MASTER

TVA APPLICATION OF INTEGRATED ONFARM FUEL ALCOHOL PRODUCTION SYSTEM

YEAR-END REPORT

Prepared by

Phillip C. Badger
Robert S. Pile

In partial fulfillment of contract No. DE-AI01-80CS80010

TVA Integrated Onfarm Alcohol Production System

Annual Report

Summary

This contract has provided for the documentation of the feasibility of fuel alcohol production with small onfarm facilities, and for the design and construction of an efficient and easily constructed production facility.

A feasibility study and a preliminary design report have been prepared. A prototype facility has been designed and constructed with a design production rate of 10 gallons per hour of 190-proof ethanol. The components of the facility are readily available through normal equipment supply channels or can be primarily owner-constructed. Energy efficiency was also of prime consideration in the design, and heat recovery equipment is included where practical. A renewable fuel boiler is used for process heat. Applicable safety standards and environmental requirements were also incorporated into the design.

Other project activities included modification of a pickup truck to use the hydrous alcohol produced, evaluation of vacuum distillation for onfarm units, and development of a computer program to allow detailed economic analyses of fuel alcohol production.

Efforts were also initiated to evaluate nongrain feedstocks, develop a preliminary design for a low-cost wood-fired boiler, and evaluate packed distillation columns constructed of plastic pipe.

Objective and Procedure

The purpose of the project was to design and construct an economical farm fuel alcohol production system sized to produce 10 gallons of 190-proof alcohol per hour and be capable of meeting an individual farmer's fuel needs. The system was to be designed to integrate into the farmstead in a manner compatible with the ecology and other agricultural activities. The completed system would serve as a basis for concept demonstration on Valley farms and as a demonstration of a working small-scale distillation system. The final accomplishments would include a strengthened national security by protection of the local food supply, protection of the public welfare by establishing facts related to fuel alcohol production and use, and educating the public to these facts.

The procedure for achieving these objectives was to (1) perform a feasibility study, including an environmental impact report; (2) design a production system based on the feasibility study and project objectives; (3) construct, operate, test, and optimize the designed production unit; and (4) use and evaluate the fuel produced.

Feasibility Study - Summary of Findings

A draft feasibility study entitled "Preliminary Assessment for Producing Fuel Alcohol from Agricultural Crops in the Tennessee Valley" was finalized in July 1980 and submitted to DOE and others for review. These review comments are presently being incorporated into a draft for final review and subsequent publication.

Topics covered in the feasibility report included energy use in agriculture, agricultural production in the Tennessee Valley, resultant environmental impacts, fuel alcohol production costs, and advantages and disadvantages of fuel alcohol production. The report showed that liquid fuels accounted for 49 percent of U.S. agricultural energy consumption; of this total consumption, gasoline consumption accounted for 17 percent and diesel fuel 28 percent with fuel oils accounting for the balance of the liquid fuels.

The typical Valley farm has 125 acres. About 20 to 25 percent of a farms' land would be required to achieve liquid fuel self-sufficiency if corn were used as the feedstock. The use of sweet sorghum would reduce this figure by one-half. Current alcohol production will be limited to fermentable carbohydrate feedstocks, such as corn, until the technology for other feedstocks is developed.

Depending on economic returns, the switch to alcohol fuels may result in use of marginal farmland. Such land generally has less productive soils, steeper slopes, and is less efficient in utilizing water and fertilizer. Erosion control is the primary concern with marginal land use. Effective methods of erosion control are known, but implementation will require farmer cooperation and education. The allowance for soil mismanagement on marginal farmland is small and the consequences can be long lasting.

Environmental impacts associated with feedstock production will be influenced greatly by the crop selected by the farmer. Fortunately, the most promising feedstock crop, sweet sorghum, may be grown using known proven cultural practices that minimize soil erosion.

The feasibility report also indicated the potential for onfarm fuel alcohol production. Alcohol of up to 192-proof concentrations may be obtained with an alcohol-water distillation system, and this techology has been known and practiced for years. At 192 proof, an azeotrope concentration is reached and equal amounts of alcohol and water vapor are given off as the mixture is heated. Further separation requires other chemicals and more costly and sophisticated equipment. For this reason, farmstead alcohol production systems are primarily limited to proofs at or below 192. Since proofs of 197 or higher are required to mix with gasoline to make gasohol, farm systems are restricted to using the fuel directly or sending it off the farm for further processing to an anhydrous farm.

The use of byproduct-spent grains is essential for economic success for units using a feed grain as feedstock. For onfarm units, the use of wet stillage for animal feeds has potential. Most animals can utilize the feed value of stillage without being dried, providing maximum economic return with the least energy expenditures.

The production of beef cattle and hogs are the primary livestock enterprises in the Valley region. Both kinds of animals can readily utilize the wet stillage byproduct as feed.

The energy balance for alcohol production depends on the quality of the product, the physical nature of the production process, and the initial point of calculation. Processing energy costs with modern technology are less than one-half the energy contained in the final product.

Production costs are contingent on feedstock, equipment, interest and operating expenses, plus the byproduct credit. When corn is used as the feedstock, estimates generally indicate costs of $1.40 to $1.80 per gallon after byproduct credits of $0.30 to $0.40 per gallon are incorporated.

The following advantages were noted for fuel alcohol production from agricultural crops.

1. Reduced dependency on foreign oil.
2. Reduced trade deficit.
3. Development of a renewable source fuel.
4. Reduction in government subsidies.
5. Increased competition in the energy field.
6. Positive environmental impact through waste utilization and fewer internal combustion engine exhaust emissions.
7. Does not decrease protein contents when grains are used as feedstocks.
8. Uses known technology that is not complex.

The folllowing disadvantages were also noted.

1. Fuel alcohol is only a partial answer to the energy problem.
2. The economics of production are currently marginal.
3. Engine modifications are necessary to use fuel alcohol.
4. Increased use of tax exempt alcohol would reduce revenue available for road construction and maintenance.
5. The questions surrounding the food versus fuel controversy have not been fully answered satisfactorily and are sensitive in relation to world politics.
6. Large-scale alcohol production may significantly impact grain prices.
7. Undesirable environmental impacts may occur as a result of use of marginal land or by the improper handling of the wastes generated.

Regulations Affecting Design

Environmental and safety requirements and regulations governing the handling and use of distilled spirits had to be assessed before facility design.

The primary Federal regulations governing the use of distilled spirits and having impact on design were as follows:

1. Design and construction of facility . . . "maintain security adequate to deter diversion of the spirits."

2. Provide for a means . . . "to determine and record the quantities of spirits produced, received, rendered unfit for beverage use, and used or removed from the premises."

3. Provide for a means to . . . "render the spirts unfit for beverage use."

Fulfilling these requirements also fulfilled applicable state and local codes related to the handling of distilled spirits.

Federal EPA regulations governing air and water quality are enforced by the respective states. The boiler system elected had to have maximum stack emissions of less than 0.02 grains per SCF at 50 percent excess air and meet opacity standards. Floor drain wastes were specified to be handled with a septic tank, gravel filter bed, and sod filter strip.

Safety regulations specified that components within three feet of the floor of an enclosed building and within eight feet of the columns had to be explosion proof. Forced ventilation with fans mounted close to the floor was required during distillation in an enclosed building. Standard safety interlocks and pressure relief valves were specified for the boiler. The boiler had to be at least 25 feet from the distillation and alcohol storage sites. Standards also dictated venting and grounding requirements for tanks and similar components. Alcohol storage greater than 1,000 gallons had to be underground and away from the building. Above-ground alcohol storage had to be within a diked area sufficient to hold the entire contents of the tank and each tank had to be diked separately. Adequate fire protection, safety showers, and other personnel protection measures are applicable to small-scale facilities.

Facility Design and Construction Summary

Based on the feasibility report findings, applicable regulations, and project objectives, the following factors were used to design the experimental facility:

1. The system would have a production capacity of 10,000 gallons of fuel-grade alcohol during a 3- to 4-month period annually.

2. Corn would be used as the initial feedstock with other feedstocks to be evaluated as rapidly as time permits.

3. A renewable fuel, or possibly coal, would be used for cooking and distillation energy.

4. The design should be simple in construction, using readily available materials and off-the-shelf components, to facilitate farmer construction and to minimize expenses.

5. Controls would be kept as simple as economics and performance permitted.

6. The system would require minimal labor to operate.

7. No effort would be made to dry the stillage, primarily based on economics.

8. No attempt would be made to produce alcohol in excess of 192 proof.

Based on these guidelines, the system would be designed and system components would be either constructed or purchased as commercially available items.

Three methods of distillation were initially considered: (1) a "pot" still, (2) a vapor feed distillation column with an evaporator for the feed, and (3) a liquid feed distillation system. The method of distillation chosen would dictate overall facility design.

The "pot" still was eliminated because of the excessive distillation energy requirement and slow production rates. Pot stills are also more difficult to operate safely since an open flame is normally used in close proximity to the still. Other problems associated with pot stills include mash scorching on the bottom of the cook pot, difficulty in regulating temperature with solid fuels, and the problem of controlling and providing increasing energy as the alcohol is distilled.

The vapor feed column has a high energy requirement due to the evaporator required (similar to a pot still) and the high reflux ratio (35 to 40) required. The evaporator increases the facility cost and can have scorching problems similar to the pot still.

For these reasons, the liquid feed distillation column was selected and the column design developed using a 1,000-pound feedstock basis. The column design for the experimental facility was then scaled to a production rate of approximately nine gallons per hour (as desired by DOE). This rate would produce 10,000 gallons of alcohol in 46 days of continuous distillation or approximately 70,000 gallons in a year with 320 days of operation. Plants of other production capacities could be scaled from the design information.

The following specific factors were used in the column design.

1. Feedstock--Slurry of approximately 25 percent solids of a maximum 20-mesh particle size and 8-volume percent ethanol.

2. Product recovery--Recover 95 percent of ethanol in the feed.

3. Product quality--Product to be 95-volume percent ethanol (190 proof).

The process flow rates and parameters as designed are shown in figure 1. Heat exchangers were designed into the system to recover process waste heat and reduce distillation energy requirements by approximately one-third.

Grain handling equipment was selected from commercially available sources and included a 7.5-ton bulk storage bin for ground corn, 4-inch diameter transfer augers, and an automatic weigher. Due to the fact that most farms have some means of preparing feeds, it was decided to purchase ground corn from a local feed company instead of purchasing a hammermill for onsite grinding.

A 750-gallon, stainless steel tank suitable for conversion into a cook tank was located as TVA surplus. A cooling coil consisting of 108 feet of 2-inch diameter mild steel pipe and a circular perforated pipe for steam injection were designed, constructed, and installed in the cook tank. A commercially available propeller-type agitator was selected and also installed in the cook tank.

Flat-bottom polypropylene tanks (3 @ 1,500 gallons) commercially available as liquid fertilizer storage tanks were purchased for fermentation tanks. Three steel tanks of over 4,000 gallons total capacity were located as TVA surplus and selected for stillage storage tanks. Two skid-mounted standard mild steel fuel storage tanks of 550 and 280 gallons were purchased for alcohol storage tanks.

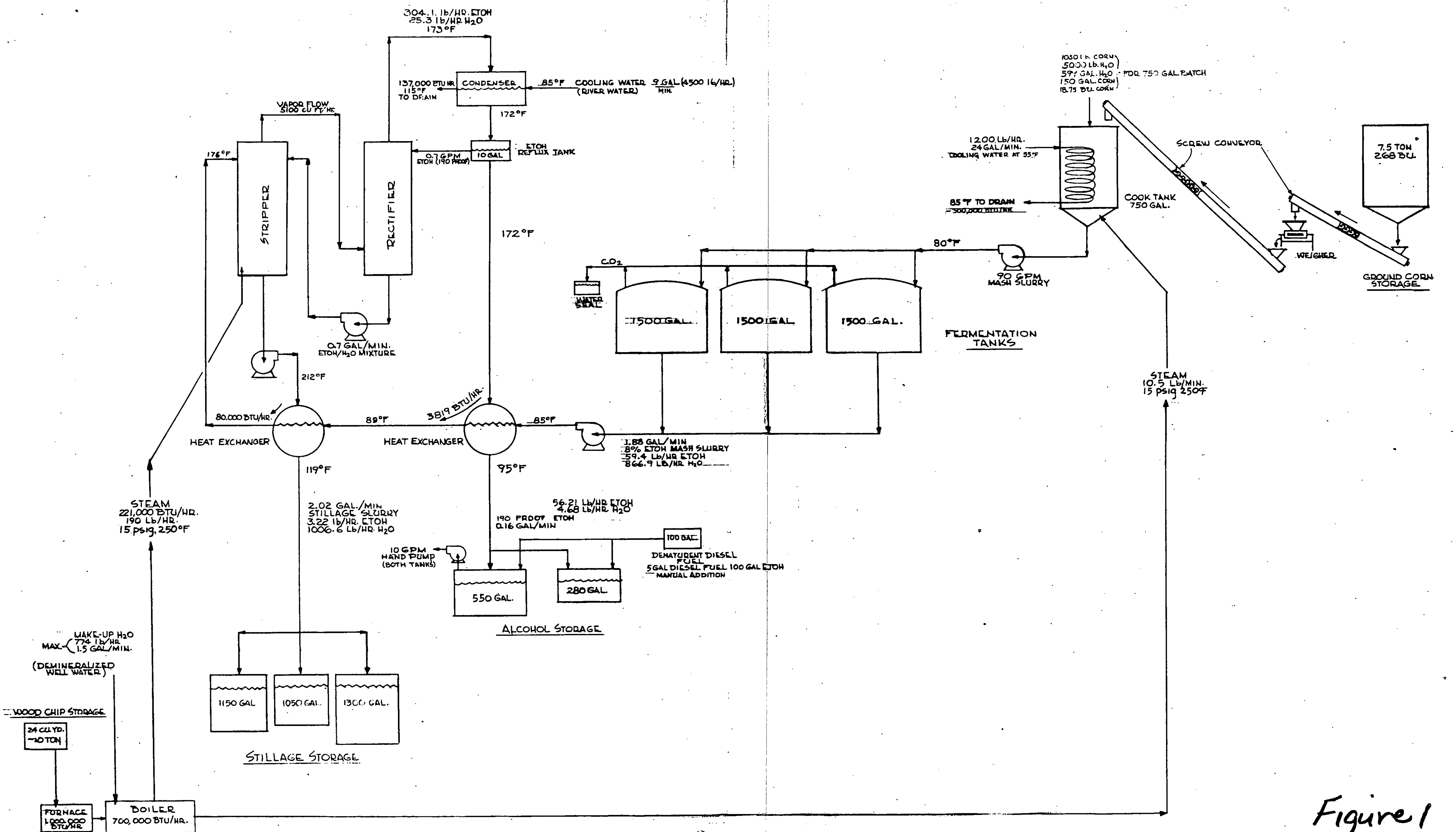

Figure 1

PROCESS FLOW DIAGRAM

MUSCLE SHOALS FUEL ALCOHOL PLANT

DIVISION OF AGRICULTURAL DEVELOPMENT
PROCESS FLOW DIAGRAM
MUSCLE SHOALS FUEL ALCOHOL PLANT
SCALE NONE DATE 5 AUG 1980
DWG. NO. MSFAP-301

Distillation columns were constructed using 8-inch diameter mild steel pipe and mild steel fittings. The columns were split at the feed plate to reduce overall height. Packed columns were used to maintain simplicity, to minimize costs, and to provide ease of cleaning. Commercially available 0.625-inch pall rings and 0.5-inch polypropylene spheres were used for the rectifying and stripper column packings respectively.

A concentric pipe heat exchanger providing over 130 ft^2 of heat exchange surface was constructed out of standard copper tube (type L) and fittings to recover product and stillage waste heat and preheat the incoming beer feed. A steel frame with a top deck was designed and constructed to support the columns and heat exchanger and provide access to the column top section.

A 20-gallon, mild steel reflux tank and shell-and-tube condenser were purchased locally. The condenser provided 16 ft^2 of heat exchange surface to be used with water flowing in the tubes (to facilitate cleaning if fouling occurred). Condenser duty was sized at 140,000 Btu/h with a water ΔT of 30° F. Water ΔT was kept low to minimize scaling.

An automated 20-hp package boiler system (Rettew Associates) capable of burning wood chips, sawdust, wood shavings, chicken litter, or ground corn cobs was purchased. The system came complete with stack, 10-ton fuel storage bin, and conveyor to feed fuel from storage to the boiler. Another conveyor was purchased to transfer fuel into the storage bin as unloaded from a delivery truck.

The boiler system was specified as low-pressure, 15-psig steam to minimize regulatory and operator requirements. Both cooking and distillation were chosen to be by live-steam injection. This would simplify maintenance, minimize scorching on hot surfaces, and simplify the system by eliminating condensate return components.

Once major components were finalized, the facility layout was determined. Most components were placed inside a building to protect them from the weather (especially rain and freezing temperatures) and to reduce the effect of ambient conditions on the process (see figure 2). Stillage and grain storage tanks were placed outside the building to reduce space

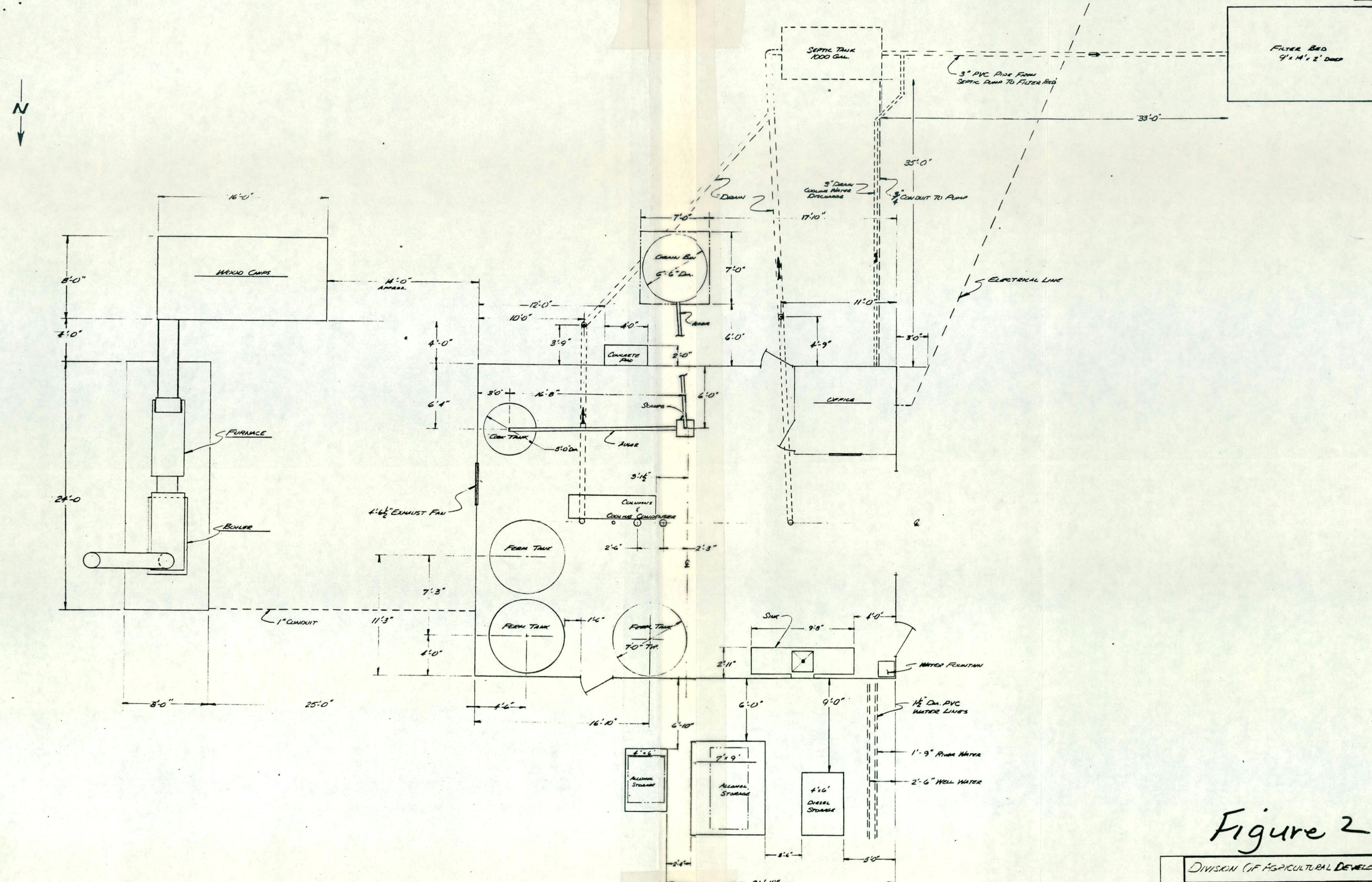

Figure 2

	DIVISION OF AGRICULTURAL DEVELOPMENT
	SCALE: 1/4" = 1'-0" · APPROVED BY: RLB · DATE: 28 JULY 80
	LAYOUT OF FUEL ALCOHOL PROJECT
R-1	MUSCLE SHOALS FUEL ALCOHOL PROJ. · M-FAP-125

requirements and the boiler system and alcohol storage tanks were located away from the building for safety purposes.

A building with a concrete floor, steel frame, and sheet-metal siding with fiberglass insulation was constructed in July. Pipelines were run to the building from a nearby well and a river water supply line. The boiler was installed 25 feet away from the main building in a partially enclosed structure with a concrete floor. Roofs were constructed over the boiler fuel storage bin and bin-to-boiler fuel conveyor to help keep boiler fuel dry. The conveyor for loading boiler fuel into storage was permanently installed, and a hopper and ramp was constructed at its base to facilitate unloading trucks.

Internal plant layout was partially dictated by distillation column and building height since the rectifying column had sufficient clearance only along the building ridge centerline. The flat-bottomed fermentation tanks were installed close together (to facilitate piping to a common pump) and on sloping platforms to facilitate drainage. A PVC pipe header was constructed between fermentation tanks to collect CO_2 for discharge through a water seal (small tank) and for subsequent venting outside.

The condenser and reflux tank were installed near the top of the rectifying column on a steel frame supported by the building frame and column supports. The condenser was equipped with a vent to permit equalization of pressure and to provide escape of noncondensable gases. This vent was constructed of coiled, 0.25-inch copper tubing and vented to the outside (for safety). The reflux tank was also equipped with a vent to the outside.

For safety purposes, no pipes were located in floor walkways. Most piping for transport of alcohol and material above 120° F was type L copper tubing with soldered joints. Other process piping for lower temperature applications was Schedule 40 PVC pipe. Material transfer between the cook tank and fermentation tanks was by flexible hose with quick-connect couplings. This would permit the hose to be removed to avoid a tripping hazard and, by connecting to each tank as needed, would eliminate piping dead ends, associated flow blockages, and sanitation problems. Steel pipe with welded joints was used for steam piping.

A water softener was installed to treat boiler makeup water. Recording water meters were installed to monitor boiler makeup water and water used for cooking purposes. Indicating flow meters were installed to measure condenser and cook tank cooling coil water flows, column feed rate, alcohol product, and reflux flow rates. Orifice plates and a recording chart flow meter were installed to measure steam flows to the column and cook tank.

Air driven, double diaphragm pumps were used for the column feed and for removing stillage from the stripper column. An air-driven gear pump was used for stripper column reflux. The product stream and rectifying column reflux were gravity flow. Automatic controls consisted of a mechanically operated temperature actuated-flow control valve in the product stream (controlling column reflux and product withdrawal) and float-actuated solenoid valve level controls on each column bottom. Steam and feed flows to the columns would be manually set to the design setting and left at a constant flow. Once started and stabilized, these controls would allow the distillation process to operate unattended. All other controls would be manual with the exception of the boiler. Automatic controls to maintain steam pressure were provided with the package boiler.

The denaturant, consisting of five gallons of unleaded gasoline per 100 gallons of product, would be manually added to the product storage tank. The amount of denaturant required would be determined by a gauging stick manually inserted into the product tank. A 55-gallon drum was installed for denaturant storage.

At the end of the 1980 fiscal year, the facility was 95 percent complete and had undergone pipeline pressure testing and boiler operational checks. Most of the remaining work was nonessential to facility operation, such as insulating, painting, etc.

A preliminary design report covering the method of facility design and base assumptions has been written. This report has been reviewed in draft form and is presently being rewritten for final review. The facility component schematic is shown in figure 3. A record has been kept of costs for the evaluation facility. These approximate facility cost figures were as follows:

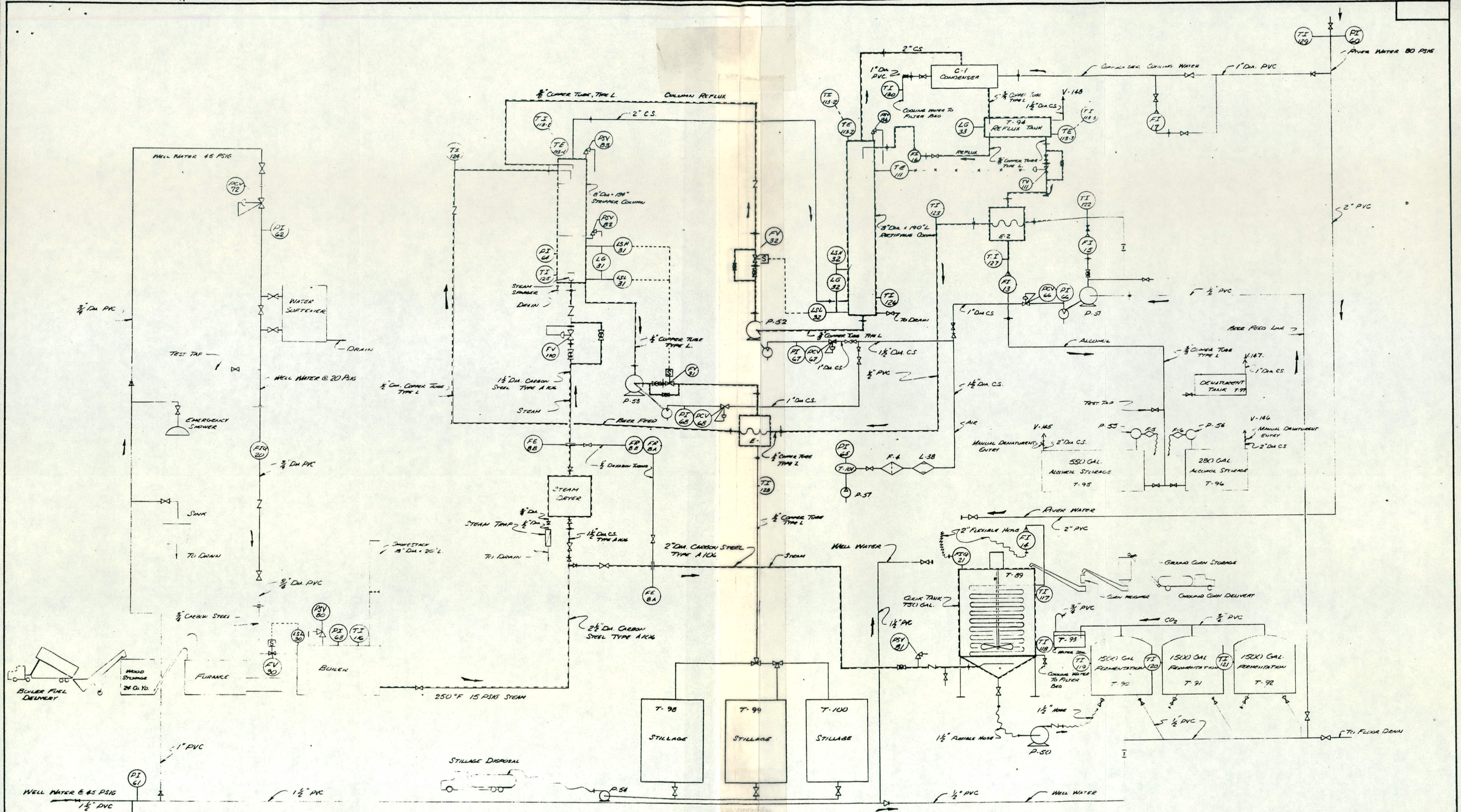

Figure 3

NOTES:

1. ——— INDICATES INSULATED SURFACE.
2. ALL COPPER TUBING TYPE L.
3. ALL STEAM PIPING CARBON STEEL TYPE A 106.

DIVISION OF AGRICULTURAL DEVELOPMENT			
SCALE: NONE	APPROVED BY		DRAWN BY
DATE: 22 JULY '80	R.B		J. MONTGOMERY
FLOW DIAGRAM			
FUEL ALCOHOL PROJECT			DRAWING NUMBER MSFAP-400

Building (includes materials and construction)	$18,600
Boiler system	31,100
Components and supplies (complete, including some installation cost and allowances for surplus components used)	39,000
Total cost (less most installation)	$88,700

A complete economic analysis is in process. Efforts will be made to lower facility cost by substitution or modification as testing and redesign pinpoint areas for cost reductions. A more detailed cost breakdown is included in the Appendix.

Other Project Activities

At the conclusion of the fiscal year, negotiations were in progress with a local farmer for disposal of the wet stillage. The farmer has since agreed to haul away any stillage produced, feed it to beef cattle, and keep records of weight gain.

A 1972 6-cylinder pickup truck used by project personnel has been modified to run on either gasoline or fuel alcohol. The changes included addition of a fuel tank, enlargement of carburetor jets, advancement of engine timing, addition of a manual choke, and addition of an in-line fuel filter. To date the truck has operated satisfactorily on fuel alcohol. Other vehicles will be modified as production increases.

The process heat source is a major expense of the present facility. Alternative sources of process heat that would be more efficient or economical are being sought. Other ways to reduce facility cost are also being investigated.

This has led TVA to fund some promising research efforts at Mississippi State University. The research is to (1) design and build a small packed distillation column using plastic pipe and test the efficiency of low-cost packings in the column, (2) prepare a preliminary design of a low-cost boiler capable of burning round wood, and (3) determine the feasibility of vacuum distillation and an internal combustion engine process heat source. A report on vacuum distillation has been completed and received for review. In general, the report was negative toward the use of vacuum distillation for farm-scale units. Reports on the first two contracts will be finalized January 1, 1981.

During the coming year all phases of the project will be continued. Studies will be made of the optimum feedstock for the Valley or Valley subregions. Plantings and processing tests of the most promising feedstocks will be conducted. The prototype facility will be thoroughly tested and benchmark data established. After satisfactory facility operation, modification, and testing, a farmer-oriented construction manual will be written and similar units will be placed on Valley farms as demonstration units.

Muscle Shoals Fuel Alcohol Facility Costs

1.	Grain handling equipment (Storage bin, two augers, weigher; includes installation, does not include anything for bin concrete pad)	$ 2,350.00
2.	750-gallon, mild steel cook tank (Includes cooling coil, steam sparger, and $2,088 for agitator and motor)	3,700.00
3.	Fermentation tanks (3 @ 1,500 gal)	2,160.00
4.	Distillation columns (Includes materials for construction, packing, steam sparger, and construction; does not include components attached to column)	2,760.00
5.	Condenser (Including vent)	480.00
6.	Reflux tank (Including vent)	160.00
7.	Stillage storage tanks	3,500.00
8.	Alcohol storage tanks (Including hand pumps, filters, and vents)	1,270.00
9.	Pumps (Includes cook-to-fermentation tank pump, stillage storage-to-truck pump, feed pump, two reflux pumps, and column stillage pump)	3,310.00
10.	Air system (Includes air compressor, lubricator, filter, regulators, valves, and piping)	850.00
11.	Denaturant tank (Includes support frame and vent)	100.00
12.	Boiler fuel-to-storage conveyor and hopper	1,400.00
13.	Steam system and boiler makeup piping (Including steam dryer, traps, flow meters, recorder, etc.)	2,500.00
14.	Water softener	450.00
15.	Flow meters (Including cook tank totalizer, condenser, cooling coils, beer, product, and reflux flow meters)	2,150.00

16.	Concentric pipe heat exchangers (Includes pipe, fittings, solder)	500.00
17.	Thermometers and thermocouples (Including thermocouple reader)	1,700.00
18.	Column controls (Including column bottom level controls and reflux control)	3,250.00
19.	Septic tank and pump (Including septic tank and filter bed--installed, and pump at $400)	1,000.00
20.	Miscellaneous piping, flexible hose, and fittings	1,900.00
21.	Miscellaneous electrical switches, wiring, etc.	1,900.00
22.	Hoist and trolley	160.00
23.	Structural steel (For support framework, etc.)	450.00
24.	Miscellaneous (Scales, fire extinguishers, safety shower, tables, etc.)	1,000.00
	Component Total	$39,000.00

SUMMARY

Building (Includes materials and installation)	18,600.00
Components (Includes some installation and allowance for TVA surplus items used)	39,000.00
Boiler facility (Includes furnace/boiler; fuel storage; fuel conveyor, for boiler building and fuel storage; and conveyor roofing)	31,100.00
Total	$88,700.00