solids from most small plants to reach an adequate market. While the solids may easily be separated and dewatered, concentrating the liquid (thin stillage) is not simple. It can be concentrated by evaporation, but the energy consumption is high unless multiple-effect evaporators are used. These evaporators are large and expensive, and may need careful management with such proteinaceous liquids as thin stillage.

Stillage from aflatoxin-contaminated grains or those treated with antibiotics are prohibited from use as animal feed.

Distillers' solubles, which is the low-concentration (3% to 4% solids) solution remaining after the solids are dewatered, must be concentrated to a syrup of about 25% solids before it can be economically shipped moderate distances or stored for short times. In this form it can be sold as a liquid protein to be used in mixed feed or it can be dried along with the damp distillers' grains.

Disposing of thin stillage. If the distance from markets for the ethanol coproduct necessitates separating and dewatering the stillage from an on-farm plant, and if the concentration of the stillage for shipment is not feasible, then the thin stillage must be processed so that it will not be a pollutant when discharged. Thin stillage can be anaerobically fermented to produce methane. Conventional flow-through type digesters are dependent upon so many variables that they cannot be considered commercially feasible for on-farm use. Experimental work with packed-bed digesters is encouraging because of the inherent stability observed [1].

Another way to dispose of the thin stillage is to apply it to the soil with a sprinkler irrigation system. Trials are necessary to evaluate the various processes for handling the thin stillage. Because the stillage is acidic, care must be taken to assure that soil acidity is not adversely affected by this procedure.

PROCESS CONTROL

Smooth, stable, and trouble-free operation of the whole plant is essential to efficient conversion of the crop material. Such operation is, perhaps, more important to the small ethanol plant than to a larger plant, because the latter can achieve efficiency by dependence on powerful control systems and constant attention from skilled operators. Process control begins with equipment characteristics and the integration of equipment. There is an effect on every part of the process if the conditions are changed at any point. A good design will minimize negative effects of such interactions and will prevent any negative disturbance in the system from growing. Noncontinuous processes (e.g.,batch fermentation) tend to minimize interactions and to block such disturbances. The basic components requiring process control in a small-scale ethanol plant are cooking and hydrolysis, fermentation, distillation, ethanoi drying system pumps and drives, and heat source.

Control of Cooking and Hydrolysis

Input control. All inputs to the process must be controlled closely enough so that the departures from the desired values have inconsequential effects. The batch process has inherently wider tolerances than the continuous process. Tolerances on the grain-water ratio can be fairly loose. A variation of ½% in ethanol content will not seriously disturb the system. This corresponds to about a 3% tolerance on weight or volume measure. Meal measurement should be made by weight, since the weight of meal filling a measured volume will be sensitive to many things, such as grain moisture content, atmospheric humidity, etc. Volume measurement of water is quite accurate and easier than weighing. Similarly, volume measurement of enzymes in liquid form is within system tolerances. Powdered enzymes ideally should be measured by weight but, in fact, the tolerance on the proportion of the enzymes is broad enough so that volume measure also is adequate.

Temperature, pH, and enzyme control. The temperature, pH, and enzyme addition must also be controlled. The allowed variation of several degrees means that measurement of temperature to a more than adequate precision can be easily accomplished with calibrated, fast-response indicators and read-outs. The time dependence brings in other factors for volume and mass. A temperature measurement should be representative of the whole volume of the cooker; however, this may not be possible because, as the whole mass is heating, not all parts are receiving the same heat input at a given moment since some parts are physically far removed from the heat source. This affects not only the accuracy of the temperature reading but also the cooking time and the action of the enzyme. Uniformity of temperature and of enzyme concentration throughout the mass of cooking mash is desired and may be attained by mixing the mass at a high rate. Thus, agitation is needed for the cooker. The temperature during the specific phases of cooking and hydrolysis must be controlled by regulating steam and cooling water flow-rates based on temperature set-points.

Automatic controls. An automatic controller could be used to turn steam and cooling water on and off. The flow of meal, water, enzymes, and yeast could be turned on and off by the same device. Therefore, the loading and preparation of a batch cooker or fermenter could easily be carried out automatically. Safety can be ensured by measuring limiting values of such quantities as temperature, water level, pH, etc., and shutting down the process if these were not satisfied. Any commercial boiler used in a small plant would be equipped with simple, automatic controls including automatic shutdown in case certain conditions are not met. There is a need for an operator to check on the system to assure that nothing goes wrong. For example, the mash can set up during cooking, and it is better to have an operator exercise judgment in this case than to leave it entirely to the controls. Since cooking is the step in which there is the greatest probability of something going wrong, an operator should be present during the early, critical stages of batch cooking. If continuous cooking is used, unattended operation requires that the process be well enough controlled so that there is a small probability of problems arising.

Control of Fermentation

Temperature and pH control. Batch fermentation does not need direct feedback control except to maintain temperature as long as the initial conditions are within acceptable limits. For the small plant, these limits are not very tight. The most significant factors are pH and temperature. Of the two, temperature is most critical. It is very unlikely that the change in pH will be great enough to seriously affect the capacity of the yeast to convert the sugar. Fermentation generates some heat, so the temperature of the fermenter tends to rise. Active cooling must be available to assure that summertime operations are not drastically slowed because of high-temperature yeast retardation.

The temperature of the fermenter can be measured and, if the upper limit is exceeded, cooling can be initiated. It is possible to achieve continuous control of the fermenter temperature through modulation of the cooling rate of the contents. Such a provision may be necessary for very fast fermentation.

Automatic control. Continuous fermentation, like continuous cooking, should have continuous, automatic control if constant attendance by an operator is to be avoided.

The feasibility of continuous, unattended fermentation in on-farm plants has not been demonstrated, although it is a real possibility.

Control with attention at intervals only. The feasibility of batch fermentation with attention at intervals has been established. After initiating the cooking and hydrolysis steps, the operator could evaluate the progress of fermentation at the end of the primary phase and make any adjustments necessary to assure successful completion of the fermentation. This interval between the points requiring operator attention can vary widely, but is usually from 8 to 12 hours. Fermentation can be very fast—as short as 6 hours—but the conditions and procedures for reliably carrying out such fast fermentations have not yet been completely identified and demonstrated. The schedule for attending the plant should allow about 15% additional time over that expected for completion of the fermentation process. This permits the operator to maintain a routine in spite of inevitable variations in fermentation time.

Controls for Distillation

The distillation process lends itself well to unattended operation. Continuous control is not mandatory because the inputs to the columns can easily be established and maintained essentially constant. These inputs include the flow rate of beer, the flow rate of steam, and the reflux flow rate. These are the only independent variables. Many other factors influence column operation, but they are fixed by geometry or are effectively constant. Once the distillation system is stabilized, only changes in ambient temperature might affect the flow balance as long as the beer is of constant ethanol content. Sensitivity to ambient temperature can be minimized by the use of insulation on all elements of the distillation equipment, and by installing the equipment in an insulated building. Occasional operator attention will suffice to correct the inevitable slow drift away from set values. The system also must be adjusted for changes in ethanol content from batch to batch.

Distillation column design can aid in achieving stable operation. Packed columns are somewhat more stable than plate columns, particularly as compared to simple sieve plates.

Starting up the distillation system after shutdown is not difficult and can be accomplished either manually or automatically. An actual sequence of events is portrayed in the representative plant described at the end of this chapter. The process is quite insensitive to the rate of change of inputs, so the demands made on the operator are not great. It is important that the proper sequence be followed and that the operator know what settings are desired for steady-state operation.

Control of Ethanol Drying System

Operation of a molecular sieve is a batch process. As such, it depends on the capacity of the desiccant to ensure completion of drying. No control is necessary except to switch ethanol flow to a regenerated column when the active column becomes water-saturated. Water saturation of the sieve can be detected by a rise in temperature at the discharge of the column. This temperature rise signals the switching of flow to the other column, and regeneration of the inactive column is started immediately. The regeneration gas, probably CO_2 from the fermenter, is heated by flue gas from the boiler. The control consists of initiating flow and setting the temperature. The controller performs two functions: it indicates the flow and sets the temperature of the gas. Two levels of temperature are necessary: the first (about 250° F) is necessary while alcohol clinging to the molecular sieve material is being evaporated; the second (about 450° F) is necessary to evaporate the adsorbed water. Here again, the completion of each phase of the regeneration cycle is signaled by a temperature change at the outlet from the column. Finally, the col-

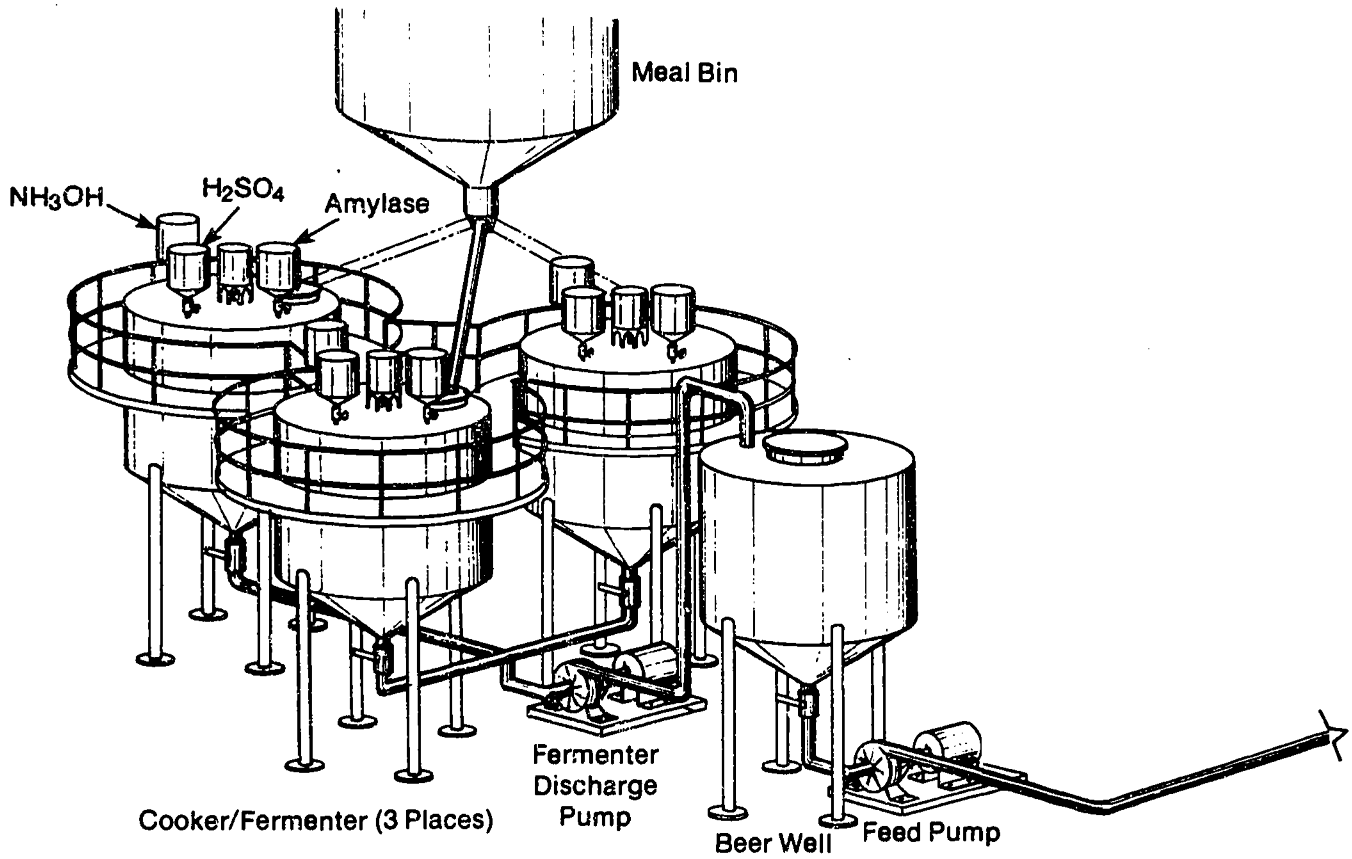


Figure V-2. Generic

umn is cooled by passing cool CO_2 through it until another outlet temperature change indicates completion of the regeneration cycle. The controls required for a dehydration distillation column are essentially the same as those required for the rectification column.

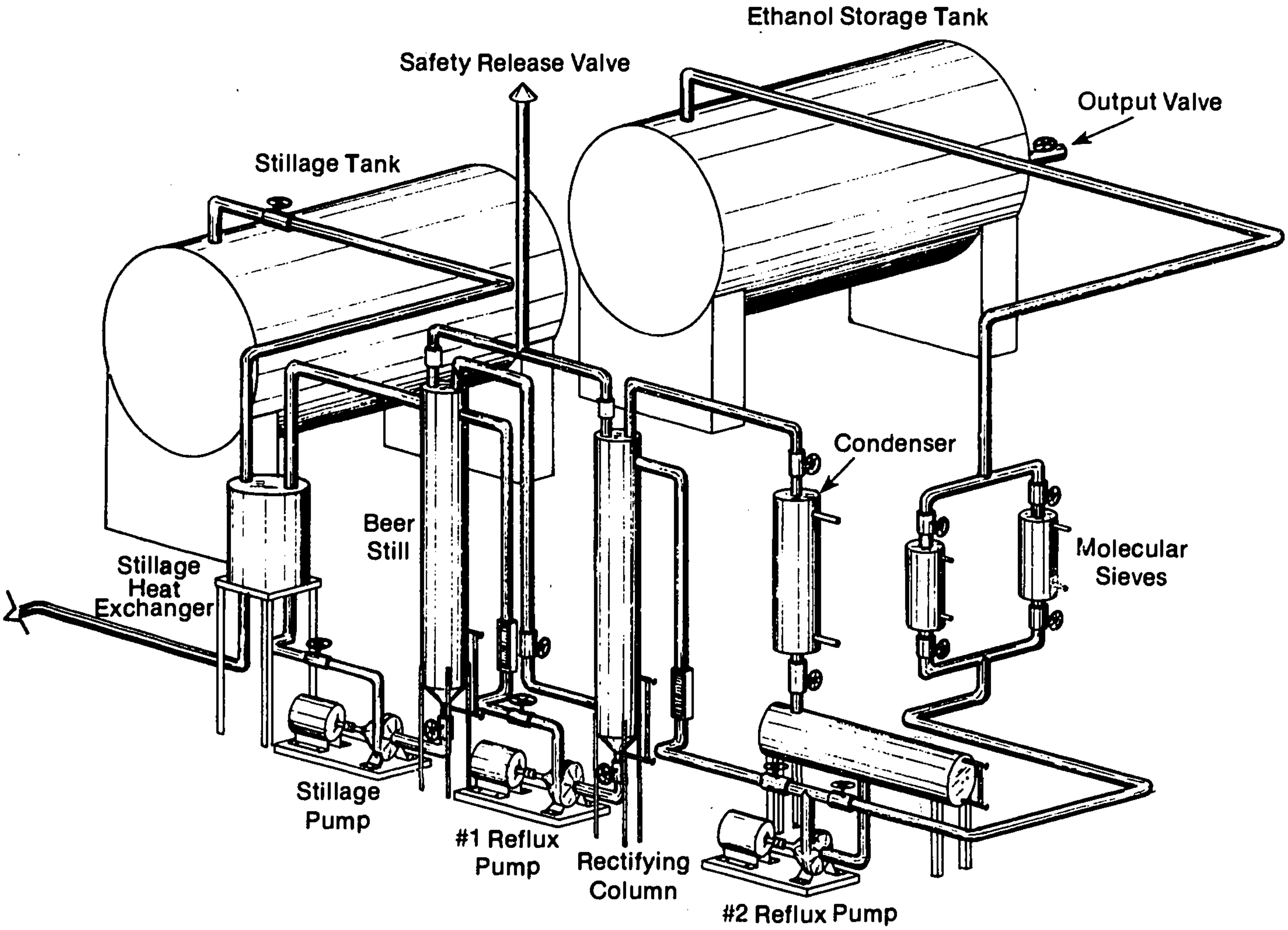
Controls for Pumps and Drives

The pumps used in this plant can be either centrifugal or any one of a number of forms of positive displacement pumps. The selection of the pump for mash or beer needs to take into account the heavy solids loading (nearly 25% for mash), the low pH (down to 3.5 for the beer), and the mild abrasive action of the mash.

The pumps might be powered by any of a number of different motors. The most probable would be either electric or hydraulic. If electric motors are used, they should be explosion-proof. Constant speed electric motors and pumps are much less expensive than variable-speed motors. Control of the volume flow for the beer pump, the two reflux pumps, and the product pump would involve either throttling with a valve, recirculation of part of the flow through a valve, or variable-speed pumps. Hydraulic drive permits the installation of the one motor driving the pumps to be located in another part of the building, thereby eliminating a potential ignition source. It also provides inexpensive, reliable, infinitely variable speed control for each motor. Hydraulic drives could also be used for the augers, and the agitators for the cookers and fermenters. Since hydraulics are used universally in farm equipment, their management and maintenance is familar to farmers.

Heat Source Controls

There are basically two processes within the ethanol production system that require heat: the cooking and the distillation steps. Fortunately, this energy can be supplied in low-grade heat (less than 250° F). Potential sources of heat include coal, agriculture residues, solar, wood wastes, municipal wastes, and others. Their physical properties, bulk density, calorific value, moisture content, and chemical constituency vary widely. This, in turn, requires a greater diversity in equipment for handling the fuel and controls for operating the boilers. Agriculture residues vary in bulk



Anhydrous Ethanol Plant

density from 15 to 30 pounds per cubic foot and the calorific value of oven-dry material is generally around 8,000 Btu per pound. This means that a large volume of fuel must be fed to the boiler continuously. For example, a burner has been developed that accepts large, round bales of stover or straw. The boiler feed rate will vary in direct proportion to the demand for steam. This in turn is a function of the distillation rate, the demand for heat for cooking (which varies in relation to the type of cooker and fermenter used—batch or continuous).

Emissions. Emissions controls on the boiler stack are probably minimal, relying instead upon efficient burner operation to minimize particulate emissions. If exhaust gas scrubbers or filters are required equipment, they in turn require feedback control. Filters must be changed on the basis of pressure drop across them which indicates the degree of loading (plugging). Scrubbers require control of liquid flow rate and control of critical chemical parameters.

Boiler safety features. Safety features associated with the boiler are often connected to the control scheme to protect the boiler from high-pressure rupture and to prevent burnout of the heat expander tubes. Alarm systems can be automated and have devices to alert an operator that attention is needed. For instance, critical control alarms can activate a radio transmitter, or "beeper," that can be worn by the farmer while performing other normal work routine.

REPRESENTATIVE ETHANOL PLANT

General descriptions of major components serve only to define possibilities. In the previous section, considerations for specifying the appropriate equipment to accomplish desired objectives were examined. The following is a description of a specific representative ethanol plant producing ethanol and wet stillage. This representative plant normally produces 25 gallons of anhydrous ethanol per hour. The distillation section can be operated continuously with shutdown as required to remove protein buildup in the beer column. Heat is provided by a boiler that uses agricultural residue as fuel. The plant is designed for maximum flexibility, but its principal feedstocks are cereal grain, with specific emphasis on corn.

This representative plant should not be construed as a best design or the recommended approach. Its primary purpose is to illustrate ethanol production technology.

Overview of the Plant

As shown in Figure V-2, the representative plant has seven main systems: (1) feed preparation and storage, (2) cooker/fermenter, (3) distillation, (4) stillage storage, (5) dehydration, (6) product storage, (7) and boiler. Grain from storage is milled once a week to fill the meal bin. Meal from the bin is mixed to make mash in one of three cooker/fermenters. The three cooker/fermenters operate on a staggered schedule—one starting, one fermenting, and one pumping out—to maintain a full beer well so the distillation section can be run continuously. The beer well provides surge capacity so that the fermenters can be emptied, cleaned, and restarted without having to wait until the still can drain them down. Beer is fed from the beer well to the beer still through a heat exchanger that passes the cool beer counter-current to the hot stillage from the bottom of the beer still. This heats up the beer and recovers some of the heat from the stillage.

The beer still is a sieve-plate column. The feed is introduced at the top of the stripping section. Vapors from the beer column flow into the bottom of the rectifying column where the ethanol fraction is enriched to 95%. The product is condensed and part of it is recycled (refluxed) to the top of the column and if ethanol is being dried at the time, part of it is pumped to the dehydration section. If the ethanol is not being dried, it flows directly to a storage tank for 190-proof ethanol (a separate tank must be used for the anhydrous ethanol).

The stillage that is removed from the bottom of the beer column is pumped through the previously mentioned heat exchanger and is stored in a "whole stillage" tank. This tank provides surge capacity when a truck is unavailable to haul the stillage to the feeder operation.

The distillation columns are designed for inherent stability once flow conditions are established so a minimum of automatic feedback control and instrumentation is required. This not only saves money for this equipment but it reduces instrument and/or controller-related malfunctions. Material flows for cooling and fermentation are initiated manually but proceed automatically. A sequencer microprocessor (a miniature computer) controls temperature and pH in the cooker/fermenters. It also activates addition of enzymes and yeast in the proper amounts at the proper times. At any point, the automatic sequence can be manually overridden.

The period of operation is quite flexible, and allows for interruptions of operation during planting or harvest time. The 25 gallons per hour production is a nominal capacity, not a maximum. All support equipment is similarly sized so that slightly higher production rates can be achieved if desired.

The control and operating logic for the plant is based on minimal requirements for operator attention. Critical activities are performed on a routine periodic basis so that other farming operations can be handled during the bulk of the day. All routines are timed to integrate with normal chore activities without significant disruption.

A complete equipment list is given in Table V-3. The major components are described in Table V-4.

Start-Up and Shutdown

The following is a sequence for starting-up or shutting down the plant.

Preliminaries. For the initial start-up, a yeast culture must be prepared or purchased. The initial yeast culture can use a material such as molasses; later cultures can be grown on recycled stillage. Yeast, molasses, and some water should be added to the yeast culture tank to make the culture. Although yeasts function anaerobically, they propagate aerobically, so some oxygen should be introduced by bubbling a small amount of air through the culture tank. The initial yeast culture will take about 24 hours to mature.

At this time, the boiler can be started. Instructions packaged with the specific boiler will detail necessary steps to bring the unit on-line (essentially the boiler is filled with water and the heat source started). These instructions should be carefully followed, otherwise there is the possibility of explosion.

The next step is the milling of grain for the cooker/fermenter. Enough grain should be milled for two fermentation batches (about 160 bushels).

Prior to loading the fermenter, it should be cleaned well with a strong detergent, rinsed, decontaminated with a strong disinfectant, and then rinsed with cold water to flush out the disinfectant.

Mash Preparation. The amount of meal put in the cooker/fermenter depends upon the size of batch desired. For the first batch it is advisable to be conservative and start small. If the batch is ruined, not as much material is wasted. A 2,000-gallon batch would be a good size for this representative plant. This will require mixing 80 bushels of ground meal with about 500 gallons of water to form a slurry that is about 40% starch.

TABLE V-3. EQUIPMENT FOR REPRESENTATIVE PLANT

Equipment	Description
Grain Bin	• ground carbon steel • 360 bu with auger for measuring and loading cooker/fermenter
Back-Pressure Regulators	• 0–50 in. of water
Back-Pressure Regulator	• 100–200 psig
Beer Storage Tank	• 6,000-gal • carbon steel
Condenser, Distiller	• 225 ft², tube and shell • copper coil (single tube, 1½-ft diameter) • steel shell cooled
Condenser	• 50 ft² • copper coil (single tube) • steel shell
Cooker, Fermenter	• 4,500-gal • hydraulic agitator • carbon steel
Microprocessor	• to control heat for cooking, cooling water during fermentation, and addition of enzymes
Beer Still	• 18-ft height • 1-ft diameter • sieve trays • carbon steel
Alcohol Still	• 24-ft height • 1-ft diameter • sieve trays • carbon steel
CO_2 Compressor	• 1,500 ft³/hr, 200 psig
Frangibles	• 4–5 psig burst • alarm system • high and low pressure
Heat Exchanger	• 150 ft², tube and shell • copper coil (single tube, 2-in.) diameter) • steel shell
Heat Exchanger	• 100 ft² • stack gas • carbon steel
Hydraulic System for Pumps	• with shut-off valves tied to microprocessor monitoring pump pressures and frangible vent temperature
Grain Mill	• 300 bu/hr • roller type
Beer Pump	• positive displacement • hydraulic drive • variable speed • carbon steel, 50 gal/min
Yeast Pump	• positive displacement • hydraulic drive • variable speed • carbon steel, 10 gal/min
Feed Pump	• 300 gal/hr • variable speed • positive displacement • hydraulic drive • carbon steel
Stillage Pump	• 300 gal/hr • variable speed • positive displacement • hydraulic drive • carbon steel
Column 2 Bottoms Pump	• 250 gal/hr • open impeller • centrifugal hydraulic drive • carbon steel
Column 2 Product and Reflux Pump	• 200 gal/hr

TABLE V-3. EQUIPMENT FOR REPRESENTATIVE PLANT—*Continued*

Equipment	Description
	• open impeller • centrifugal hydraulic drive • carbon steel
Ethanol Transfer Pump	• centrifugal • explosion-proof motor • 50 gal/min
Water Pump	• electric • open impeller • centrifugal • 300 gal/min
Rotameter	• water fluid • glass • 25 gal/min
Rotameter	• glass • 0–250 gal/hr
Rotameter	• glass • 0–150 gal/hr
Rotameter	• glass • 0–50 gal/hr
Rotameter–CO_2	• glass • 200 psig • 100 actual ft^3/hr
Boiler	• 500 hp, with sillage burning system
Stillage Pump	• electric motor • positive displacement • 600 gal/hr
Pressure Gauges	• 6, 0–100 psig • 1, 0–200 psig
Pressure Transducers	• 4, 0–100 psig
Ethanol Drying Columns	• includes molecular sieve packing 3-angstrom synthetic zeolite
Condensate Receiver	• 30-gal, horizontal • carbon steel
Ethanol Storage Tank	• carbon steel • 9,000-gal
CO_2 Storage	• 100-gal, 200 psig
Stillage Storage Tank	• 4,500-gal • carbon steel
Thermocouples	• type K, stainless sheath
Multichannel Digital Temperature Readout	• 15 channels
Ball Valve-65	
Metering Valve-6	
Three-Way Valve-4	
Snap Valve	
Water Softener	• 300 gal/hr
Yeast Culture Tank	• carbon steel • 200-gal

TABLE V-4. FEATURES OF MAJOR PLANT COMPONENTS

Components	Features
Feedstock Storage and Preparation	
Grain Mill	• roller mill that grinds product to pass a 20-mesh screen
Meal Bin	• corrugated, rolled galvanized steel with 360-bu capacity

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TABLE V-4. FEATURES OF MAJOR PLANT COMPONENTS—*Continued*

Components	Features
Auger	• used for feeding meal to cooker/fermenter
Trip buckets	• used to automatically measure meal in proper quantity; as buckets fill, they become unbalanced and tip over into the cooker/fermenter; each time a bucket tips over, it trips a counter; after the desired number of buckets are dumped, the counter automatically shuts off the auger and resets itself to zero
Cooker/Fermenter	
3 Cookers	• 4,500-gal right cylinder made of cold-rolled, welded carbon steel

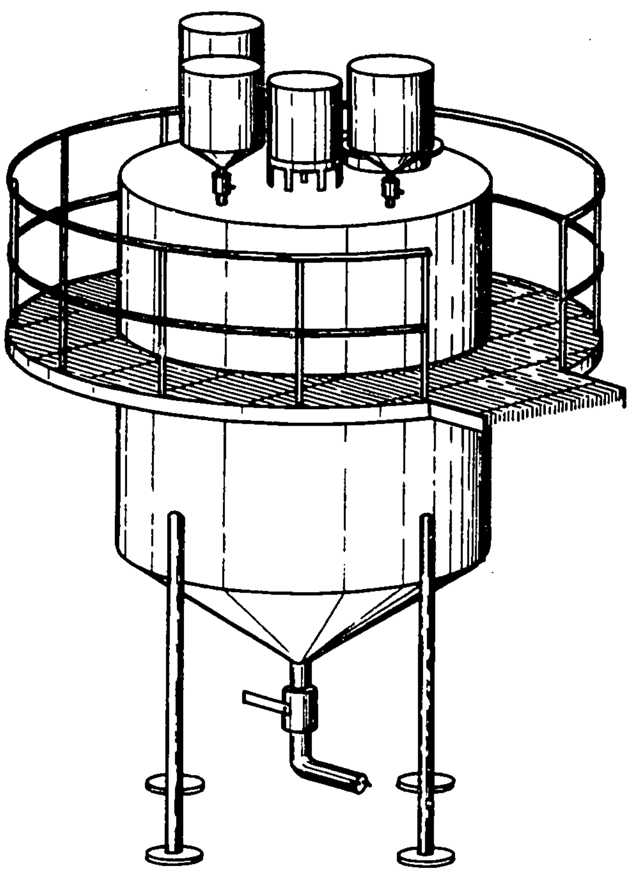

Figure V-3. Cooker/Fermenter

Components	Features
	• flat top • conical bottom • ball-valve drain port • top-mounted feed port • hydraulic agitator • cooling coils • pH meter • sodium hydroxide tank • dilute sulfuric acid tank • temperature-sensing control, preset by sequences • steam injection
Glucoamylase Enzyme Tanks	• 5-gal capacity • fitted with stirrer • ball-valve port to cooker/fermenter triggered by sequencer
Sequencer	• controls cooking fermentation sequences • actuates ball-valve to add glucoamylase enzyme after temperature drops from liquefaction step • sequences temperature controller for cooker/fermenter • sets pH reading for pH controller according to step • 6,000-gal capacity • cold-rolled, welded carbon steel • flat top • conical bottom • ball-valve port at bottom • man-way on top, normally kept closed (used for cleaning access only)

TABLE V-4. FEATURES OF MAJOR PLANT COMPONENTS—*Continued*

Components	Features
Beer/Stillage Heat Exchanger	• 2-ft diameter, 3-ft tall—beer flows through coil, stillage flows through tank

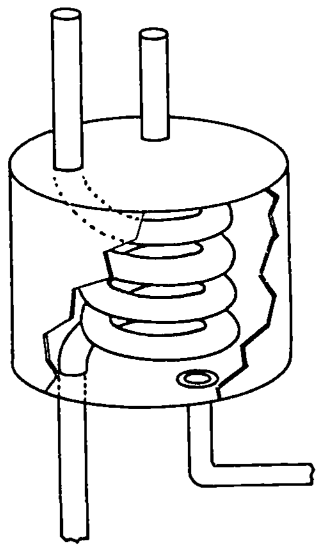

Figure V-4. Beer/Stillage Heat Exchanger

Components	Features
Beer Pump	• pump from any of the three cooker/fermenters to beer well, hydraulic motor on pump

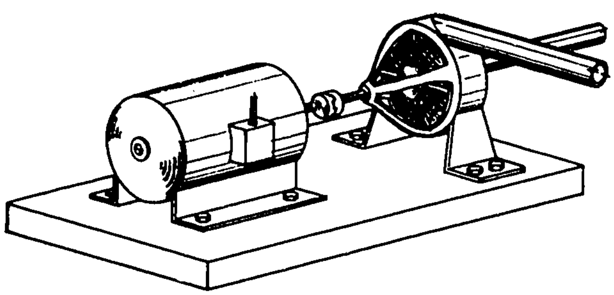

Figure V-5. Beer Pump

Components	Features
Feed Pump	• pump beer to distillation system, hydraulic motor on pump
Distillation	
Beer Still	• 1-ft diameter • 20-ft tall coated carbon steel pipe with flanged top and bottom • fitted with a rack of sieve trays that can be removed either through the top or bottom • steam introduced at bottom through a throttle valve • pump at the bottom to pump stillage out, hydraulic motor on pump • input and output flows are controlled through manually adjusted throttle valves • safety relief valves prevent excess pressure in column • instrumentation includes temperature indication on feed line and at the bottom of the still, sight-glass on bottom to maintain liquid level, pressure indicators on the outlet of the stillage pump

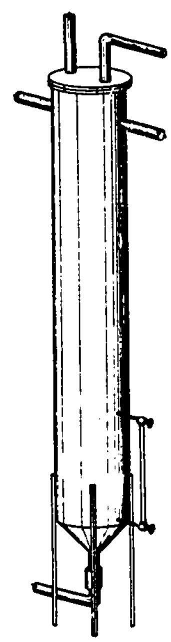

Figure V-6. Beer Still

Components	Features
Rectifying Column	• 20-ft tall • 1-ft diameter • coated carbon steel pipe with flanged top, welded bottom to prevent ethanol leaks • fitted with rack of sieve-plates which can be removed through the top

TABLE V-4. FEATURES OF MAJOR PLANT COMPONENTS—*Continued*

Components	Features
	• pump at bottom of column refluxes ethanol at set rate back to beer still, rate is set with throttle valve and rotameter, hydraulic motor on pump

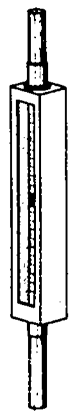

Figure V-7. Rectifying Column Rotameter

Components	Features
	• instrumentation consists of temperature indication at top and bottom of column and level indication at bottom by sight-glass, pressure is indicated on the outlet of the recirculation pump

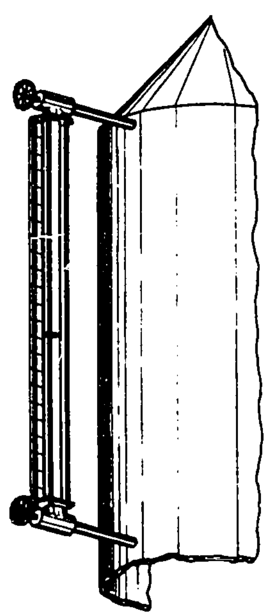

Figure V-8. Rectifying Column Sight-Glass

Components	Features
Condenser	• ethanol condenses (in copper coil), water flows through tank
	• cooling water flow-rate is manually adjusted

Components	Features
Dehydration Secton	
2 Molecular Sieves	• packed bed
	• synthetic zeolite, type 3A-molecular sieve material
	• automatic regeneration
	• automatic temperature control during regeneration
	• throttle flow control to sieves adjusted manually

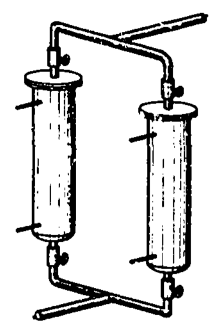

Figure V-9. Molecular Sieves

Components	Features
CO_2 Compressor	• 2-stage air compressor with reservoir (conventional)
Denaturing Tank	• meets Bureau of Alcohol, Tobacco, and Firearms specifications (See Appendix B)
Ethanol Storage	
2 Ethanol Storage Tanks	• 3,000-gal capacity each
	• same as gasoline storage tanks
	• cold-rolled, welded carbon steel
Stillage Storage Tank	• 6,000-gal capacity
	• cold-rolled, welded carbon steel

Cooking. The water and meal are blended together as they are added to the cooker/fermenter. It is crucial to use rates that promote mixing and produce no lumps (the agitator should be running). The alpha-amylase enzyme can be blended-in during the mixing (the enzyme must be present and well mixed before the temperature is raised because it is very difficult to disperse the enzyme after gelatinization occurs).

Since cooking in this representative plant is initiated by steam injection during slurry-mixing, the enzyme must be blended in simultaneously. (Dry enzymes should be dispersed in a solution of warm water before mixing is started. This only takes a small amount of water, and the directions come on the package. Liquid enzymes can be added directly.) If the pH is lower than 5.5, it should be adjusted by addition of a calculated amount of sodium hydroxide. If the pH is higher than 7.0, a calculated amount of sulfuric acid should be added. Steam is added at a constant rate to achieve uniform heating. When the temperature reaches 140° F (60° C), the physical characteristics of the mash change noticeably as the slurry of starch becomes a solution of sugar. If there is insufficient enzyme present or if heating is too rapid, a gel will result that is too thick to stir or add additional enzyme to. If a gel does form, more water and enyzme can be added (if there is room in the tank, and the cook can start over.

Once liquefaction occurs, the temperature is uniformly raised to the range for optimum enzyme activity (about 200° F) and held for about half an hour. At the end of this time, a check is made to determine if all of the starch has been converted to sugar. A visual inspection usually is sufficient; incomplete conversion will be indicated by white specks of starch or lumps; a thin, fluid mash indicates good conversion. The mash is held at this temperature until most of the starch is converted to dextrin.

Saccharification. Once the mash is converted to dextrin, the microprocessor is manually started and (1) reduces the temperature of the mash to about 135° F (57° C) by circulating cooling water through the coils; and (2) adds dilute sulfuric acid (H_2SO_4) until the pH drops to between 3.7 and 4.5 (H_2SO_4 addition is controlled by a pH meter and a valve on the H_2SO_4 tank). Once the pH and temperature are within specified ranges, the microprocessor triggers the release of liquid glucoamylase (which must be premixed if dry enzyme is used) from its storage tank. Either sodium hydroxide or sulfuric acid is added automatically as required to maintain proper pH during conversion. The microprocessor also holds the mash at a constant temperature by regulating steam and/or cooling water flow for a preset period of time. The sequencer can be overridden if the conversion is not complete.

Fermentation. After hydrolysis is complete, the sequencer lowers the temperature of the mash to about 85° F by adding the remaining 1,500 gallons of water (and by circulating cooling water thereafter as necessary). The water addition will raise the pH of the solution so the sequencer automatically adjusts the pH to between 4.5 and 5.0. Next, the sequencer adds a premeasured quantity of dispersed distillers' yeast from the yeast tank. (Note that the yeast tank is not on top of the cooker/fermenter as high temperatures during cooking would kill the culture.) Thereafter, the sequencer maintains the temperature between 80° F and 85° F and the pH between 3.0 and 5.0. The agitator speed is reduced from that required during cooking to a rate which prevents solids from settling, but does not disturb the yeast. The batch is then allowed to ferment for 30 to 36 hours.

Pump-Out and Cleanup. After a batch is complete, it is pumped to the beer well and the fermenter is hosed out to remove any remaining solids.

Distillation. Once the beer well is full, the distillation system can be started up. This process involves the following steps.

1. **Turn on the condenser cooling water.**

2. **Purge the still with steam.** This removes oxygen from the system by venting at the top of the second column. When steam is seen coming out of the vent, the steam can be temporarily shut off and the vent closed. Purging the still with steam not only removes oxygen, but also helps to preheat the still.

3. **Pump beer into the still.** The beer is pumped in until it is visible at the top of the sight-glass.

4. **Turn steam on and add beer.** This process of adding beer and watching the liquid level movement to adjust the steam level will be repeated several times as the columns are loaded. Initially, steam flows should be set at a low level to prevent overloading the trays which might require shutdown and restart. During this period the valves in the reflux line are fully opened but the reflux pump is left off until enough liquid has built up in the condensate receiver. This prevents excessive wear on the pump. The reflux line *between* the two columns should also be opened and that reflux pump should be left off. The liquid level in the bottom of the beer still should be monitored and when it drops to half way, beer should be fed back into the column to refill the bottom of the still. The liquid level should continue to drop; if it does not, additional steam should be fed into the still bottom.

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5. **Start reflux pump between the beer still and rectifying column.** When liquid starts to accumulate in the bottom of the rectifying column, the reflux pump between this still and the beer still is started. Flow in this line should be slow at first and then increase as more and more material reaches the rectifying column. When reflux is started to the beer still, the steam feed-rate will have to be slightly increased, because reflux tends to cool down a column.

6. **Start pump for reflux from the condensate receiver to rectifying column.** Eventually, enough vapor will have been condensed to fill the condensate receiver. Then, the pump for the reflux to the rectifying column can be started. Flow for this reflux line should be slow at first and then increased as more and more material distills. It should be noted that temperatures in the columns will be increasing as this process takes place. When the top temperature of the rectifying column is no longer increasing, the liquid levels in the bottom of the two columns are changing, and the condensate receiver level is no longer changing. Then, the reflux flow rates are at their designed flow and the column has reached equilibrium.

7. **Set beer feed pump, stillage pump, and product take-off at their designed flow.** Initially, the beer feed entering the beer still will be cooler than normal; the heat exchanger has not heated up yet. For this reason the steam to the beer still will need to be slightly increased. The thermocouple at the feed point will indicate when the feed is being heated to its designed temperature. At this time, the steam rate can be slightly lowered. Some minor adjustments will probably be needed. It must be kept in mind that this is a large system, and it takes some time for all points to react to a change in still conditions. All adjustments should be made, and then a period of time should be allowed before any additional adjustments are made.

8. **Check product quality.** Product quality at this time should be checked to insure that ethanol concentration is at the designed level. If it is lower than anticipated, the reflux ratio should be increased slightly. An increase in reflux cools the columns and additional heat must be applied to compensate for this. Also, the product flow-rate will be slightly decreased; therefore, flow rate to the still should also be varied. The ethanol concentration in the stillage should be checked to ensure that it does not exceed design concentration significantly.

9. **Dry ethanol.** After the ethanol leaves the distillation column, it must be further dried by passing through the molecular sieve drying columns and then stored in the ethanol storage tank. Literature from the vendor of the molecular sieve material will indicate at what temperature that flow must be switched to the other unit.

10. **Regenerate spent sieve material.** Carbon dioxide (CO_2) is used to regenerate the molecular sieve material. The CO_2 is collected from the fermentation system and compressed-CO_2 storage tank. To regenerate the molecular sieve material, the lines for regeneration are opened. Next, the CO_2 line is opened to allow flow to the stack heat exchanger and then on to the sieve columns. A rotameter in the CO_2 line is set to control the CO_2 flow-rate to the desired level. The molecular sieve columns are heated to about 450° F during regeneration. After regeneration is complete, the column is cooled down by CO_2 which bypasses the stack heat exchanger.

This essentially covers all the steps involved in the start-up of the plant. It should again be emphasized that caution must be exercised when operating any system of this complexity. If proper care is taken, and changes to the system operation are thought out sufficiently, successful plant operation will be achieved.

Shutdown. The second period of operation which differs significantly from normal operation is that period when the plant is being shut down. Proper care must be taken during shutdown to ensure both minimal losses of product and ease of restarting the process.

As the fermenters are individually shut down, they should be cleaned well to inhibit any unwanted microbial growth. The initial rinse from the fermenters can be pumped to the beer storage tank. Subsequent rinses should be discarded. The processing of this rinse material through the stills can continue until the top temperature of the beer column reaches 200° F. At this time, the unit should be put on total reflux.

During this shutdown period, the product quality will have degraded slightly, but the molecular sieve column will remove any additional water in the ethanol product. The stillage from the distillation system can be sent to the stillage storage system until the stillage is essentially clean. At this point, the steam to the column should be shut off and the column should be allowed to cool. During cooling, the column should be vented to prevent system damage. The pressure inside the column will be reduced as it cools. The air which enters the column at this time can be purged with steam prior to the next period of operation. The molecular sieve drying columns can be regenerated if necessary. The boiler should be shut down. If the shutdown period is of any significant duration, the boiler should be drained. If the plant is to be shut down for a short term, the fermenters should not require any additional cleaning. After an extended shutdown period, it is advisable to clean the fermenters in a manner similar to that performed at the initial start-up.

Shutdown periods are the best time to perform preventive maintenance. The column trays can be cleaned, pump seals replaced, etc. The important thing to remember is that safety must not be overlooked at this time. Process lines should be opened carefully because, even after extended periods of shutdown, lines can still be pressurized. If it is necessary to enter tanks, they must be well vented. It is suggested that an air line be placed in the tanks and that they be purged with air for several hours before they are entered. Also, a tank should never be entered without another person stationed outside the tank in case an emergency situation arises.

Daily Operation

The day-by-day operation of the representative on-farm plant requires the attention of the operator for two periods of about two hours each every day.

Each morning, the operator begins by checking the condition of the plant. All systems are operative because the operator would have been alerted by the alarm if there had been a shutdown during the night. A quick check will confirm that the beer flow and reflux flows are near desired values. The temperature of the top plate of the rectifying column and the proof of the product before drying should be checked. Even if the proof is low, the final product should be dry because the dryer removes essentially all of the water, regardless of input proof. However, excessively low entering proof could eventually overload the regeneration system. If the proof before drying is low, reflux flow is adjusted to correct it.

Next the fermenter that has completed fermentation is checked. The concentration of ethanol is checked and compared to the value indicated by the sugar content at the beginning of fermentation. If the concentration is suitable, the contents of the fermenter are dumped into the beer well. The inside of the fermenter is washed briefly with a high-pressure water stream. Then the fermenter is filled with preheated water from the holding tank.

The operator next checks the condition of the boiler and bale burner. The bale burner is reloaded with two of the large, round bales of corn stover from the row outside of the building. A front-end loader is used for this. The operator returns to the fermenter that is being filled. It is probably half filled at this time, and the flow of meal into the tank is begun from the overhead meal bin. The flow rate is continuously measured and indicated, and will cut off when the desired amount is reached. The agitator in the tank is started. The liquefying enzyme is added at this time. The operator checks the temperature. When the tank is nearly full, steam is admitted to bring the temperature up to cooking value. The operator checks the viscosity until it is clear that liquefaction is taking place.

The operator now prepares for the automatically controlled sequence of the remaining steps of cooling and fermenting. The microprocessor controls these steps, and it will be activated at this time. However, the operator must load the saccharifying enzyme into its container. The enzyme is dumped into the fermentation tank on signal from the microprocessor. The yeast is pumped into the fermenter from the yeast tub, also on signal from the microprocessor. After cooking is complete, the microprocessor initiates the flow of cold water into coils in the vessel which cools the mash to the temperature corresponding to saccharification. When the appropriate temperature is reached, the enzyme is introduced. After a predetermined time, the converted mash is cooled to fermentation temperature, again by circulating cold water through the coils. When fermentation temperature is reached, the yeast is pumped into the fermenter. All of these operations are controlled by the microprocessor and do not require the operator's presence.

Once the fermentation is initiated, the operator can check the condition of the distillation columns and turn his/her attention to the products. The driver of the truck which delivers the whole stillage to the dairies and feeding operations will have finished filling the tank truck. If it is time for the pick-up of the ethanol, the operator will be joined by a field agent of the BATF who supervises the denaturing operation and checks the recorded flows of the plant to ensure that the product in storage is all that has been produced since the last pick-up. The distributions driver would then load the truck and start back to the bulk station.

In the evening the operator repeats the same operation with the exception of grinding meal and delivering the product.

MAINTENANCE CHECKLIST

Table V-5 provides a general timetable for proper maintenance of a representative ethanol plant.

TABLE V-5. MAINTENANCE CHECKLIST

Bale Burner		**Steam Lines**	
Remove ash	daily	Blow condensate	daily
Lubricate fans	monthly		
Check fan belts	monthly	**Beer Preheater**	
		Clean both sides	weekly
Water Softener			
Regenerate and backwash	weekly	**Beer Column**	
Check effectiveness	yearly	Clean out	weekly
Boiler		**Sight Glasses**	
Blow flues and CO_2 heater	monthly	Clean out	weekly
Check tubes and remove scale	monthly		
		Flow Meters	
Roller Mill		Clean out	as needed
Check for roller damage	weekly		
Check driver belts	monthly	**Condenser**	
		Descale water side	monthly
Elevator Leg to Meal Bin			
Lubricate	monthly	**Stillage Tank**	
		Clean and sterilize	monthly
Yeast Tubs			
Change air filter	monthly	**Pumps**	
		Check seals and end play	weekly
Fermenters		Lubricate	per manufacturer
Sterilize	every 3rd week		
Wash down outside	weekly	**Hydraulic System and Motors**	
		Check for leaks	daily
Back Pressure Bubblers		Change filter	per manufacturer
Clean out	weekly	Top-up	as necessary
Beer Well			
Sterilize and wash down	weekly		

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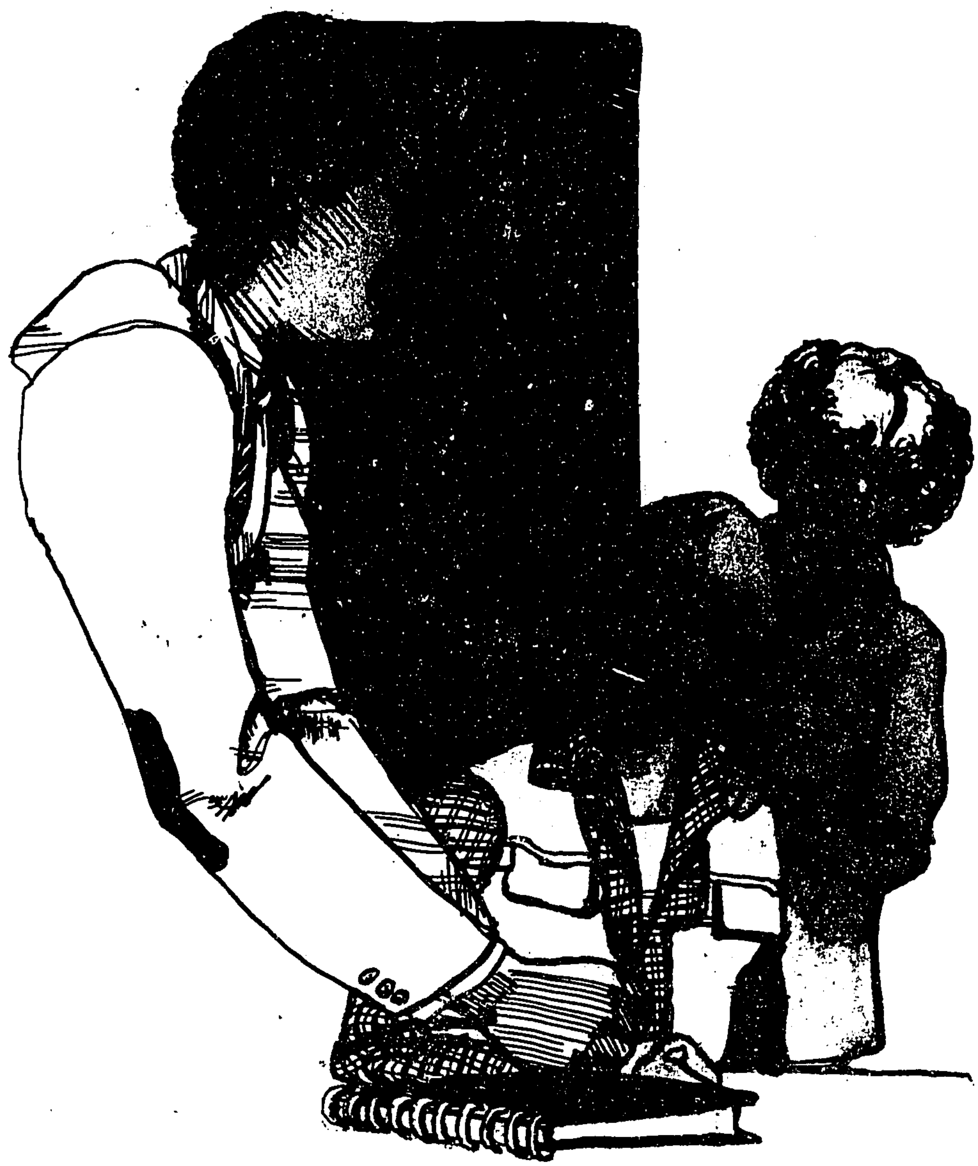
1. Ladisch, Michael R.; Dyck, Karen. "Dehydration of Ethanol: New Approach Gives Positive Energy Balance." *Science*. Vol. 205 (no. 4409): August 31, 1979; pp. 898–900.

CHAPTER VI

Business Plan



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CHAPTER VI
BUSINESS PLAN

Preliminary planning is a prerequisite for the success of any project. Development of an ethanol plant involves planning not only the production process but also the management form and financial base.

The first step is to determine the financial requirements and relate that to the individual situation. From this the optimal organizational form can be selected, and the financing options can be examined.

The case study included in this chapter is an example of how a business plan may be completed. Every situation is different, however, and this can serve only as an example. The decision and planning worksheets at the end of Chapter II can be used in conjunction with the information in this chapter as tools in the decision-making process. The worksheets assist in analyzing financial requirements, choosing an organizational form, and selecting potential financing sources.

ANALYSIS OF FINANCIAL REQUIREMENTS

Financial requirements are determined by delineating capital costs, equity requirements, and operating costs. These requirements are then compared to potential earnings. Capital requirements include the costs for:

- real estate,
- equipment,
- business formation,
- installing equipment, and
- cost of licenses.

Although additional real estate may not be necessary, transfer of real estate to the business entity may be a consideration. Some of the equipment required for ethanol production has other farm uses and need not be charged totally to the ethanol production costs, e.g., grain bins and tractors with front-end loaders.

Equity requirements are established by the financial lending institution if borrowed capital is used. Equity can be in the form of money in savings, stocks and bonds, equipment, real estate, etc. Operating costs include:

- labor,
- maintenance,
- taxes,
- mortgages,
- supplies (raw materials, additives, enzymes, yeast, water),
- delivery expenses,
- energy (electricity and fuels),
- insurance and interest on short-term and long-term financing, and
- bonding.

Potential earnings are determined by estimating the sales price of ethanol per gallon and then multiplying by the number of gallons that the facility can sell, as well as income that may be derived from the sale of coproducts (determined by the sales price times the quantity that can actually be sold). Careful planning of markets for coproducts can significantly affect the net income of an ethanol production plant. In the case study projected financial statement included in this chapter, note the difference in net income based on different coproduct prices. In addition to actual income derived from the sale of ethanol and the coproducts, any savings realized by using ethanol to replace other fuels for on-farm use can be added to earnings. This is also true for coproducts such as stillage that might replace purchased feed.

Once the financial requirements and potential earnings are determined, they can be related to the specific situation. Capital costs and equity requirements are related to the individual capability to obtain financing. Operation costs are compared to potential earnings to illustrate cash flow.

Once this information is acquired and analyzed in relation to the individual's specific situation, a decision can be made about the organizational form for the production business.

ORGANIZATIONAL FORM

The organizational basis is the legal and business framework for the ethanol production facility. Broadly speaking, there are three principal kinds of business structures: proprietorship, partnership, and corporation.

A proprietor is an individual who operates without partners or other associates and consequently has total control of the business. A proprietorship is the easiest type of organization to begin and end, and has the most flexibility in allocating funds. Business profits are taxed as personal income and the owner/proprietor is personally liable for all debts and taxes. The cost of formation is low, especially in this case, since licensing involves only the BATF permit to produce ethanol and local building permits.

A partnership is two or more persons contractually associated as joint principals in a business venture. This is the simplest type of business arrangement for two or more persons to begin and end and has good budgetary flexibility (although not as good as a proprietorship). The partners are taxed separately, with profits as personal income, and all partners are personally liable for debts and taxes. A partnership can be established by means of a contract between two or more individuals. Written contractual agreements are not legally necessary, and therefore oral agreements will suffice. In a general partnership, each partner is personally liable for all debts of the partnership, regardless of the amount of equity which each partner has contributed.

A corporation is the most formalized business structure. It operates under the laws of the state of incorporation; it has a legal life all its own; it has its scope, activity, and name restricted by a charter; it has its profits taxed separately from the earnings of the executives or managers, and makes only the company (not the owners and managers) liable for debts and taxes. A Board of Directors must be formed and the purposes of the organization must be laid out in a document called "The Articles of Incorporation." Initial taxes and certain filing fees must also be paid. Finally, in order to carry out the business for which the corporation was formed, various official meetings must be held. Since a corporation is far more complex in nature than either a proprietorship or a partnership, it is wise to have the benefit of legal counsel. A corporation has significant advantages as far as debts and taxes are concerned. Creditors can only claim payments to the extent of a corporation's assets; no shareholder can be forced to pay off creditors out of his or her pocket, even if the company's assets are unequal to the amount of the debt.

There are often differences in the ease with which a business may obtain start-up or operating capital. Sole proprietors stand or fall on their own merits and worth. When a large amount of funding is needed, it may be difficult for one person to have the collateral necessary to secure a loan or to attract investors. Partnerships have an advantage in that the pooled resources of all the partners are used to back up the request for a loan and, consequently, it is often easier to obtain a loan because each and all of the partners are liable for all debts. Corporations are usually in the best position to obtain both initial funding and operating capital as the business expands. New shares may be issued; the company's assets may be pledged to secure additional funding; and bonds may be issued, backed up by the assets of the corporation.

A nonprofit cooperative is a special form of corporation. Such a cooperative can serve as a type of tax shelter. While the cooperative benefits each of its members, they are not held liable, either individually or collectively, for taxes on the proceeds from the sale of their products.

After determining the organizational form, financing options can be explored.

FINANCING

The specific methods of financing ethanol production plants can be divided into three general classes: private financing, public grants and loans, and foundations.

Private Financing

Private financing may be obtained from banks, savings and loan associations, credit unions, finance corporations, venture capital corporations, corporation stock issues, and franchise arrangements.

Foundations

Foundations provide funding either through grants or through direct participation by gaining equity, usually in the form of stocks in the production company. Often the investment portfolios that are used to generate income for foundations are composed in part of stocks in enterprises they deem appropriate to support the mission of the foundation.

Public Financing

Grants or loans are available from several federal agencies. See Table E-1, Sources of Public Financing contacts, in Appendix E. Each of the agencies has operating procedures and regulations that define appropriate use of their funding. The availability of funds varies from year to year.

CASE STUDY

The following case study of the Johnson family demonstrates the process for determining the feasibility of a farm-sized fermentation ethanol plant by developing a business plan. It is a realistic example, but the specific factors are, of course, different for every situation. This process may be used by anyone considering ethanol plant development, but the numbers must be taken from one's own situation. Table VI-1 delineates the assumptions used in the case study.

TABLE VI-1. CASE STUDY ASSUMPTIONS

- Corn is the basic feedstock.
- 25-gal EtOH/hr production rate.
- Operate 24 hrs/day; 5 days/week; 50 weeks/yr.
- Feed whole stillage to own and neighbors' animals.
- Sell ethanol to jobber for $1.74/gal.
- Sell stillage for 3.9¢/gal.
- Corn price is $2.30/bu (on-farm, no delivery charge, no storage fees).
- Operating labor is 4 hrs/day at $10/hr.
- Corn stover cost is $20/ton.
- Equity is $69,000.
- Debt is $163,040; at 15% per annum; paid semi-annually.
- Loan period is 15 yrs for plant; 8 yrs for operating capital and tank truck.
- Miscellaneous expenses estimated at 12¢/gal EtOH produced.
- Electricity costs estimated at 2¢/gal EtOH produced.
- Enzymes estimated at 4¢/gal EtOH produced.

Background Information

The Johnson family operates a 1,280-acre corn farm which they have owned for 15 years. They feed 200 calves in their feedlot each year. The family consists of Dave, Sue, and three children: Ted, 24 years old and married, has been living and working at the farm for 2 years, and he and his wife have a strong commitment to farming; Sara is 22 years old, married, and teaches in a town about 250 miles away; Laura is 15 years old, goes to high school in town 25 miles away, and also works on the farm.

The Johnsons are concerned about the future cost and availability of fuel for their farm equipment. The Johnsons have known about using crops to produce ethanol for fuel for a long time, and recent publicity about it has rekindled their interest.

They have researched the issues and believe there are five good reasons for developing a plan to build a fermentation ethanol plant as an integral part of their farm operation:

- to create another market for their farm products,
- to produce a liquid fuel from a renewable resource,
- to gain some independence from traditional fuel sources and have an alternate fuel available,
- to gain cost and fuel savings by using the farm product on the farm rather than shipping it, and by obtaining feed supplements as a coproduct of the ethanol production process, and
- to increase profit potential by producing a finished product instead of a raw material.

They first analyzed the financial requirements in relation to their location, farm operations, and personal financial situation.

Analysis of Financial Requirements

The local trade center is a town of 5,000 people, 35 miles away. The county population is estimated at 20,000. Last year 7,000,000 gallons of gasoline were consumed in the county according to the state gasoline tax department. A survey of the Johnsons' energy consumption on the farm for the last year shows:

Gasoline = 13,457 gals

Diesel = 9,241 gals

LP Gas = 11,487 gals

They decided to locate the plant close to their feedlot operation for ease in using the stillage for their cattle. They expect the plant to operate 5 days a week, 24 hours a day, 250 days a year. It is designed to produce 25 gallons of anhydrous ethanol per hour or 150,000 gallons in one year, using 60,000 bushels of corn per year. In addition to ethanol, the plant will produce stillage and carbon dioxide as coproducts at the rate of 230 gallons per hour.

After researching the question of fuel for the plant, this family has decided to use agricultural residue as the fuel source. This residue will be purchased from the family farm. The cost of this fuel is figured at $20 per ton.

They will have to purchase one year's supply of fuel since it is produced seasonally in the area. The tonnage of residue per acre available is 6 tons per acre based on measurements from the past growing season.

The water source is vitally important. They will need about 400 gallons of water each hour. To meet this demand, a well was drilled and an adequate supply of water was found. The water was tested for its suitability for use in the boiler, and the test results were favorable.

The family has determined that they can operate both the plant and the farm without additional outside labor. The ethanol they produce will be picked up at the farm as a return load by the jobbers making deliveries in the rural area. The Johnsons will deliver stillage in a tank truck to neighbors within 5 miles.

At the present there are no plans to capture the carbon dioxide, since the capital cost of the equipment is too high to give a good return on their investment. There is no good local market for the carbon dioxide; but there are many uses of carbon dioxide, and selling it as a coproduct may prove to be profitable in other situations.

The family's plan is to market their products locally. They have contacted local jobbers who have given them letters of intent to purchase the annual production of ethanol. They plan to use the distillers grains in their own feedlot and to sell the rest to their neighbors. The neighbors have given them letters stating they would purchase the remainder of the distillers grains produced. These letters are important in order to accurately assess the market.

Organizational Form

The Johnsons chose to establish a closely held corporation for this business. Other possibilities they considered included partnerships, sole proprietorships, and profit and nonprofit corporations. If additional equity had been needed, a broader corporation or a partnership would have been selected. However, their financial status was sufficient to allow them to handle the investment themselves, as shown by their balance sheet which follows.

Dave and Sue Johnson
Balance Sheet as of January 1979

Assets:	
Current Assets:	
Cash	$15,000
Inventory	$70,000
Total current assets	$85,000
Equipment	$125,000*
Land and buildings	$512,000*
Total assets	$722,000
Liabilities and Capital:	
Operating notes at local bank	$20,000
Equipment loans at local bank	$69,000
Federal Land Bank loan	$350,000
Total Liabilities	$439,000
Total Capital	$283,000
Total Liabilities and Capital	$722,000

*These assets shown at fair market value.

The Johnsons formed a corporation because it afforded the ability to protect themselves from product liability and gave them the option to give stock to all family members as an incentive compensation package. Also, the use of a corporation avoids an additional burden on their credit line at the bank for their farming operation since they were able to negotiate a loan with no personal guarantee of the corporate debt. In a partnership they would have had personal liability for the product, the debt, and the actions of the partners in the business. The record-keeping requirements of the corporation and the limited partnership were equal, and the former afforded greater security. Co-ops and nonprofit corporations were considered also, but these two options were discarded because of operating restrictions.

After formation of the corporation, they transferred (tax-free) half of a year's supply of corn (30,000 bushels) in exchange for stock in the corporation. They elected Subchapter S treatment upon incorporation and had the first year of operation reported on a short-period return. Generally, Subchapter S has many of the advantages of a partnership but not the liabilities. (Consult an accountant or lawyer for a detailed description of this.) They could pass through the investment credit which is proposed to be 20% of the capital cost, assuming that the Internal Revenue Service would authorize a fuel-grade ethanol plant to qualify for the additional investment credit for being a producer of renewable energy. After the first short-period return is filed, the stockholders can then elect not to be a Subchapter S corporation. This plan helps the cash flow as they would personally recover some tax dollars through the investment credit.

The corporation will lease from the family, on a long-term basis, 2 acres of land on which to locate the plant. They considered transferring this land to the corporation, but the land is pledged as security for the Federal Land Bank so it would be cumbersome to get the land cleared of debt. Also, the 2 acres would require a survey and legal description, thereby adding additional cost, and there are no local surveyors who could do this work.

The corporation will purchase corn and agricultural residue from the family farm and damaged corn from neighbors when there is a price advantage to do so. The family will also purchase the distillers' grains and ethanol used on the farm from the corporation as would any other customer. All transactions between the family farm and the corporation will use current prices that would be paid or received by third parties.

Conclusion

The initial visit with the bank was encouraging. The local banker was well acquainted with ethanol production through the publicity it had been receiving. The bank was receptive to the financing, saying they would consider it an equipment loan. The bank required a schedule of production, funds-flow projections, projected income statements, and projected balance sheets for the next 2 years. The bank was primarily concerned that these statements demonstrate how the plant could be paid for.

Before meeting with their accountant, the Johnsons prepared decision and planning worksheets as described in Chapter II. This work on their part saved them some accountant's fees and gave them an idea as to the feasibility of such a plant. The projected financial statements were then prepared with the assistance of their accountant for the bank's use.

The following projected financial statement is based on decisions made about the operations and management of the plant. It served the Johnsons as a tool in deciding whether or not the plant would be a good investment for them and also as a final presentation to the bank for loan approval. The assumptions used in preparing these financial statements are included with the financial statements and represent an integral part of the management plan.

After the financial projections were completed and the bank had reviewed them, there was one more area of concern. The bank wanted to know whether the system as designed was workable and could produce what it was projected to do from a technical feasibility standpoint. The family furnished the bank with the engineer's report which documented systems that were in operation and that were successfully using their proposed technology. The bank contacted some of the people operating these plants to verify their production. The bank then completed their paperwork and made a loan to the family's corporation secured only by the equipment. They also approved the line of credit for the working capital required based on the projected financial statements.

GALUSHA
HIGGINS &
GALUSHA

GLASGOW, MONTANA

November 6, 1979

National Bank of Golden Rise
Golden, Colorado

We have assisted in the preparation of the accompanying projected balance sheet of Johnson Processors, Inc. (a sample company), as of December 31, 1980 and 1981, and the related projected statements of income and changes in financial position for the years then ended. The projected statements are based solely on management's assumptions and estimates as described in the footnotes.

Our assistance did not include procedures that would allow us to develop a conclusion concerning the reasonableness of the assumptions used as a basis for the projected financial statements. Accordingly, we make no representation as to the reasonableness of the assumptions.

Since the projected statements are based on assumptions about circumstances and events that have not yet taken place, they are subject to the variations that will arise as future operations actually occur. Accordingly, we make no representation as to the achievability of the projected statements referred to above.

The terms of our engagement are such that we have no obligation or intention to revise this report or the projected statements because of events and transactions occurring after the date of the report unless we are subsequently engaged to do so.

James Sumrcka

G, H & G
Certified Public Accountants

JOHNSON PROCESSORS, INC.
PROJECTED BALANCE SHEET
UNAUDITED

(NOTES 1 THROUGH 4 ARE AN INTEGRAL PART OF THESE PROJECTED FINANCIAL STATEMENTS AND PROVIDE AN EXPLANATION OF ASSUMPTIONS USED IN THIS REPORT)

		FOR YEAR ENDED December 31, 1980		December 31, 1981
Assets				
Current assets				
Cash		$24,617		$18,452
Accounts receivable		55,350		55,350
Raw materials and supplies		22,214		26,785
Work in process inventory		1,362		1,601
Finished goods inventory		18,765		22,041
Marketable securities		30,000		30,000
Total current assets		$152,308		$154,229
Plant, equipment, and structures				
Plant and equipment	$107,000		$107,000	
Building	17,280		17,280	
Total plant and equipment	$124,280		$124,280	
Less accumulated depreciation	8,605		17,210	
Net plant and equipment		115,675		107,070
Total assets		$267,983		$261,299
Liabilities and Capital				
Current liabilities				
Accounts payable		$3,800		$4,130
Current portion of loans		2,997		3,500
Total current liabilities		$6,797		$7,630
Long-term liabilities				
Bank loan	$156,043		$113,821	
Less current portion	2,997		3,500	
Total long-term liabilities		153,046		110,321
Total liabilities		$159,843		$117,951
Capital		108,140		143,348
Total liabilities and capital		$267,983		$261,299

JOHNSON PROCESSORS, INC.
PROJECTED INCOME STATEMENT
UNAUDITED

(NOTES 1 THROUGH 4 ARE AN INTEGRAL PART OF THESE PROJECTED FINANCIAL STATEMENTS AND PROVIDE AN EXPLANATION OF ASSUMPTIONS USED IN THIS REPORT)

		FOR YEAR ENDED		
		December 31, 1980		**December 31, 1981**
Revenue				
Alcohol		$229,680		283,500
Stillage		55,525		55,973
Total sales		$285,205		$339,473
Cost of goods sold				
Beginning finished goods inventory		0		$18,765
Cost of goods manufactured		$225,634		266,634
Cost of goods available for sale		$225,634		$285,399
Ending finished goods inventory		18,765		22,041
Cost of goods sold		$206,869		$263,358
Gross profit		$78,336		$76,11[illegible]
Selling expenses				
Marketing and delivery expenses (scheduled)	$25,545		$29,074	
Total selling expenses		$25,545		$29,074
Net operating profit		$52,791		$47,041
Income taxes		13,651		11,833
Net income		$39,140		$35,208

JOHNSON PROCESSORS, INC.
PROJECTED STATEMENT OF CHANGES IN FINANCIAL POSITION (Cash Basis)
UNAUDITED

(NOTES 1 THROUGH 4 ARE AN INTEGRAL PART OF THESE PROJECTED FINANCIAL STATEMENTS AND PROVIDE AN EXPLANATION OF ASSUMPTIONS USED IN THIS REPORT)

	FOR YEAR ENDED	
	December 31, 1980	December 31, 1981
CASH GENERATED		
Net income	$39,140	$35,208
Add (deduct) items not requiring or generating cash during the period		
Trade receivable increase	(55,350)	(0)
Trade payable increase	3,800	330
Inventory increase	(42,341)	(8,086)
Depreciation	8,605	8,605
Subtotal	$(46,146)	$36,057
Other sources		
Contributed by shareholders	69,000	
Bank loan	163,040	
Total cash generated	$185,894	$36,057
CASH APPLIED		
Additional loan repayment	$ 4,000	$38,722
Purchase of plant and equipment	107,000	
Purchase of building	17,280	
Reduction of bank loan	2,997	$3,500
Total cash applied	$131,277	$42,222
Increase in cash	$ 54,617	$(6,165)*

*Net decrease in cash is caused by an accelerated pay-off of the operating capital rate in the amount of $38,722.

JOHNSON PROCESSORS, INC.
EXHIBIT I
UNAUDITED

(NOTES 1 THROUGH 4 ARE AN INTEGRAL PART OF THESE PROJECTED FINANCIAL STATEMENTS AND PROVIDE AN EXPLANATION OF ASSUMPTIONS USED IN THIS REPORT)

	FOR YEAR ENDED	
	December 31, 1980	December 31, 1981
ETHANOL		
Projected Production Schedule		
Projected gallons sold	132,000	150,000
Projected inventory requirements	18,000	18,000
Total gallons needed	150,000	168,000
Less inventory on hand	0	18,000
Projected production	150,000	150,000
Sales price per gallon	$1.74	$1.89
Projected Cost of Goods Manufactured		
Projected production costs:		
Labor	$20,805	$20,328
Corn	138,000	180,000
Electricity	3,000	3,300
Straw	10,714	11,785
Miscellaneous (scheduled)	18,000	19,800
Depreciation	6,730	6,730
Interest	23,747	18,330
Enzymes	6,000	6,600
Total costs of production	$226,996	$266,873
Add beginning work-in-process inventory		1,362
Subtotal	$226,996	$268,235
Less ending work-in-process inventory	1,362	1,601
Projected cost of goods manufactured	$225,634	$266,634

JOHNSON PROCESSORS, INC.
NOTES TO THE PROJECTED FINANCIAL STATEMENTS
UNAUDITED

1. SIGNIFICANT ACCOUNTING POLICIES

Following is a summary of the significant accounting policies used by Johnson Processors, Inc. in the projected financial statements.

- Assets and liabilities, and revenues and expenses are recognized on the accrual basis of accounting.
- Inventory is recorded at the lower value (cost or market) on the first-in, first-out (FIFO) basis.
- Accounts receivable are recorded net of bad debts.
- Depreciation is calculated on the straight line basis.

2. ASSETS

Current Assets

- Accounts receivable are projected at each balance sheet date using 30 days of sales for ethanol and 90 days of sales for stillage.
- Inventory—raw materials—is made up of corn and corn stover. Thirty days in inventory is used for corn and one year's supply is used for stover.
- Inventory—work in process—consists of 1½ days' production.
- Inventory of finished goods consists of raw materials and cost of production. Thirty days in inventory is used for ethanol and 2 days is used for stillage.

The estimates of number of days in accounts receivable and finished goods inventory are higher than those quoted in Robert Morris Associates averages for feed manufacturers and wholesale petroleum distributors.

Fixed Assets

Management anticipates purchasing the equipment for production of ethanol. Consulting engineers contacted verified that the equipment and plant costs listed in Table VI-2 were reasonable.

REPRESENTATIV- PLANT COSTS

Equipment and Materials	$ 71,730
Piping	4,000
Electrical	1,500
Excavation and Concrete	2,000
Total Equipment and Materials	79,230
10% Contingency	7,923
Total	87,153
Tank Truck	14,847
Erection Costs	5,000
Grand Total	$107,000

Investments

Investments consist of the amount of excess cash accumulated from operation during the first and second year of operation.

3. LIABILITIES AND CAPITAL

Management estimated accounts payable using 30 days in payables for conversion costs. It is anticipated that corn will be paid for a month in advance.

Management estimates that a bank loan in the amount of $163,040 will be required, payable semiannually at 15% interest. Anticipated payback period for the portion of the loan covering plant and equipment is 15 years. The payback period for the portion covering working capital is 8 years. The payback period for the truck is 8 years. An additional $4,000 the first year is projected to be paid on the equipment loans and to repay the working capital loan in the second year. The loan will be used to finance plant and equipment and working capital. The anticipated plant and equipment and working capital for the first year is estimated as follows.

Plant and equipment	$124,280
Working capital	$107,760
Total	$232,040

Cash could be very lean during the first year that the plant operates at capacity because of dramatic increases in working capital resulting from accounts receivable and inventory requirements. Inadequate financing would make maximum production impossible because of inability to fund working capital demands.

4. INCOME STATEMENT

Sales

Sales volume was estimated at maximum production (150,000 gallons of ethanol and 1,380,000 gallons stillage) for the first year. Ethanol price was taken to be $1.74 per gallon (the actual delivered price at Council Bluffs, Iowa on November 6, 1979). The price of ethanol is projected to increase by 9.1% for the entire period covered by the projections. The increase of 9.1% is the projected price increase by a marketing firm from Louisiana.

It is conceivable that as the price of gasoline increases to a point greater than the price of ethanol, producers could raise the price of ethanol to equalize the prices of the two liquid fuels. In order to be conservative, management did not consider this effect .

The stillage sales price was taken to be 3.9 cents per gallon for the 2 years. This sales price was based on the sales price charged by Dan Weber in Weyburn, Saskatchewan, Canada. The local stillage market is, however, worthy of a thorough study before a decision is made to enter the fermentation ethanol business. If a large brewery or distillery is located in the area, the price of stillage can be severely depressed. For example, Jack Daniels and Coors sell their stillage for 0.4 cents per gallon and 0.8 cents per gallon, respectively.

Cost of Sales

Management has projected cost of sales to include raw materials and production costs. The cost of corn is projected at $2.30 per bushel during the first year of operation (the price received by farmers in Iowa on November 6, 1979). Management has the total amount of corn available from the corporate shareholder. To demonstrate the effect of substantial increases in corn prices on profitability and cash flow, management projected that the cost of corn would rise to $3.00 per bushel for year two.

Management anticipates that depreciation will remain constant using the straight line method. A 15-year life for the plant was used with a salvage value of $4,000, while an 8-year life and 20-year life were used for the truck and building respectively. No other salvage values were taken into consideration.

Labor cost was computed allowing 4 hours per day for work necessary in the processing of the ethanol, based on the engineer's time requirement estimates. The labor was valued at $10 per hour, including a labor overhead factor. Bookkeeping labor was computed at $6,000 per year, assuming this plant would only require part-time services. It is anticipated that some additional time may be required the first year. For this, $2,325 has been added to the labor cost as a contingency.

Enzyme cost was estimated at $6,000 per year by the engineers working on the project. Electricity was estimated at 2 cents per gallon of ethanol produced.

Stover cost was computed based on a cost of $20 per ton. A Btu value of 7,000 Btu per pound (as estimated by the engineers) was used. An 80% efficiency for the boiler was assumed, so anticipated Btu values were 5,600 Btu per pound of straw, and a total Btu requirement of 40,000 per gallon of ethanol produced.

Miscellaneous Expenses

Miscellaneous expenses were estimated at 12 cents per gallon. These expenses are shown in the detail schedule at the end of this report. To be conservative, figures are included in the miscellaneous expenses for shrinkage due to the grain handling and a contingency for any minor items that may have been overlooked.

Interest expense is for the bank loan. Interest expense is calculated at 15%. In year two of the operation, it is projected that the working capital portion of the notes payable will be paid off.

Management projects that other projected costs will increase 10% per year because of inflation. To be conservative, management did not estimate the cost savings potential of improved technology. Research is currently being performed in crops that have the potential of producing several times the amount of ethanol as does corn. Use of such crops could produce substantial cost savings in ethanol production. The process is very new in design, so improvements in the production process are also probable. Such improvements could further reduce the cost of producing ethanol.

Selling and Administrative Expenses

To be conservative, management estimated marketing expenses at 5% of sales. It is anticipated that this expense may not actually be necessary. Delivery expenses take into consideration the following items:

- interest was computed at 15% on the bank loan for the truck based on semi-annual payments;
- the time necessary to deliver the stillage was estimated based on 10 hours per week at $10 per hour including labor overhead;
- maintenance for the truck was estimated at $1,000; and
- fuel for the truck was computed based on 75 miles per week and a fuel consumption of 4 miles per gallon and a fuel cost of $1.025 per gallon. The cost is estimated to increase 36.5% for the second year of operation.

Income Taxes

The shareholders of Johnson Processors, Inc. plan to elect to have income taxed to the shareholder rather than to the corporation, under Internal Revenue Code Section 1372(a). The shareholders anticipate changing the election after the first year of operation. Taxes have been estimated based on a 6% state tax rate and a 6.75% federal tax rate in effect during 1979. For purposes of these projections, the projected financial statements (assuming a conventional corporation and a full 12 months of operation in each period) have been shown to demonstrate the projected results of operation that could be anticipated.

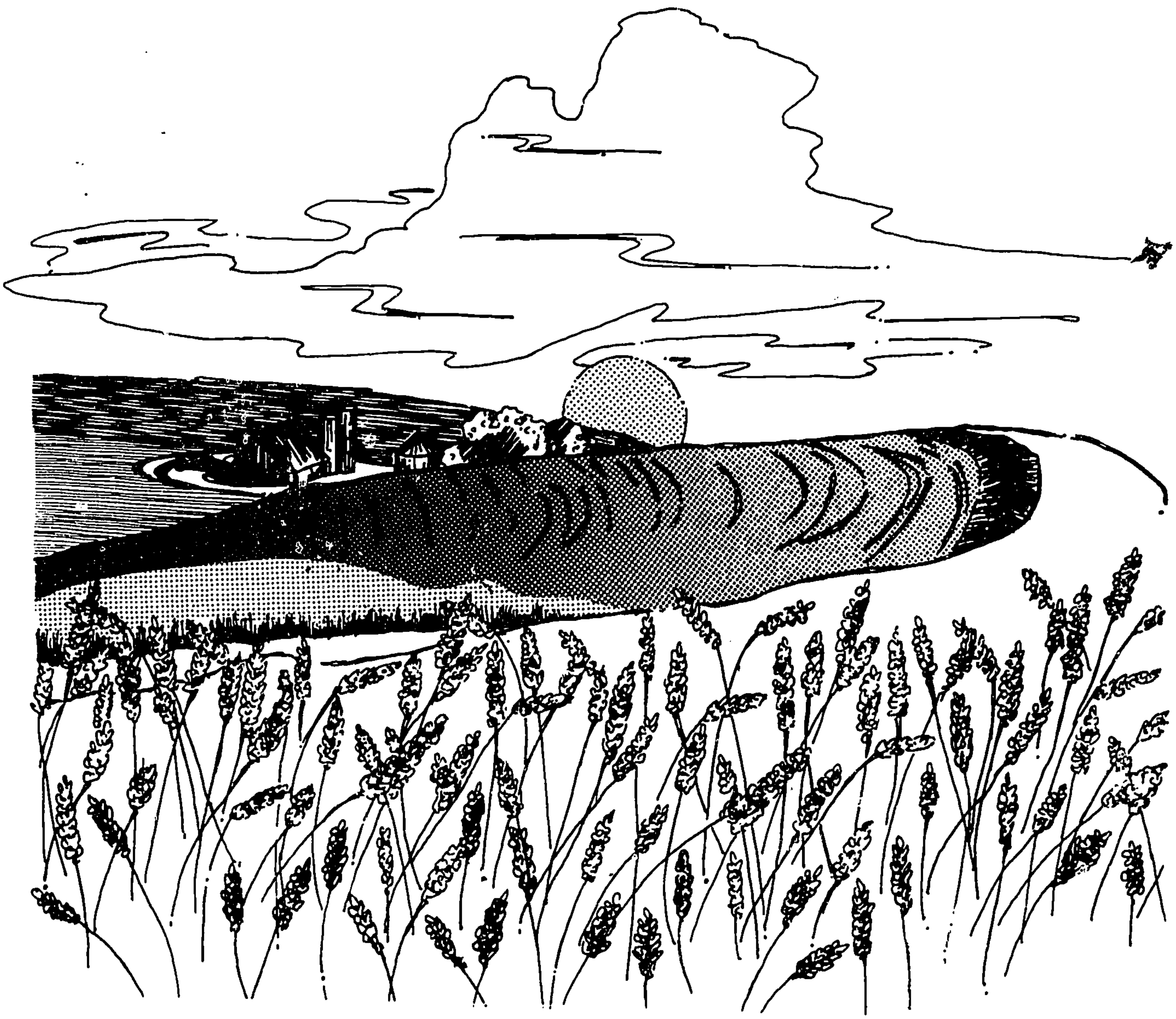
The shareholders of Johnson Processors, Inc. anticipate contributing $69,000 to the corporation. This amount is 30% of the total project. This will be contributed by transferring corn inventory equal to the ½-year supply necessary for processing. For purposes of this illustration, the contribution of corn is treated as cash to demonstrate to the bank the payback potential of the plant.

JOHNSON PROCESSORS, INC.
DETAIL SCHEDULES
UNAUDITED

(NOTES 1 THROUGH 4 ARE AN INTEGRAL PART OF THESE PROJECTED FINANCIAL STATEMENTS AND PROVIDE AN EXPLANATION OF ASSUMPTIONS USED IN THIS REPORT)

	FOR YEAR ENDED	
	December 31, 1980	**December 31, 1981**
Schedule of Marketing and Delivery Expenses		
Marketing 5% of sales	$14,260	$16,974
Interest on truck	2,211	2,045
Depreciation	1,875	1,875
Labor	5,200	5,720
Maintenance	1,000	1,100
Fuel	1,000	1,360
Total	$25,546	$29,074
Schedule of Miscellaneous Expenses		
Property taxes	$2,250	$2,475
Insurance	2,100	2,310
Chemicals and supplies	600	660
Yeast	450	495
Shrinkage	4,200	4,620
Other	2,550	2,805
Contingencies	5,850	6,435
Total	$18,000	$19,800

Appendices



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APPENDIX A

Summary of Ethanol Legislation

- National Legislation
- State Legislation

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