Designation: E 1344 – 90 (Reapproved 2006)

Standard Guide for
Evaluation of Fuel Ethanol Manufacturing Facilities[1]

This standard is issued under the fixed designation E 1344; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The purpose of this guide is to provide guidelines and evaluation criteria to enable a prospective purchaser, or lender, or both, to effectively review the plans, specifications, and plant operating concept of a mass produced fuel ethanol manufacturing facility (FEMF) and to determine whether its design, as proposed, meets the requirements of ASTM design practice standards. ASTM Practice E 1117 is a recognized standard for the evaluation of performance and design practices for fuel alcohol manufacturing facilities.

1. Scope

1.1 This guide shall apply to FEMF as defined in Terminology E 1126. The guide is primarily intended for, but not exclusively limited to the evaluation of fermentation ethanol (ethyl alcohol) processes. This guide is primarily intended for, but not exclusively limited to, fermentation ethanol processes for small scale (less than 1 000 gal/day capacity) plants.

1.2 This guide applies to both batch process and continuous process FEMF systems. Since a wide variety of equipment configurations can exist, this guide will describe the necessary general requirements common to all FEMF facilities.

1.3 This guide is to be used in conjunction with applicable local, state, and Federal codes for designing, constructing, and operating FEMF facilities.

1.4 This guide is limited to use with plants possessing the following operational characteristics, which are fairly typical of small scale ethanol plants and are as follows:

1.4.1 *Capacity:* Up to 500 000-proof gal/year of 190-proof ethanol,

1.4.2 *Normal Feedstocks:* No. 2 yellow corn, or other suitable sample grade corn, barley, or grain sorghum (also referred to as milo). There are other starch grains such as wheat, rye, or oats, and starch tubers such as potatoes that can be used as feedstocks. Sugar crops (sugar cane, sugar beets, and molasses, that is a by-product of sugar plants) and cellulose crops (wood chips, straw, etc.) are also potential feedstock sources. However, since much of the interest in proposed ethanol plants in recent years has centered on the use of corn, barley, and milo as feedstocks for ethanol production, it is expected that the majority of plants proposed in the near future will be largely based on these abundant feedstocks. This guide concentrates on the use of corn, milo, and barley as feedstocks,

1.4.3 *Normal Process Fuels:* Natural gas, propane, fuel oil, wood, or coal,

1.4.4 *Products:* Ethanol at 190-proof or less. Distillers grains at 60 to 75 % moisture by weight and thin stillage, for use as animal grade feed and not human grade food,

1.4.5 *Process:* The ethanol production process referred to in this guide involves dry milling of grain, batch or continuous cooking, enzyme hydrolysis, batch fermentation, continuous distillation, and pressing or centrifuging for dewatering of stillage (for example, separating suspended solids from the stillage), and

1.4.6 *Variations:* One variation in the ethanol production process is addressed in this guide. This variation allows for the cooking, hydrolysis, and fermentation processes to be completed either as a batch in the same process vessel or in separate vessels.

1.4.6.1 With limitations, this guide can be used to evaluate facilities with operating characteristics that differ from those just listed. However, variations from those characteristics listed will tend to lessen the reliability of the guide.

1.4.6.2 An example of a fairly minor variation would be the substitution of wheat as a feedstock. Wheat processing characteristics are reasonably similar to those of corn, barley or milo. However, wheat tends to foam considerably more than corn, so vessels need to be sized at least 10 % greater than if corn is used, or the use of an antifoam agent would be advisable.

1.4.6.3 An example of a significant variation from the process characteristics utilized in this guide would be the substitution of potatoes as a starch feedstock. Processing requirements for use of potatoes vary significantly from

[1] This guide is under the jurisdiction of ASTM Committee E48 on Biotechnology and is the direct responsibility of Subcommittee E48.05 on Biomass Conversion.

Current edition approved Feb. 1, 2006. Published March 2006. Originally approved in 1990. Last previous edition approved in 1997 as E1344–90 (1997)$^{\epsilon 1}$.

processing requirements of corn, barley, and milo. Therefore, use of this guide is not recommended for evaluation of a potato feedstock ethanol facility.

1.5 *Use of Guide as Checklist* This guide should be used as a checklist for evaluation of proposed small scale manufactured fuel ethanol facilities. It is intended to be used by investors, bankers, and other parties interested in the commercial development of such fuel alcohol facilities. It is not intended to be used as a guide for the designing of these facilities, but as a guide to assist in the evaluation of designs already completed by sellers or manufacturers of such facilities. This guide may also be utilized by FEMF designers or sellers who may wish to review their systems' conformance with the recommendations of the guide. This guide is to be used in conjunction with applicable local, state, and Federal codes and regulations.

1.6 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 6 on Hazards, and the safety sections for each procedure in Section 10.

1.8 This guide is arranged as follows:

2. Referenced Documents

2.1 *ASTM Standards:* [2]

E 1117 Practice for Design of Fuel-Alcohol Manufacturing Facilities

E 1126 Terminology Relating to Biomass Fuels[3]

2.2 *NFPA Standards:*[4]

No. 10 Standard for Portable Fire Extinguishers

No. 13 Standard for Installation of Sprinkler Systems

No. 30 Flammable and Combustible Liquids Code

No. 70 National Electric Code

No. 77 Recommended Practice on Static Electricity

No. 85A Prevention of Furnace Explosions in Fuel Oil and Natural Gas-Fired Single Burner Boiler-Furnaces

No. 101 Life Safety Code

No. 395 Standard for the Storage of Flammable and Combustible Liquids on Farms and Isolated Construction Projects

2.3 *Other Standards:*

Article 16 Fire Prevention Code[5]

UL 30 Cans, Metal Safety[6]

UL 58 Tanks, Steel Underground, for Flammable and Combustible Liquids[6]

UL 142 Tanks, Steel Above-Ground, for Flammable and Combustible Liquids[6]

CFR Title 49 Parts 100 through 199[7]

ASME Boiler Construction Codes, Sections I, IV, VII, and VIII [8]

3. Terminology

3.1 *Definitions:*

3.1.1 *alcohols*—series of liquid products composed of a hydrocarbon plus a hydroxyl group, such as ethanol (C_2H_5OH).

3.1.1.1 *Discussion*—Other alcohols include methanol, isopropanol, butanol, amyl alcohol, etc. Typical fermentation alcohol is ethanol.

3.1.2 *alpha-amylase*—enzyme that acts specifically to accelerate the hydrolysis of starch to dextrins.

3.1.3 *anhydrous, without water*—term used in chemistry to denote absence of water. 199+ proof ethanol is considered anhydrous ethanol.

3.1.4 *anhydrous ethanol*—100 % ethanol, neat ethanol, 199 + proof ethanol.

3.1.5 *azeotrope*—constant boiling mixture, for ethanol-water, the azeotrope of 95.6 % ethanol and 4.4 % water (both percentages by volume) boils at one atmosphere pressure.

3.1.6 *azeotropic distillation*—the use of an organic solvent to create a new constant boiling point mixture, a method used to produce anhydrous ethanol from the ethanol water azeotrope.

3.1.7 *backset*—the liquid portion of the thin stillage that is recycled as part of the process liquid in mash preparation.

3.1.8 *basic hydrolysis*—the chemical addition of water to a compound.

3.1.9 *batch fermentation*—batch of nutrient mixture and microorganisms mixed in a vessel and allowed to ferment.

3.1.10 *beer*—term used to describe the product of ethanol fermentation by microorganisms.

3.1.10.1 *Discussion*—Usually means the alcohol solution remaining after yeast fermentation of sugars. About 10 %

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

[4] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101.

[5] Engineering and Safety Service, 1976.

[6] Underwriters Laboratories, Inc. (UL), 333 Pfingsten Rd., Northbrook, IL 60062.

[7] Code of Federal Regulations available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[8] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

alcohol is normally contained in the beer solution for a small scale fuel grade ethanol plant.

3.1.11 *BTU*—one British Thermal Unit is the amount of heat required to raise 1 lb of water 1°F.

3.1.12 *carbohydrates*—molecules consisting of carbon, hydrogen and oxygen that include celluloses, starches and sugars.

3.1.13 *centrifuge*—machine that separates a mixture of solids and liquids by centrifugal force.

3.1.14 *continuous fermentation*—nonstop flow of nutrients into a fermenting vessel, with the simultaneous outflow of products, organisms, and by-products.

3.1.14.1 *Discussion*—Optimum culture conditions are maintained to maximize the production of desired products.

3.1.15 *conversion efficiency*—the ratio of the actual to theoretical fuel ethanol yield per unit mass of the feedstock.

3.1.16 *denaturant*—toxins or noxious materials added to ethanol to make it unfit for human consumption.

3.1.17 *denatured ethanol*—ethanol that is mixed with other chemicals or denaturants to make it unsuitable for human consumption.

3.1.18 *dextrins*—high molecular weight sugars, intermediates obtained in the conversion of starch to fermentable sugar.

3.1.19 *distillate*—the overhead product of distillation such as ethanol liquid from the top of a beer still.

3.1.20 *distillation*—the act of vaporizing and condensing a liquid in sequential steps to effect separation from a liquid mixture.

3.1.20.1 *Discussion*—Ethanol is purified by distillation from a solution of water and alcohol.

3.1.21 *distillers grains*—the insoluble solids that have been separated from the stillage bottoms or beer. Moisture content may range from 60 to 85 %, depending upon the level of dewatering during separation.

3.1.22 *enzyme*—biological catalyst that is protein in nature.

3.1.22.1 *Discussion*—Enzymes are used in ethanol production to convert starch to glucose sugars (fermentable sugar).

3.1.23 *ethanol*—ethyl alcohol, the chemical compound C_2H_5OH, a two carbon alcohol.

3.1.24 *feedstock*—the base raw material that is the source of carbohydrate, such as starch, for producing sugars that can be fermented into alcohol and carbon dioxide.

3.1.25 *fermentation*—the biochemical reaction process where microorganisms in a nutrient medium convert a feedstock to a product.

3.1.26 *flash point*—the temperature at which a combustible liquid ignites.

3.1.27 *FEMF*—Fuel Ethanol Manufacturing Facility.

3.1.28 *fuse oils*—complex group of higher molecular weight materials including ketones and aldehydes produced as a byproduct by the yeast fermentation during ethanol production.

3.1.28.1 *Discussion*—Primary constituent is amyl alcohol, which has 5 carbon atoms in its molecules. Fusel oils have a value for use as fuel.

3.1.29 *gelatinization*—treatment of starch grains with heat and water to cause the swelling and expansion of the starting material.

3.1.30 *glucoamylase*—enzyme that acts specifically to convert dextrins to glucose by hydrolysis.

3.1.31 *glucose*—the most prominent simple sugar (6-membered $C_6H_{12}O_6$) produced from starches and cellulose material by hydrolysis.

3.1.32 *hydrolysis*—the act of cleaving or splitting of complex molecules by the chemical addition of a water molecule. Acid hydrolysis is defined as the chemical addition of water to a compound such as starch in the presence of an acid as a catalyst that will form another compound such as glucose.

3.1.33 *mash*—the mixture of sugars, nutrients, and water that is capable of being fermented by microorganisms such as yeast in ethanol fermentation.

3.1.34 *packed distillation column*—a column or tube constructed with internals of ceramic, steel, or fiberglass-type materials to separate one or more volatile liquids by distillation.

3.1.35 *pH*—the measurement of the acid concentration of a solution. Range is 0 to 14 (acid to basic), with pH 7 being neutral.

3.1.36 *plate distillation column*—column constructed with perforated plates to separate one or more volatile liquids by distillation.

3.1.37 *press*—mechanical device that removes liquids from solids by mechanically pressing the solids against a porous surface.

3.1.38 *proof*—measurement term of concentration of ethanol in water solutions.

3.1.38.1 *Discussion*—100-proof ethanol is 50 % alcohol (by volume) and 50 % water. 200-proof is pure or 100 % ethanol.

3.1.39 *protein*—general term used to cover single cell microorganisms, extract of the microorganisms, (bacteria or fungi or algae) that is used for food or feed to animals and humans.

3.1.40 *reflux, in distillation processes*—reflux is the liquid condensate recycle to the top of a distillation column to aid in purification of the overhead product (ethanol).

3.1.41 *saccharification*—the breaking of dextrins (starch) into simple sugars (hydrolysis).

3.1.42 *solids*—two types of solids are present in mash. First, insoluble solids are present as solid matter present in the liquid portion of the mash. Secondly, soluble solids are dissolved in the liquid portion of the mash.

3.1.43 *Stillage*—the liquid products or waste remaining after distillation of a beer. The soluble residue are water, proteins, etc.

3.1.44 *sugars*—molecules of carbohydrate, namely monosaccharides and disaccharides such as glucose, galactose, mannase, sucrose or fructose, etc.

3.1.45 *supernatant*—that liquid remaining after separation of a liquid/solid mixture.

3.1.46 *vacuum distillation*—to affect separation of two or more liquids under reduced pressure operation of a distillation column. Vacuum reduces the boiling points of the liquids being separated.

3.1.47 *yeast*—single cell microorganisms (*fungi*) that produce alcohol and CO_2 under normal fermentation conditions.

4. Summary of Guide

4.1 The guide described herein provides minimum recommendations to be used in evaluating the design, construction, and operations of fuel alcohol manufacturing facilities. These recommendations are intended to provide guidelines and evaluation criteria to ensure good engineering practices for organizations engaged in these FEMF activities.

4.2 This guide is not intended to provide recommendations regarding management, organizational or marketing requirements for FEMF plants. However, strong consideration should be given to the general management, marketing, and technical expertise available, to ensure the success of the intended business.

5. Significance and Use

5.1 This guide is intended to be used by prospective purchasers or lenders, or both, who should be knowledgeable of the design, fabrication, modification, and equipment requirements of mass-produced FEMF systems.

5.2 This guide provides minimum recommendations to be used in protecting public safety and enhancing equipment reliability for the intended life of the facility.

5.3 The objective of this guide is to identify the overall design, manufacturing and modification considerations for FEMF systems. This guide is not intended to list all the standards to be used with every type of process, since there are many different types of designs and equipment utilized in the fuel ethanol industry. The application of the following guide is the responsibility of the particular purchaser, lender or other user of the guide.

5.4 This guide is designed with the intention that the process design requirements narrative (10.2.1) will assist to define the recommended design criteria for use in the evaluation of FEMF plants. The design review checklist included as Appendix X1. is intended to be utilized in conjunction with the guide. The checklist is intended as a quick review reference to enable review of the adequacy or appropriateness of a particular FEMF design. The guide is arranged in such a manner as to provide an explanation of the ethanol production process, followed by a discussion of design parameters and potential problem areas within the process. The process design narrative and the design review checklist provided in Appendix X1. are both formatted sequentially according to process steps, for ease of comparison between the two documents.

6. Hazards

6.1 Various safety recommendations are included in previous sections of this guide addressing specific process sections of the FEMF plant. In addition, several excellent publications are available that provide thorough explanations of safety and hazard control problems and standards for alcohol plants.[9,10] The following paragraphs provide a summary of safety recommendations that pertain to the entire FEMF plant.

6.2 The ethanol production process involves various health and safety hazards resulting from the use of powered equipment and chemicals to produce alcohol and carbon dioxide, each of which has unique hazards. Although fire and explosion are the major hazards, various other potential hazards must be considered in the design of an FEMF plant. The FEMF plant must be designed to eliminate hazards and be properly operated and maintained by well-trained personnel to minimize accidents.

6.3 *Fire and Explosion*:

6.3.1 **Warning—**Grain handling, milling, and feed preparation at FEMF plants present dust explosion hazards. Although grains and feeds are slow burning, fires in these materials may be deep-seated and difficult to extinguish. Wet grains will heat and sour if not utilized promptly.

6.3.2 In view of the quantities of grain that is stored, handled, and processed in an FEMF plant, it is desirable to have grain storage or milling sections, or both, segregated due to the danger of a dust explosion and fire. Complete information on the prevention of dust explosions and methods of minimizing potential damages are provided in the Engineering and Safety Service bulletin.[5]

6.3.3 Process fire and explosion hazards are present during distillation, but are considered negligible during hydrolysis and fermentation. Strict government regulations that require seals on every pipe joint, valve, and spigot reduce the probability of flammable liquid or vapor being released during distilling operations.

6.3.4 Flammable liquid hazards are also present in varying degrees in the ethanol handling areas. Because of ethanol's lower heat of combustion, and radiant heat energy, and its complete miscibility with water, lower sprinkler system demands are required than with other flammable liquids of equivalent flashpoint. The quality of water needed to extinguish fires in alcohol water mixtures depends upon the temperature of the liquid above its fire point and the effectiveness of mixing. The amount of water can be estimated from the following equation, assuming perfect mixing:

Volumes of water needed per volume of burning liquids are as follows:

$$\frac{\text{\% alcohol in solution before fire}}{\text{\% alcohol at point of fire extinguishment}} - 1 \qquad (1)$$

6.3.5 Fire and explosion hazards recommendations relating to plant layout and design are included as follows. Make sure that the ethanol plant is separated from other buildings by at least 100 ft (304 m) if possible to reduce exposure to other buildings, facilities or equipment, and to reduce risks from fires originating elsewhere. In FEMF plants, practical considerations often prohibit separation of the various operations, ranging from the raw materials storage to finished product storage. Be sure to recognize this inherent hazard of small-scale, batch-type processes. Buildings that are separated by clear spaces (100 ft) are recommended, but where this is impractical from a processing standpoint, make sure that units are separated by standard fire walls with all openings protected on each side by automatic fire doors suitable for Class A openings (3-h doors). For ethanol plants located less than the

[9] American Insurance Association, "Special Hazards Bulletin," December 1981.

[10] Roberts, D. E., "Health and Safety Hazards in Fuel Ethanol Production," *Proceedings of Moonshine to Motor Fuel Workshop*, U.S. Department of Energy et al., October 1981.

recommended distance from a main building, one of the two fire resistive classes of construction (International Organization for Standardization (ISO) Classes 5 or 6) are desirable, although perhaps not practical for FEMF plants. Explosion venting considerations are extremely important for these classes of construction.

6.3.6 It may be necessary to enclose the ethanol production equipment in a building designed with damage-limiting construction (that is, make sure that walls and roofs that face areas not containing exposures are pressure relieving, and walls and roofs facing exposures of inadequately separated structures are of fire and explosion resistant construction), depending upon the fire and explosion hazard potential and the size of the plant.

6.3.7 The prevailing wind direction may be a factor to consider in the location of the process building, due to potential exposure fires or ethanol vapor travel to an ignition source, as well as to minimize odor problems.

6.3.8 Even though steam pressures in heating systems utilizing boilers are usually low, there is always the possibility of an explosion if the boiler is corroded or if safety valves do not operate properly. Thus establish a testing program to check out the heating system prior to its initial operation and at regular intervals. Take precautions also to make sure the fuel supply is stored in a safe manner.

6.3.9 The physical and chemical properties of ethanol require that various precautions be taken to reduce fire or explosion hazard. Ethanol plant hazards depend on such conditions as the quantity of ethanol, whether it is exposed to air or is in a closed system, the probability of accidental leakage or overflow, its location relative to other buildings, equipment and ignition sources, building construction, and the adequacy of fire protection. **Warning**—Ethanol is a volatile, flammable, colorless liquid with a penetrating odor and burning taste. 120 to 200-proof ethanol is considered a Class IB flammable liquid, since its flash point is below 73°F (22.8°C) and its boiling point is above 100°F (37.8°C). Detailed regulations concerning the prevention of a fire and explosion during the production, storage and use of ethanol are covered in Article 16 of the *Fire Prevention Code.*[5]

6.3.10 FEMF plants are typically located in rural areas. As a result, city water supplies and fire departments are typically not readily accessible which places the responsibility for fire protection almost entirely on the plant itself.

6.3.11 Safety also depends on good construction, and proper arrangement and safeguards for processes.

6.3.12 Because of the fire and explosion hazards inherent in handling grains and flammable liquids, safety depends on supervision by well-trained operators, good maintenance, and process equipment safeguards.

6.4 *Equipment Safety Design*:

6.4.1 Make sure that cookers or fermenters, or both are constructed of heavy metal (boiler plate) construction and should rest on noncombustible supports. In closed cookers, the temperature may exceed 300°F and pressures may reach 75 to 80 lb/in.^{2} The cooking process itself presents little fire hazard, but an explosion hazard exists in closed cookers. Make sure that relief valves are provided for closed cookers.

6.4.2 Make sure that distillation units are fabricated with noncombustible materials on noncombustible supports. Provide adequate clearance from combustible material. Make sure that each column is provided with a relief vent of adequate size and type, piped directly to the outside, with no valves or other obstructions in vent piping. Distillation systems usually run at atmospheric pressure, although in some systems distillation may occur at pressures below (partial vacuum) or at pressures in excess of atmospheric. It is important that the normal operating pressure of a distillation unit not exceed the design working pressure.

6.4.3 Make sure that vacuum and pressure relief devices piped to outdoors are provided. Also, make sure that any condenser vents are piped to outdoors. Vents should be sized to discharge the maximum vapor generation possible at zero feed and maximum heating within the pressure limitations of the protected equipment. Vents should terminate at least 20 ft (60 m) above the ground and preferably at least 6 ft (18 m) above roof level and be so located that vapor will not reenter the building. Make sure that vent terminals are equipped with flame arresters.

6.4.4 Make sure that approved gaging devices are provided where required. If ordinary gage glasses are used, make sure that both connections are normally kept closed and are provided with weight-operated, quick-closing valves. Protect the glass against mechanical injury. Replace tail boxes with armored rotameters and specific gravity indicators where possible, or with other instrumentation not subject to accidental breakage or leakage.

6.4.5 Make sure that the steam supply for the distillation unit is thermostatically controlled and interlocked to shut down and sound an audible alarm on cooling water failure. Alternately, provide powered standby pumps or gravity supplies of cooling water.

6.4.6 Make sure that columns and other large equipment containing flammable liquids are purged with steam or an inert gas (typically steam) before opening for inspection or repair. Wash equipment with water following steaming.

6.4.7 Provide ventilation systems designed and installed to ensure air movement throughout the entire distillation area to prevent the accumulation of explosive vapor air concentrations within the building. The stack effect (that is, natural ventilation) may suffice if the building is high, permanent openings are provided at grade and roof elevations, the equipment can be drained and cleared of vapors during shutdowns, and heat losses from the equipment maintain a temperature above that of the outdoors during all operating periods. If these operating conditions cannot be satisfied, or if blank walls or solid floors interfere with natural ventilation, make sure that the mechanical exhaust ventilation is designed to provide 1 $ft^3/min/ft^2$ of floor area. Make sure that suction intakes are located near floor level to ensure a sweep of air across the area.

6.4.8 Use noncombustible, vapor-tight construction for all tanks containing flammable concentrations of alcohol. Keep tanks tightly closed except when taking samples, Equip tanks with vents of adequate size terminating outdoors. Equip vents with approved flame arresters if the flashpoint of the contents is less than 100°F (38°C).

6.4.9 Make sure that liquid-level gages are installed on all tanks. Use only gage glasses tested and listed by a nationally recognized testing laboratory for use with flammable liquids and for use with the anticipated pressures and temperatures that could be developed. If ordinary gage glasses must be used, make sure that weight-operated, normally closed valves are installed at both tank connections and the glass protected against physical damage. Wherever possible, provide top tank connections and liquids transferred by pumping through the top rather than by gravity flow. If draw off stations are located in the same area as the supply tank, make sure that automatically operated, emergency shutoff valves are provided in gravity feed lines. Use flexible, metallic hose on all connections to scale tanks where fire exposure would release the tank contents or expose its vapor space.

6.4.10 Materials that make up the ethanol production equipment must be suitable for their intended use. For example, do not use aluminum if chlorinated organic products are to be distilled, cast iron may be unsuitable for high temperatures, and special alloys may be needed to resist corrosion. Except for laboratory purposes, it is recommended that materials such as glass, porcelain and brittle or heat sensitive plastics not be used.

6.4.11 Make sure that all equipment is installed in accordance with the manufacturer's instructions. Review actual equipment to be purchased for appropriate operation in the system, since oversize equipment may require revisions to control valve sizes, relief valve settings, etc.

6.5 *Pumping and Piping Systems*—Make sure that ethanol distillation, storage and handling equipment are vapor-tight systems utilizing closed pumping and piping systems between the various units. Include automatic and remote manual shutoff that are easily accessible, to promptly stop the flow of ethanol so that loss from leaks, overflows, or spills will be minimized. Post signs indicating the locations of manual emergency shutoffs in conspicuous posted spots.

6.6 *Inside Drainage Systems*—Make sure that curbs, ramps or trapped floor drains at doorways and other openings are provided to prevent the spread of flammable liquids to other areas. Make sure that floor drains in each ethanol handling area are designed to handle expected sprinkler discharge unless the maximum possible spill can be extinguished by dilution while confined. Floor drains should lead to an adequately sized diked area, outside pit, sump, or holding tank at a safe location, and should not discharge into municipal storm or sanitary sewers, rivers, lakes, or other bodies of water because of the fire and explosion hazard and ecological damage that can occur.

6.7 *Outdoor Drainage Systems and Dikes*—Provide outdoor areas where ethanol is produced, handled or stored with adequate drains or diversionary dikes to carry off burning ethanol that might be released due to a leak or rupture during a fire.

6.8 *Ethanol Storage*:

6.8.1 Generally store ethanol outside. However, if ethanol must be stored indoors, it should be in a detached noncombustible building (ISO Classes 3 to 6) used solely for the storage of ethanol, and make sure that it is well separated from other buildings and the production area. If ethanol is stored in the process building, make sure that it is strictly segregated from other areas by noncombustible walls with not less than a 1-h fire resistance rating. Avoid location of tanks and drums in the upper stores of a building. It is preferable that there be no basement areas where concentrations of vapors could accumulate.

6.8.2 All ethanol storage tanks should meet appropriate standards. (UL 30, UL 58, UL 142, and CFR Title 49)

6.8.3 Bulk storage of flammable materials should conform to local, state, and Federal standards. Consider underground storage where possible, to reduce fire risks.

6.8.4 Supports for aboveground storage tanks should be either: (1) protected steel having a fire resistance rating of 2 h, concrete or masonry also with a 2-h fire resistance rating, or (2) protected by automatic water spray or sprinklers to protect supports from early failure when involved in a fire. Make sure that tanks, drums and other containers are protected from physical damage.

6.8.5 Avoid storage of ethanol in drums to avoid serious fire and explosion hazards. Leakage problems are usually caused by rough handling, falling from a high pile, deterioration of the drum, or structural failure of the drum due to heat or a nearby explosion. If drums must be utilized, use Department of Transportation (DOT)—approved types.

6.9 *Ethanol Loading*:

6.9.1 Make sure that safety shutoff valves (which cannot be blocked open) are provided at connections on containers where transfer is by gravity; dispensing methods where ethanol is transferred from faucets into open containers are not recommended.

6.9.2 Instruct personnel as to the importance of constant attendance during all load-out operations, whether or not the system is equipped with automatic controls. Do not permit smoking in the ethanol load-out area. Post clearly visible no-smoking signs.

6.9.3 Accomplish tank-truck and tank-car loading and unloading on a level roadway, and utilize suitable grounding and bonding connections. Set hand breaks and block the wheels before ethanol is dispensed. Make sure that the truck or car is on the owner's property, not on the street. Where there is other vehicle traffic, post warning signs on the roadway at both ends of the truck or car.

6.10 *Lighting and Power*:

6.10.1 Make sure that all lighting and power is electric, with all wiring and equipment installed in accordance with the National Electrical Code.[4] Do not permit temporary electrical installations. The selection of the proper classification of electrical equipment for a particular location is governed by factors involved in the particular installation. However, generally install Class I, Division I, Group D, listed electrical equipment in all areas subject to a potential ethanol atmosphere. Provide Class II, Division I, Group G, listed electrical equipment in grain handling buildings or areas subject to a potential dust atmosphere.

6.10.2 Provide a clearly identified and easily accessible switch to cut off electric power to dispensing pumps in the event of fire or physical damage to the dispensing unit.

6.11 *Grounding and Bonding*:

6.11.1 Utilize proper grounding or bonding methods so that equipment and containers are protected against accumulation of static electricity. Ground tanks, distillation units, and power operated equipment, when constructed wholly or partly of metal, and when located inside of buildings subject to ethanol atmospheres. Also, ground conveyors, grinders, and other machinery used in connection with grain or other dust producing material. Make sure that all belts in dusty atmospheres or where ethanol vapors may be present are grounded, and static collectors may be required. Utilize suitable grounding and bonding connections during dispensing operations.

6.11.2 Further information and details on grounding and bonding is available from NFPA No. 70, and No. 77.[4]

6.12 *Fire Protection*:

6.12.1 Fires at ethanol plants exhibit many of the same characteristics as fires at petroleum plants. Because of the intense heat generated in an ethanol fire, large quantities of highly flammable vapors are produced, causing fire to spread rapidly, which can make fire fighting exceedingly difficult. Ethanol fires (if detected before large quantities become involved) may be successfully attacked and extinguished. Fire protection requirements for an ethanol production operation are to a great extent determined by the size of the operation. However, there are a number of other factors that may influence fire protection needs, including the following:

6.12.1.1 The cost effectiveness of providing different types of fire protection equipment and the capability of plant equipment to extinguish potential fires, and

6.12.1.2 The capability of the public fire department to respond with appropriate equipment and sufficient personnel trained in combating an ethanol fire.

6.12.2 Portable extinguishers may be utilized for fighting small, localized fires. Such extinguishers should meet the following criteria:

6.12.2.1 Provide uniform distribution,

6.12.2.2 Provide easy accessibility,

6.12.2.3 Be free of blockage by storage and equipment,

6.12.2.4 Be near normal paths of travel,

6.12.2.5 Be near entrance and exit doors,

6.12.2.6 Be free from potential physical damage, and

6.12.2.7 Be readily visible.

6.12.3 Make sure that persons expected to use an extinguisher are familiar with its proper operation and all information contained on the manufacturer's nameplate and in the instruction manual. Implement a regular program for inspection, maintenance and recharging of all portable fire extinguishers on the premises. Test all portable fire extinguishers and make sure that they are listed by a nationally recognized, independent testing laboratory. For complete guidance on portable fire extinguishers, consult NFPA No.10.[4]

6.12.4 The selection of a wheeled extinguisher is generally associated with a recognized need to provide additional protection for special or extra hazard areas. Where wheeled extinguishers are to be utilized, make sure that consideration is given to mobility in the area in which it will be used.

6.12.5 Fire hoses are desirable in some instances for manually extinguishing of ethanol fires, grain fires or other combustible fires. Hose lines may be used to flush away burning or escaping ethanol or for cooling to prevent re-ignition. Because heat from ethanol fires can cause severe damage to buildings and equipment in a short period of time, prompt attack with properly applied water spray is necessary. The recommended hose size is 1½ in. (38 mm) with a combination nozzle (shutoff, spray and solid stream), having a capacity of at least 20 gal/min (76 L/min) at 50 psi flowing pressure. Make sure that hose streams are capable of reaching all parts of the production and storage areas. Care must also be taken to prevent water from serving as a vehicle to spread burning ethanol. For this reason, proper fire fighting training is of vital importance.

6.12.6 Automatic sprinkler systems are the basic fire-control safeguard and can extinguish fires in ethanol production operations and provide protection against exposure fires. Whether automatic sprinklers are provided for protection of operations within buildings or open-air distillation equipment, make sure that protection is complete when provided. This includes locations where pumps, piping, tanks, and other parts of the ethanol transfer system exist. Make sure that sprinkler piping are supported by the primary structural members; make sure that sprinkler risers are located at or within building columns to provide protection against damage due to explosion. Complete details are provided in NFPA No.13.

6.13 *Personnel Safety*:

6.13.1 The FEMF plant should meet the requirements of NFPA No. 101, so as to permit prompt escape of its occupants in an emergency. Make sure that evacuation and emergency procedures are planned in advance and periodically reviewed with all employees and posted permanently in a conspicuous manner.

6.13.2 Also, make sure that appropriate fire-aid equipment is readily available for treatment of injured personnel. Make sure that there is a person or persons adequately trained to render first aid.

6.13.3 To prevent scalding from steam gasket leaks, make sure that baffles are placed around flanges to direct steam jets away from operating areas; and make sure that all steam delivery lines are insulated to prevent contact burns. The design of FEMF facilities should conform to current OSHA, NIOSH and other local, state and Federal regulations.

7. Environmental

7.1 *Environmental Considerations and Permits*—Ethanol plants must comply with the appropriate national, state and local environmental regulations. The National Environmental Policy Act and Federal Water Pollution Control Act require persons intending to build, install or operate an ethanol production facility to file with the Bureau of Alcohol, Tobacco, and Firearms, information concerning the environmental impact of the proposed operation. Most state governments also require that various permits be obtained prior to construction or installation of an alcohol plant. Potentially adverse environmental impacts may result from the boiler operation (air emissions), from cleanup operations, and from improper handling of cooling and process water, of wet stillage, or of "bad" batches. However, most air emission and waste disposal problems can be controlled through the proper design of and operating techniques in a facility.

7.2 *Air Pollution*—Two forms of air pollution could result from development of an FEMF ethanol plant: (1) the release of emissions from the boiler used to produce steam from process heat, and (2) vaporization of ethanol lost during the production process. If crop residues are used as boiler fuel, the resulting emissions are primarily particulate matter that can be controlled through the use of flue stack scrubbers. Air emission problems can also result from other sources, including odor problems caused by improper handling of stillage, odors from wastewater disposal systems, ethanol vapors lost to the air by faulty or improperly designed distillation units, and large amounts of carbon dioxide gas released from the fermentation process.

7.3 *Wastewater*:

7.3.1 Waste disposal problems may result from plant cleanup operations, the improper disposal of batches ruined by contamination, or the improper disposal of stillage. Odor and acidity problems can result from applying thin stillage to the land. The impacts of applying thin stillage to the land can be attenuated by using a sludge plow, recycling a portion of the thin stillage within the plant, or use of anaerobic digestion to reduce the pollution potential of the thin stillage. Federal, state and local regulations concerning waste disposal should be consulted including the "Resource Conservation and Recovery Act" regulations.

7.3.2 All discharges from the FEMF plant should conform to local, state and federal regulations and codes. Careful consideration should be given primarily to wastewater streams resulting from fermentation/cooking and solids/liquid separation processes, since these streams can be significant water pollution sources.

7.3.3 Applicable permits for construction and operation should be obtained by the owner or operator, with technical data being supplied by the vendor/engineer.

7.3.4 Ventilation within FEMF buildings should conform to local, state and federal codes, as well as applicable fire protection and insurance company requirements. The plant design should include emergency air and routine evacuation provisions for carbon dioxide or ethanol fumes buildup.

7.3.5 The FEMF systems should be designed for proper operation in extreme ranges of weather conditions for the site specific location. This may require that a FEMF design be modified to operate cold or hot weather, humid or dry conditions, rain or snow, inside or outside of buildings, and other variations of operating conditions. Vendor and owner should have specific understandings of the design conditions under which the plant will operate, so that appropriate plant facilities are provided.

7.3.6 The Bureau of Alcohol, Tobacco and Firearms (ATF), a branch of the U.S. Treasury Department, is responsible for administering the federal laws and regulations concerning taxation, production, denaturation, storing, and distribution of alcohol fuel. The ATF classifies alcohol production operations into three classes depending upon the amount of alcohol the plant is capable of producing. FEMF plants would be considered small plants (less than 10 000 gal/year) or medium plants (10 000 to 500 000-proof gal/year). ATF requires that alcohol plants be licensed and inspected to ensure that adequate security and reporting procedures are in place at the plant.

8. Other Considerations

8.1 Detailed written operating, maintenance, and emergency procedures should be provided to the owner/operators by the manufacturer or vendor of the FEMF system before plant operation begins. It is recommended that the vendor should also provide training to the owner/operators to include background theory, operating techniques, start-up/shutdown, quality control, and emergency procedures for all phases of the operation. Training should include all process operations and utilities systems (boilers, power, water, gas, etc.). Startup assistance should also be provided from the system vendor to the owner/operator.

8.2 The design of FEMF facilities should conform to current OSHA, NIOSH and other local, state and federal regulations.

8.3 If novel or special equipment is used in the process, the vendor should provide guidance to the owner/operator for obtaining special repair parts or replacement items.

8.4 After the owner/operator has formally accepted the full responsibility for the plant, it is recommended that future revisions of the process be reviewed for applicability with the original vendor. It is also recommended that these revisions, modifications, and changes be evaluated with the same care and consideration as identified in the ASTM standard engineering practices.

8.5 It is recognized that many other specific guidelines and engineering practices can be included in any specific FEMF design for mass-produced plants. Accordingly, good engineering practices are encouraged at all times to achieve high standards of public safety and plant performance as represented by the system vendor.

9. Additional Facilities

9.1 *Site*:

9.1.1 The location of an FEMF plant should be selected based on a number of technical factors, as well as numerous business and marketing factors, which are beyond the scope of this guide. FEMF plants are typically located in rural areas due to the immediate accessibility to feedstock. A number of plants are also located within small or medium sized communities. In either situation, the plant site should possess the following characteristics, at a minimum.

9.1.2 The proposed plant site should have suitable soil conditions to support the plant building and equipment with minimal settling, or costly subsurface foundations may be required. The plant site should have an adequate water supply either from an on-site well or municipal water supply. If municipal water is to be used, consideration should be given to the impact of water costs on operating costs of the FEMF plant. An analysis of the water quality should be obtained to determine the requirements for water treatment. If the plant is to be located within a community, it must be determined whether the community wastewater treatment system has sufficient excess capacity to handle the effluent of the plant. Plants located in rural areas that do not have access to municipal treatment systems should have sufficient land available for on-site treatment systems. Consideration should be given to the location of nearby residents or other facilities that may be impacted by odors from the ethanol plant, wastewater system, or stillage land spreading area.

9.2 *Cooling Water*:

9.2.1 Some type of cooling water system, such as a cooling tower is required to maintain proper process temperatures. If adequate water supply is available for cooling, the used cooling water could be reused for slurry water for new batches, for watering livestock, or would need to be discharged to a sewer system. With a cooling tower, the water is reused, which reduces water consumption and operating costs. Cooling towers must have provisions to control the quality of the recycled water, such as blowdown, addition of water treatment chemicals, etc. Treated cooling tower blowdown that contains chemicals that could detrimentally affect enzyme and yeast activities should not be used for backset or fresh process water makeup.

9.2.2 In warmer climates, a water chiller may also be required during the hot weather months to maintain the proper process temperatures. The water chiller could be tied in to supplement the cooling tower system. This would be required in the fermentation area, where cooling loads are greatest and temperature control is critical.

9.2.3 Water used in the cooling tower must be treated to minimize hardness and organic growth. Well water to be utilized for cooling in heat exchangers must also have minimal hardness to prevent fouling in the heat exchanger.

9.3 *Air System*—Compressed air is very beneficial for enhancement of yeast production in fermentation. This requires an air compressor, sterilizing filter, de-oiling filter and piping. The air system could also be used for plant air requirements. However, only sterile air should be used at the beginning of the fermentation cycle to promote yeast growth (aerobic conditions) and reduce contamination problems. Air should not be used during the ethanol production cycle of the yeast (unaerobic conditions), because ethanol would be lost through the vent system and the metabolism of the yeast would change to produce more yeast and less ethanol.

9.4 *Utilities*:

9.4.1 This guide is limited to consideration of four fuel types; natural gas, propane, wood or coal. Fuel oil is also a common fuel source for small scale ethanol plants. These are typically the most prevalent fuels considered for small-scale fuel ethanol facilities. More exotic fuels, such as municipal garbage or methane from landfills can look attractive, but reliability of supply and hidden costs of production need to be examined carefully.

9.4.2 Steam generators and boilers should be designed or specified in accordance with local, state, federal and NFPA No. 85A codes.[4] Applicable alarms and emergency facilities shall be included in the design for partially attended boiler operations. Appropriate boiler feed water treatment capability should be available to ensure design performance of the boiler over its expected life.

9.4.3 Fuel (gas, fuel oil, coal, biomass, etc.) to be used should meet applicable boiler manufacturer specifications and resulting emissions should meet local, state and federal requirements.

9.4.4 All electrical, fuel gas, steam, water and other utilities supply lines should have easily identified shutoff devices that are accessible during an emergency.

9.4.5 Fresh, potable water supply sources should be isolated from process water systems with approved back flow preventers, as required by local, state, and federal health codes.

9.4.6 Cross connections should be avoided between different utilities such as fuel gas, water, inert gas, etc. If interconnections at a manifold are necessary, then isolation systems (double block valves and bleeder, back flow preventors, etc.) should be installed to prevent undesired mixing.

9.5 *Quality Control*:

9.5.1 The vendor should specify all laboratory test and analytical procedures that shall be used to monitor, control, and adjust the process to achieve expected process performance. These procedures should be described in a detailed process testing manual to be provided to the owner.

9.5.2 Appropriate sample points, product run down tanks, and other quality control provisions should be included in the system design.

9.5.3 Storage and sampling facilities should be designed to provide ethanol security required by Bureau of Alcohol, Tobacco, and Firearms (BATF) or other appropriate agencies, as well as for general safety and efficiency of operations.

9.6 *Instrumentation and Controls*:

9.6.1 In general, the more instrumentation that is utilized and centralized, the less labor is necessary to operate the plant. However, additional trained instrumentation personnel will be required.

9.6.2 Sensing and detection instruments (temperature, pressure, flows, etc.) should be located at the most effective position for accurate measurements.

9.6.3 Backup manual control systems should be provided where automatic control devices are used, such as manual bypasses around control valves. It is desirable to be able to utilize manual operations to avoid shutdown of an entire process section in the event an automatic control device fails. Safety devices on the system must avoid equipment overpressure and other unsafe conditions.

9.6.4 Alarms and automatic shutdown facilities should be provided on critical process controls such as boilers (high pressure, low water, fuel ignition failure), etc. A thorough instrumentation study and design documentation should be provided to identify the proper controls, failure action of each control loop, application of alarms, and automatic shutdown devices, etc.

9.6.5 Controls, sensors, valves, dampers, emergency shutdown devices and other instruments should be clearly identified with labels, tags, signs or other devices. Controls should be placed at locations convenient to the operators and should be centralized in a control room, if possible.

9.6.6 Occupational Safety and Health Act (OSHA) approved warning labels should be permanently mounted where hazardous or corrosive materials are used in the system. Instructions for emergency treatment should also be prominently displayed. Emergency treatment facilities should be provided for accidental contact with hazardous or corrosive materials. Such provisions may include deluge showers, eye wash fountains, etc.

10. Procedure

10.1 *General Process Description*:

10.1.1 The review of the design of any fuel alcohol manufacturing facility must start with an understanding of the proposed process strategy. In other words, how is the feedstock converted into the products, ethanol and distillers grains?

10.1.2 Ethanol production consists of three major process phases: (*1*) formation of a solution of fermentable sugars, (*2*) fermentation of sugars to ethanol, and (*3*) distillation of the ethanol. More specifically, the small scale plant process using grains as feedstock includes the following:

10.1.2.1 Milling of the grain feedstock to expose the starch,

10.1.2.2 Cooking the feedstock in a water slurry to sterilize and gelatinize the starch,

10.1.2.3 Hydrolyzing the starch with enzymes to break down the starch to a sugar solution. This is also called saccharification,

10.1.2.4 Fermenting the sugar with yeast into ethanol,

10.1.2.5 Distilling the ethanol from the fermented mash or beer, and

10.1.2.6 Dewatering the stillage.

10.1.3 Process steam generation and other utilities are also required for the cooking and distillation processes. The six process steps just listed, process utilities, and other support facilities are described in the following sections of this guide.

10.2 *Process Design Requirements*—The following information provides a description of each of the individual process steps in the ethanol production process, as well as a discussion of equipment design requirements or recommendations for each of the process steps. The process design and equipment requirements are based on the production parameters previously defined, namely the FEMF plant is assumed to produce 1 000 gal or less of 190-proof ethanol per day, wet distillers grains, etc. Variations of fermentation and cooking strategies are discussed to include both single vessel and separate vessel designs.

10.2.1 *Grain Handling and Dry Milling*:

10.2.1.1 Although a wide variety of other starch grains, starch tubers, and sugar crops can be utilized for the production of ethanol, this guide is limited to the use of corn, milo and barley.

10.2.1.2 Grain feedstock may either be delivered to the ethanol plant site, or may be conveyed to the plant from existing storage if the ethanol plant is located on a farm or at a grain elevator. If grain receiving is required, deliver whole grain to the plant by truck, preferably with bottom unloading capability. The whole grain can be discharged into a dump pit and conveyed to a bucket elevator. Provide a coarse grate over the dump pit and screens to prevent foreign matter or grain dust from entering the conveyors.

10.2.1.3 Size the grain receiving system to allow the typical truck size expected at the plant to be dumped in a reasonable amount of time (15 to 30 min). This will minimize demurrage charges on the truck. The bucket elevator conveys the whole grain into either a storage bin, directly to a feed hopper above the mill, back to the truck for returning unacceptable grain, or to the ground for additional storage. Provide a conveyor to move whole grain from the storage bin back to the bucket elevator to feed the mill. The grain should pass over a magnet to remove iron objects that could damage the mill and process equipment.

10.2.1.4 The whole grain then is milled to break down the particle size that will be acceptable for processing. Grain milling strategies vary widely. Plants utilizing existing on-farm grain milling equipment can simply auger ground grain from existing storage to the process. A conveying system is required to take materials away from the mill (hammermill or rollermill, depending on the feedstock). A dust recovery system may be necessary to remove dust from the milling and unloading operations if required by health and safety regulations or standards.

10.2.1.5 The determination of whether to use a rollermill or hammermill is a function of the feedstock. Wet feedstocks are normally ground in a rollermill system. In a rollermill, the feedstock passes through rolls that exert a compressive force. Certain types of rollermills use rollers operating at different speeds, which results in shearing of the grain. On the other hand, dry corn can be easily cracked in a hammermill. It may be desirable to have the feedstock to be used, test ground in both types of systems to determine the proper equipment to use. Equipment vendors usually have excellent recommendations and experience on various feedstocks. The initial investment requirement is considerably different for these mills, rollermills typically being more costly then hammermills. Therefore, an analysis of the feedstock is strongly recommended before the final decision is made regarding the type of mill to be used.

10.2.1.6 The size of the grain grind is also dependent upon the particular feedstock to be utilized. The size should produce grain particles small enough to achieve the desired ethanol yield and pass through equipment such as a hydroheater, yet large enough to facilitate solids recovery for distiller feeds. Solids recovery is more efficient with as large a solid particle as possible. These particles are removed more easily on the screens of a press or by the gravitational forces present in a centrifuge. However, too large a particle will not allow complete hydrolysis and thus lower yields will result because the starch availability will be physically limited. Too small or too large of a particle size will also cause plugging and caking problems throughout the process. Large particles could collect to plug smaller diameter lines in the process (see Fig. 1).

10.2.1.7 Feed the ground grain from the mill into a ground grain surge bin. The surge bin should provide a short-term (1 h) reserve supply of feedstock to enable a continuous plant to operate during times of mill downtime due to repair or failure. The ground grain can be conveyed either pneumatically or mechanically to the cooking system. It may be desirable to include a screening device with a magnet to remove tramp metal and large objects that may enter the grain after the milling section. A weighing system, such as a batch weigh hopper or a weight belt, is required on either the whole grain or the ground grain to enable an accurate measurement of the amount of grain being fed to the process. The grain feed rate

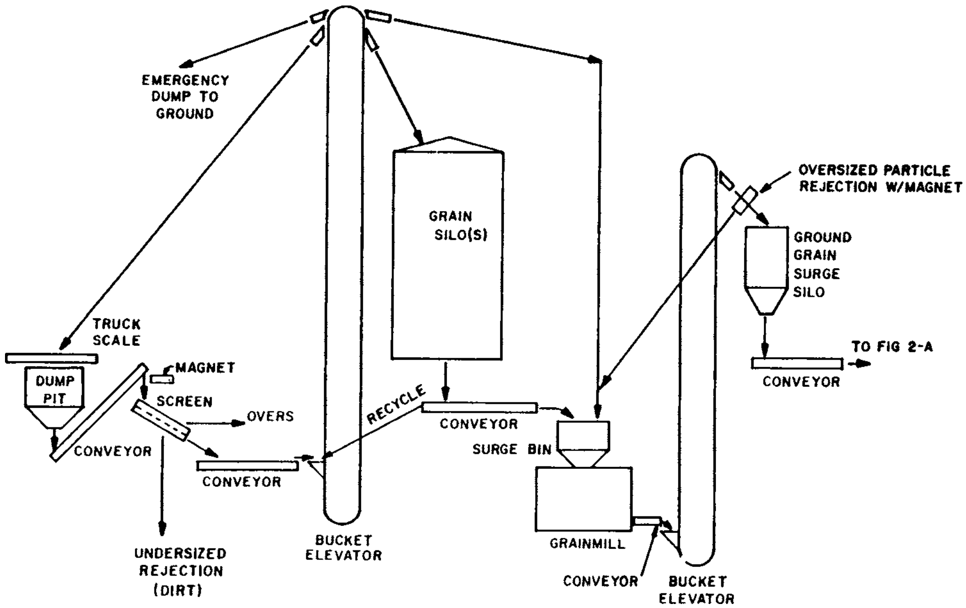

FIG. 1 Ground Grain Receiving

can also be calculated by measuring total solids on the slurry and the slurry flow rate in a continuous cooking design.

10.2.1.8 As previously noted, this guide is limited to consideration of the use of three starch grains; corn, barley and milo. Distressed grains may also be utilized to effect lower feedstock costs, although they may produce lower ethanol yields, depending on their condition. There can also be a potential health hazard to animals fed stillage or distillers grains produced from distressed grain containing aflatoxins.

10.2.1.9 *Specific Processing Requirements of Corn, Milo, and Barley (see Table 1)*:

(1) Corn—Corn is a high starch content grain that fractures easily when dry, in either a hammermill or rollermill system. Corn above 15 to 20 % moisture will probably grind better in a rollermill. A realistic yield for the small scale plant should be 2.3 to 2.5 gal/bu. Corn is the most commonly utilized grain for fuel ethanol production. One bushel of #2 yellow corn is defined to weigh 56 lb at 15.5 % maximum moisture content.

(2) Barley—Barley generally has a lower starch content than corn and is more fibrous, so it fractures less easily upon grinding and requires more grinding horsepower. Barley contains a high level of beta-glucans, a substance that causes high viscosity problems (thick and gummy slurry) during processing. The use of a special enzyme, beta-glucanase, during the slurry preparation will break the high viscosity and eliminate the viscosity problem. The beta-glucanase enzyme is commercially available. The normal liquefaction and saccharification enzymes required for processing corn or milo are also required for barley.

(3) Grain Sorghum (Milo)—Milo is less fibrous than barley, but does not fracture as easily and is a smaller kernel than corn. As a result, the required grinding horsepower is less than barley, but greater than corn. Mash slurries of milo tend to foam more than corn slurries and form a crust on top of the mash in the fermenter. Because of milo's small size, a rollermill is probably the best equipment for grinding this grain, although hammermills can also be utilized with acceptable results.

10.2.1.10 According to a major manufacturer of hammermill equipment, typical mill horsepower (HP) requirements vary according to three factors.

Horsepower requirements are calculated according to the following equation:

$$HP = \frac{Q}{N\,F} \tag{2}$$

where:
Q = lb/h required,
N = screen number, and
F = F-factor that is associated with the type of grain.

The F-factor is an index number obtained through experience and testing of firms in the grain industry relating to the grindability of grain. The higher the number, the easier the grain is to grind. F-factor values for the three feedstocks are shown in Table 1.

TABLE 1 Typical Properties of Selected Grains

NOTE 1— Theoretical ethanol yields are continuously maintained in only FEMF plants of the most sophisticated design and equipment with the highest level of operational capability. Sustained production levels of 80 to 90 % of theoretical yield are more typical in the FEMF.

Item (as received)	Corn	Barley	Milo
Starch	60–65 %	55–65 %	60–65 %
Moisture	12–15 %	12–15 %	14–15 %
Protein	8–10 %	7–10 %	7–10 %
Temperature of gelatinization	155°F	130–145°F	145–150°F
Weight/bu	55–56 lb	48–52 lb	54–56 lb
Theoretical ethanol yield/bu (see Note)	2.5–2.6 gal	1.9–2.2 gal	2.4–2.5 gal
Typical F factors	32	26	28

For example, a mill required to grind 44 bu/h of corn through a #8 ($\frac{8}{64}$-in.) screen would require a 10 *HP* drive:

$$HP = \frac{44 \times 56}{8 \times 32} = 9.6 \quad (3)$$

10.2.1.11 *Equipment Design Considerations*:

(1) Provide excess capacity of approximately 10 times the hourly demand rate for the grain handling system in order to provide surge capacity to avoid plant downtime caused by failure of the grain system (that is, if plant requires 44 bu/h to produce alcohol, make sure that the grain handling system is sized to handle 440 bu/h). The recommended size of storage bins is dependent upon the availability of feedstock in the area and the strategy of the plant management regarding grain delivery and storage logistics.

(2) Most of the grain handling equipment will generally be located outside and exposed to the elements. It is recommended that grain handling equipment be located outside of the process area to reduce noise and dust problems and explosion risks. Therefore, make sure that grain handling equipment is fabricated of galvanized steel or prime painted carbon steel.

(3) Make sure that all electric motors are of explosion-proof and dust-proof design when operating in areas of high proof ethanol, or grain dust or both. Weatherproof enclosures are advised for all motors installed on outside service. The remainder of the motors should be rated Totally Enclosed–Fan Cooled (TEFC). Motor selection should also conform to existing codes, standards and insurance company requirements.

10.2.1.12 *Safety Considerations*:

(1) Grain handling and milling processes produce dust hazards that can potentially cause dust fires, explosion, or respiratory disorders in workers if accumulation is not controlled and safeguards are not provided. Make sure that grain milling is performed in an area where dust can be collected. Other recommendations for preventing fire and explosion in the grain handling and milling areas include:

(a) (*a*) Elimination of possible heat sources that could cause ignition,

(b) (*b*) Provision of adequate grounding to eliminate static electricity sparks, and

(c) (*c*) Avoidance of storage conditions that may cause grain fire, for example, wet grain heating in storage.

(*2*) Provide personnel protection on drive shafts, pulleys, drive belts, gears, etc, on all grain handling equipment, as well as all other equipment in the plant.

(*3*) Also adhere to Practice E 1117 throughout the plant. Selection of motors and motor controls, conduits, enclosures, etc, should conform to hazard classifications as specified by insurance companies, local, state or National Electrical Codes as appropriate. Make sure that explosion-proof electrical equipment meeting NEC Explosive Atmosphere Classification requirements is utilized in the design of FEMF equipment.

10.2.1.13 *Grain Handling Issues*—Make sure that the project reviewer is aware of the impact of grain handling design on facilities design requirements. The adequacy of the design can significantly affect the success or failure of an ethanol project as follows:

(1) How the plant can utilize multiple grades, distressed or moist grains: The use of below market grade grains such as high moisture or distressed grains can result in substantial operating coat savings. However, adequate grain handling facilities must be provided if the plant is to utilize below market grade grain, including multiple grain bins to segregate below market grains from market grade grain. The cost of multiple bins to enable separate storage and use of several types of grain (for example, corn and milo) must be balanced against the savings in grain purchasing. In addition, if moist grains (higher than 15 to 20 % moisture) are to be utilized, a rollermill may be required, since moist grain does not fracture well with a hammermill. Use of moist grains may also require special storage facilities to protect against excessive degradation of the grain.

(2) Screening devices are provided to ensure proper particle size feed for the milling and cooking sections: Include screening devices for the milling and cooking sections to prevent oversize particles from entering the process. This screening device should also include a magnet to capture metal contamination before it enters the cooking equipment. This metal contamination could come from equipment breakage in the milling and conveying systems.

(3) How the grain handling facilities are arranged to provide safe access for operation and maintenance: Since the conveying devices such as bucket elevators, diverter valves, scalping screens, intermediate storage bins and screw conveyors are often located in elevated structures, make sure that these facilities are accessible to the employees for safe operation and maintenance. Provide proper ladder cages and platforms that are consistent with current safety codes.

(4) How storage facilities are adequate for grain buying strategy: Provide adequate storage capacity for the volume, type and quality of grain required. Also, provide sufficient storage capacity to ensure adequate feedstock supply during times of inclement weather, when grain delivery is impractical. Excess storage capacity may also be desirable to enable the purchase of excess supplies of feedstocks at advantageous prices, although excess storage capacity will increase the plant capital cost and storage of excess grain may increase working capital requirements.

(5) How sufficient quantities of the selected grain are available locally: Verify that the quantity of grain required by the proposed ethanol plant is available locally and will not result in grain shortages or price increases in the project area. This is generally not a problem with small scale plants because the grain usage rate is relatively small.

(6) How the grain receiving facilities are of sufficient capacity to receive grain at the rate required to avoid demurrage charges: A1000-gal/day plant would receive an average of approximately 400 bu of grain per day, or approximately 3 semitrailer loads per week.

(7) Sufficient surge capacity is included in the grain handling and milling area: Provide surge capacity of 1 h for milled grain. The grain receiving and milling section should have excess capacity of approximately 10 times the demand rate to enable the plant to catch up on production after a limited