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Farm Scale Electrical Power Production From Animal Waste

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Final Report for Research, Design, Construction, & Operation
June 30, 1981 - December 30, 1983

By:

Phillip A. Carpenter

ENTEC Research & Development Company
Knoxville, Tennessee

MASTER

Work Performed under Grant No. DE-FG4481R410416

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DOE/RW/10416--T2

FARM SCALE ELECTRICAL POWER
PRODUCTION FROM ANIMAL WASTE

Volume I, Final Report
for the Period 30 June 1981 to 30 December 1983

By:
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Date Published: 31 January 1984

PREPARED FOR THE UNITED STATES

DEPARTMENT OF ENERGY

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FARM SCALE ELECTRICAL POWER
PRODUCTION FROM ANIMAL WASTE

by:

P. A. Carpenter

ABSTRACT

Under DOE Appropriate Technology Grant No. DE-FG4481R410416, the ENTEC Research & Development Company has researched, designed, managed construction, and begun startup of a 1 1/2 (dry) tons per day biodigester cogeneration plant. This project is part of a federal program to promote energy conservation and the use of non-conventional energy resources. The main purpose of the project is to demonstrate that a dairy farm can generate it's own power and supply excess power to a local utility. Such a facility can produce significant energy savings to livestock farms and small communities by allowing them to get energy from raw animal and human waste. Also, an odorless by-product is produced that is nearly pathogenically free and has the possibility of several end uses such as: fertilizer and soil conditioner, protein-rich animal refeed, livestock bedding material, and aquatic food for fish farming.

The experimental facility was constructed at the Cleek Dairy Farm (CDF) owned by Charles W. Cleek and C. Alan Cleek in Kingsport, Tennessee. CDF contributed the site for the plant, the dairy cows that provide the manure feedstock, certain capitol equipment, the construction equipment and part of the construction labor, utilities and supplies for plant operation, and the plant operating personnel.

Research and project planning began in June 1981, design began in July 1981, construction began in August 1981, and plant startup began in November 1983. Continuous operating conditions have not yet been reached at the experimental facility due to biogas leaks in the biodigester roof (gas collector) however, full operation of the cogeneration plant is expected to be ready soon and complete operational data and information will be issued in volume 2 of the final report (to be issued in June 1984). It is hoped that the economic viability of the project will be supported by the results of volume 2.

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1 PROJECT SUMMARY

1.1 Background & Objectives

In March 1981 a proposal was filed jointly by C. Alan Cleek of Cleek Dairy Farm and Phillip A. Carpenter of ENTEC Research & Development Company for funding of a project to convert biomass (animal manure) into bio-methane gas to be used as a fuel source for an on-farm cogeneration plant. After an extensive review by the Tennessee Energy Authority the proposal was one of thirteen selected for possible funding under the third cycle of the U.S. Department of Energy's Appropriate Technology Small Grants Program. On June 30, 1981 the Region IV Office of the Department of Energy gave notification that our project had been approved for funding.

The project entitled; "Farm Scale Electrical Power Production From Animal Waste", was envisioned to consist of the following steps:

- A.) Collection and preparation of raw dairy cow manure at an onsite below-ground pit and then pumping the slurry to a bio-reactor to be processed.
- B.) Conversion of the volatile solids (organic) portion of the manure slurry to biogas (methane, carbon dioxide, and hydrogen sulfide gases) in an onsite biodigester. Subsystems for maintaining the temperature, monitoring the pH, agitating the slurry, collection and transport of the biogas, removal of sludge buildup, and transport of the processed effluent were to be included.
- C.) Biogas purification in an onsite scrubber system for removal of the corrosive hydrogen sulfide portion of the gas prior to use as a fuel in the engine/generator unit. (The carbon dioxide will not be scrubbed initially, but provisions would be made for using this option in the future if so desired).
- D.) Utilization of the cleaned biogas (containing methane and carbon dioxide) by an onsite electrical power cogeneration unit to provide process heat for the biodigester and to provide electricity for the farm's needs with the excess being sold to the local utility.
- E.) Storage of excess biogas onsite to provide for a 2-3 day supply of gas for the engine/generator should the biodigester unit be down for maintenance or repair.
- F.) Storage of the processed effluent in an onsite holding pond with provisions for the use of irrigation equipment for ultimate effluent disposal.

The following sequence of events were required to complete the project:

- A.) Completion of research and investigations of the various processes/systems that could be used and make the final selection (i.e. plug flow reactor versus continuous stirred tank reactor).
- B.) Initiate and complete the plant design (including equipment selection and sizing), select the site for the plant location and layout the plant structures.
- C.) Procure the materials and equipment for plant construction, coordinate and supervise construction efforts and subcontractor work.
- D.) After construction is completed, initiate testing of the various systems prior to plant startup to make sure each system operates as it should.
- E.) After testing is completed and all systems are functioning properly, begin plant startup and monitor plant's performance (adjustments are made as required).

The original project schedule estimated completion of the plant 20 months after the project start date of August 1, 1981 (or by April 1, 1983). The original project cost was estimated at \$43,500 (excluding most labor, in which the labor breakdown was as follows; on-farm employees-paid by Cleek Dairy Farm, volunteer help from relatives and friends-not paid, and some subcontractor work-paid from grant funds).

The overall project objective was to construct an onsite biodigester cogeneration plant to demonstrate the technical and economic feasibility of a dairy farm to produce it's own power and sell excess power to a local utility. This type of plant has been constructed on many university research farms but by early 1981 few had been built on private farms. Experience was needed in operating such plants under actual private farm ownership and this project should be instrumental in providing information on the long term operating capabilities of a typical private farm.

1.2 Initial Research Findings

I found that research in the area of converting animal waste to biogas was being conducted at several universities (Agricultural Engineering Departments) and research institutes. Letters were sent to the following institutions for information:

- Iowa State University
- Pennsylvania State University
- Cornell University
- Biomass Energy Institute (Manitoba, Canada)
- University of Missouri
- University of Nebraska
- University of Arkansas
- Purdue University

Research of this kind was not presently being conducted at the University of Tennessee (courtesy Dr. L. M. Safley, Agricultural Engineering Department). In studying the various systems I decided to follow the work being done at Penn State University as a guide due mainly to their experience with actual plant operation. Their pilot plant had been in operation for a two year period, also a well written report was available from the university which seemed to cover all areas of the conversion process. Their system was of course not problem free and thus additional research was conducted so as to improve on their design for use in this project. I realized early in my research studies that much work was needed to fully optimize gas production and also to improve the following; system balance & control, reliability, capital cost reduction, operating cost reduction, and by-product utilization. Each of these areas can effect the project's economic feasibility and so I wanted to address all of these areas on this project with diligence. A more detailed study of each of the systems available was conducted and I decided that a trip was needed to see such experimental systems in operation. Details of the trip is discussed in a later part of this report.

1.3 Biomass Conversion Process

The basic process used here for converting animal waste to a fuel gas involves the use of anaerobic digestion. In simple terms, all animal waste contains an organic and an inorganic portion of material. The organic portion is called the volatile solids and this determines the amount of biogas that can be produced. Different types of manure contain their own volatile solids level and thus can produce differing amounts of biogas per pound of waste. The dairy cows being used here are on the higher end of volatile solids level as can be seen in table 1 below.

Table 1. Gas production from animal wastes per 1000 lbs body weight.

Animal Type	Volatile Solids (pounds/day)	Expected % V. S. Bioreduction	Biogas Production (cubic feet/day)
Poultry	10.7	60	82
Dairy	8.6	48	44
Beef	5.9	45	30
Swine	4.8	50	29

(From Iowa State University CES bulletin Pm-593).

As can be seen from the table, not all of the volatile solids can be converted to biogas. The amount of volatile solids as well as the percent converted determines the total expected gas production. The object here is to increase the percent of volatile solid breakdown which would in turn optimize the gas production. There are several factors that determine the percent of volatile solids that can be bio-digested, these are; reactor hydraulic detention time, temperature level, pH level, dilution percentage, and the type of organic contents. All of these factors must be used to design the system for maximum performance at least cost, at best tradeoffs are necessary. For instance the reactor size determines the hydraulic detention time, but also is the largest cost of the overall system.

The process consists of loading the manure (influent) periodically into a sealed bio-reactor where a facultative anaerobic bacteria converts the volatile solids or complex organics into volatile acids (known as liquefaction step) then a methane bacteria converts the volatile acids or simple organics into methane and carbon dioxide gases (known as gasification step). The size of the bio-reactor fixes the retention time of the waste material. Tight controls are maintained on the bio-reactor (i.e. temperature, pH level, dilution, and mixing to prevent scum buildup) to keep the environment at a level to support bacteria activities. The biogas produced is utilized as a fuel and the effluent is used as fertilizer since it is high in nitrogen value and has a much reduced odor level. Each of the factors affecting biodigester operation will now be discussed.

1.3.1 Temperature

The bio-reactor temperature is critical in controlling gas production and supporting bacteria activity. There are two main temperature levels where bacteria activity remains stable. The lower stable bacteria activity occurs at 95 degrees Fahrenheit (called mesophilic bacteria) and their stability to produce biogas decreases substantially as you approach either 90 or 100 degrees Fahrenheit. The mesophilic temperature supports a hardened type of bacteria. The higher stable bacteria activity occurs at 130 degrees Fahrenheit (call thermophilic bacteria), here the bacteria produces greater biogas quantities but is more sensitive to changes in the bio-reactor. Since most biomass feedstocks digest well at the mesophilic temperature and it requires less heat to maintain this level, then this is chosen as our initial operating level. The design of our biodigester includes provisions to operate the system at the thermophilic level if so desired (see figure 1 for graph of bacteria operating temperature range).

1.3.2 pH Level

My research has found that dairy cow manure is generally very stable in the pH level needed to support bacteria activity (anaerobic bacteria require a pH of 6.8, near neutral) being close to 7.2 pH. Chicken manure has been found to have varying degrees of ammonia level which causes the pH to be too low (acidic) and often requires buffering. It should not be necessary to make adjustments to the pH of this bio-reactor during normal operating conditions. It has been found that any

BIOMASS ENERGY CONVERSION PROJECT

Graphs of
Reactor Variable
Characteristics

BIOMASS ENERGY CONVERSION PROJECT

DIGESTER SYSTEMS COMPARISON DIAGRAM

CONTINUOUS STIRRED TANK REACTOR (CSTR)

PLUG-FLOW (Tunnel type) REACTOR

animals that are being heavily treated by antibiotics should be kept away from the main herd feedlot so the manure in question can be diverted from the feedstock collection pit. The design of this biodigester has provisions to monitor the pH level and if necessary, compounds can be added to adjust the pH level. Other materials such as hay, straw, sawdust (all bedding material), and grit can affect the pH level of the manure somewhat (see figure 1 for bacteria operating pH range).

1.3.3 Dilution

Manure contains varying percents of water, inorganic solids, and organic (volatile) solids. Generally dairy cow manure contains 85-90% water, 10-7.5% organic solids, and 5-2.5% inorganic solids. The amount of dilution needed depends on; the percent of total solids, the type of transport pump used, the type of manure, and the presence of bedding material. Most manure pumps can handle at best 15% solids content and bedding materials could clog the system, thus dilution is necessary. However, it is best to keep dilution at a minimum and generally this can be done in the case of dairy cow manure. Chicken manure often requires dilution to maintain easy handling (it often contains a higher percentage of solids) and proper pH levels (chicken manure is high in ammonia). The pump selected is capable of handling 12% solids and the design includes a spraying system at the collection pit for dilution water as required to maintain this solids level.

1.3.4 Agitation

The liquid manure tends to settle out in various layers and thus mixing is required to maintain common temperature levels at all points in the biodigester. Also, scum can collect at the top of the liquid level which can inhibit bacteria activity and clog the various system components at this level. The design of this digester includes a means to agitate the slurry both continuously or intermittently.

1.4 Biodigester Systems Comparison

There are two basic biodigester types each having their own advantages and disadvantages. They are the plug flow reactor and the continuous stirred tank reactor (CSTR). In the plug flow system a trench type (septic tank) reactor is used and all incoming slurry works its way to the other end after a set retention time that is determined by the reactor volume. The system mixes itself somewhat by natural means, but scum has been noted to buildup on the surface and thus becomes a problem. The main advantages of this system are ease of construction, lower cost, and simple operation. The main disadvantages are lower gas production, scum buildup, no way to clean settled particles from the reactor floor without disturbing its operation, and rapid deterioration of the cover used to collect gas and seal the reactor (butyl rubber is affected by sunlight). In the CSTR (complete mix) system, the biodigester is a cylindrical tank (silo type) that can have either a fixed or floating roof. As new slurry enters the bio-reactor then the same volume entering the biodigester overflows out of an effluent pipe. The bio-reactor slurry is mixed by artificial means

which keeps surface scum broken up. The main advantages of this system is that an external means is used to remove sludge that collects on the bio-reactor floor (sludge removal auger or suction lines). and this technique does not affect biodigester operations. The agitation system maintains better bio-reactor control by eliminating scum buildup and homogeneously mixing the slurry. The tank roof (gas collector) is made of materials that has a long life. The main disadvantages are it's higher cost and more difficult construction. Also, the system is somewhat more complex to operate. A comparison of performance parameters of two different installations is shown in table 2 below.

Table 2. Biodigester Systems Comparison.

System Parameters	System Types	
	Complete Mix	Plug Flow
Biodigester volume (cf)	394	492
Herd Size	100	100
Daily Biogas Yield (cf)	4720	3680
Operating Temperature (F)	95	95
Retention Time (days)	10	15

(From "Fuel Gas Production from Biomass", CRC Press, 1981).

As can be seen, the complete mix reactor produces more biogas at a shorter retention time and requires less reactor volume than the plug flow reactor. The data was collected at installations in Jefferson, Wisconsin and Rice Lake, Wisconsin. For this reason the complete mix reactor type was chosen for this project. The above noted advantages and disadvantages were verified during a trip that Alan Cleek and myself took to see such systems in operation. Details of this trip are discussed in a later part of this report.

1.5 General Design Description

The biodigester plant was designed to handle manure from a maximum of 200 cows per day. The Cleek Dairy Farm currently milks 125 cows from which manure must be disposed of during the nine warmer months of the year and the farm also has approximately 75 "dry" cows (not milking) in the replacement herd in the pastures, however during the three winter months these cows are brought in to shelter with the milk cows. Therefore, for nine months of the year manure from 125 cows is available for processing and during three months of the year manure from 200 cows is available for processing (annual average is 143).

Each cow produces 100 pounds of manure per day (at 13% solids) which means our average of 143 cows produce 7.1 (wet) tons per day of feedstock. The biodigester is designed to handle the maximum loading from 200 cows (or 10 wet tons/day). The average volatile solids loading rate per day is 1,144 pounds/day. This plant is designed to optimize biogas production by having an increased retention time of 26 days (the average biogas production per cow per day is 60 cubic feet). See figure 1 for bacteria conversion rate at varying retention times. The biodigester plant is capable of producing a daily average output of 8,580 cubic feet of biogas (based on 143 cows per day annual average). The biogas contains a thermal content of approximately 600 BTU's per cubic foot. This represents an annual average output of 1.79 billion BTU's of energy (based on 95% plant availability). This system is capable of producing an average of 14.5 kW per hour or a total annual average of 120,000 kWhr/year of electricity. Also, waste heat is recovered from the engine/generator by use of heat exchangers to remove heat from the engine cooling water, oil, and exhaust. The total expected output of 195 degree Fahrenheit water on an annual average basis is approximately 1.05 billion BTU's/year.

The biodigester also produces a liquid effluent (at approximately 6% solids) that has destroyed practically all of the harmful pathogenic organisms found in raw manure, thus making it an excellent fertilizer. The raw manure contains a large amount of nitrogen that is bound up in proteins, however after digestion at least 50% of this nitrogen is converted to ammonia nitrogen. Also, a large quantity of phosphate and potash are present in the manure and are not affected by the digestion process. An effluent holding pond was designed to hold the some 775,000 gallons of processed slurry produced per year (this includes dilution water). The holding pond was designed by the USDA Soil Conservation Service and can hold approximately 1,000,000 gallons of digested effluent and rainwater.

The following systems and subsystems were required as part of the design to support operation of this facility:

- A.) Manure collection and handling system.
- B. Biodigester (bio-reactor) system.
- C.) Biogas handling and purification subsystem.
- D.) Biodigester slurry agitation subsystem.
- E.) Biodigester sludge removal subsystem.
- F.) Biodigester monitoring subsystem.
- G.) Heat-recovery and biodigester heating subsystem.
- H.) Biogas utilization/electrical power generation system.
- I.) Effluent slurry storage and disposal system.

The design details (including modifications and additions) are covered in a later section of this report.

1.6 Construction

After a quick trip was taken in July 1981 to see other biodigester installations in operation in Pennsylvania and New York, the selected project site was surveyed to layout each of the main structures. Construction on the biodigester tank foundation, the manure collection pit foundation, and the holding pond was begun in August 1981. Work on the holding pond was completed by the end of August 1981 (except for the installation of fencing). Construction on the manure collection pit walls was begun in September 1981. Work on the manure collection pit continued until installation of the manure handling equipment was completed in September 1982. Erection of the biodigester tank was begun in October 1981 and installation of the tank roof (gas collector) was completed in November 1981. Other work on the biodigester tank continued until October 1983. The only remaining work on the biodigester tank is the installation of external insulation on the tank roof and on a portion of the tank wall. The completion of this work is being restrained by gas leaks that developed in the tank's bolt-together roof. These leaks are caused by poor seals between each of the bolt-together sections and also where the roof joins the tank wall. These gas leaks will be sealed tight by the application of a 30-mil thickness of a spray-on hypalon coating. The coating is to be backed by a two inch thickness of spray-on polyurethane foam insulation to provide compressive strength and to insulate the tank roof. A subcontractor skilled in the application of these materials has been contacted to proceed with the work, however the inclement weather has halted all progress to date (the coating requires a dry surface with an ambient temperature of 50 degrees Fahrenheit for a day). Construction of the building that houses the cogeneration equipment was started in February 1982 and was completed in September 1982. The prime mover (engine) for the cogeneration unit was received in January 1982 and the induction generator was received in June 1982. The control unit for the induction generator was received in December 1982. The cogeneration unit engine and induction generator were bolted together and mounted on a skid along with the waste heat recovery equipment in February 1983. The auxiliary (backup heating) boiler was received in September 1982. Installation of the biodigester subsystems (gas handling, gas purification, and biodigester heating) was begun in November 1982 and completed in October 1983. The procurement of equipment and materials for the project was conducted in a "piecemeal" fashion due mainly to the long construction schedule and to the nature of the workforce (volunteer labor).

1.7 Systems Testing

During the course of the project, each system was tested as construction on the individual systems was completed. The first system that was ready for testing was the manure handling system. In late October 1982, the hydraulic ram pump (used to move the manure) was tested for the first time. Only a few minor problems were encountered and the system was placed into operation in November 1982 (a bypass in the transport line enabled us to pump manure directly to the

holding pond with the biodigester portion of the line closed off-- see layout sketch in the detailed design section of this report.

The next system that was ready for testing was the gas handling and purification system. By using a portable air compressor, a leak rate test was conducted on the biogas line, valves, regulators, and flow meter. The tests were completed and all detected leaks were sealed by late November 1983. In September 1983 the biodigester tank was filled with water to test for liquid leaks. Several leaks developed and were plugged with a quick hardening cement in October 1983. The biodigester tank was refilled with water and the gas recirculation pump was operated to test the capability of the biodigester tank roof to hold gas pressure and to test the pump's ability to overcome the liquid head and provide agitation. It was found that the biodigester tank would not hold pressure (note comments in construction section above) and tests continued to locate the source of the leaks. The agitation part of the gas recirculation system worked well, however it was found that the motor chosen to drive the gas pump had a RPM rating that was too high. The motor was removed and returned and a new motor was ordered. The new motor was received in early December 1983 and leak tests were continued on the biodigester tank roof. Leak tests on the waste heat recovery/biodigester heating system was conducted in November 1983. By early December 1983 this system was checked out and filled with a 50/50 mixture of antifreeze and water. The backup LP gas tank and line was tested for leaks by a local gas company in late November 1983. All leaks were sealed and the tank was filled with gas in early December 1983. The engine portion of the cogeneration unit was started and tested (using LP gas fuel) in mid December 1983. The only problems encountered was some mis-wiring on the magnetic starter switch and on the electric governor which caused these to malfunction. The auxiliary (backup heating) boiler was fired-up and tested in late December 1983. The hot water circulation pump worked fine but the high temperature limit switch would not cut off the main burners upon reaching extreme temperatures. A new limit switch will be ordered to replace the malfunctioning one. All other equipment (such as pumps, fans, etc.) was checked out and is ready for service as soon as the gas leak problem in the biodigester tank roof is corrected.

2 PROJECT BACKGROUND

2.1 Research Trip

Before the detailed design of the biodigester cogeneration plant could be started, a final decision had to be made on the type of bio-reactor that would be used. In order to verify the advantages and disadvantages of both the plug flow and the continuous stirred tank reactor systems, I made arrangements for Alan Cleek and myself to leave from July 17-21, 1981 to meet with the owners/researchers of the following biodigester facilities:

Mason-Dixon Dairy Farm; Gettysburg, Pennsylvania
Cornell University Research Farm; Ithaca, New York
Agway Farm Research Center; Tully, New York
Pennsylvania State University Farm; State College, Pennsylvania

Each of these facilities had experimental biodigester systems that were either in operation or under construction. Two of the installations were of the plug flow type and two others were of the continuous mix type. This trip allowed us the opportunity to see both types of bio-reactor systems in operation and to discuss various details with officials at each location.

2.2 Mason-Dixon Dairy Farm

Our first stop was on July 18 (Saturday) to visit the Mason-Dixon Dairy Farm just out of Gettysburg, Pennsylvania. We met with the elder Mr. Waybright who I had contacted for a tour of the farm. Mason-Dixon had one of the first commercial biodigesters in operation. The farm had 800 dairy cows which provided the waste resource for a large plug flow bio-reactor. The basic system description begins with their loafing barns which are flushed with recycled cleaning water each day. The water "flushed" the manure to a holding pond where a vibrating screen separated the solids into a wet sludge pit. The water was pumped to a storage holding tank for recycle and the wet sludge was pumped into the biodigester. A flexible gas bag was used to cover the biodigester to collect the biogas. From here the biogas was piped to a diesel engine generator set that was designed to burn 90% biogas and 10% fuel oil. A metal building enclosed the biodigester and engine/generator. The effluent from the biodigester was squeezed of moisture and the dry compound (30% wet) was used as bedding material while the water was used to irrigate the fields. Due to the use of water flushing, they experienced problems with settlement in the bottom of the biodigester as well as surface scum buildup. This was probably due to the input slurry to the biodigester being too dilute. The Mason-Dixon system had been installed as a turn-key contract from Sheaffer & Roland an engineering consultant firm in Chicago. The main problem in the system was that no method had been provided to clean out sludge that collected on the biodigester floor. To clean out the sludge required shutting down the entire system and manually loading out the waste material. Then, it took about three weeks for full biogas production to resume. Mr. Waybright said that they were now installing a second biodigester so that the two separate units could alternate to maintain continuous

biogas production. Their first system had been operating for a year and the 125 kw generator provided about two-thirds of the farm's electrical needs. A second generator had just been installed to give the farm the ability to produce more electricity than it consumes. Waste heat from the engine(s) was used to heat the biodigester(s) and the extra heat was going to be used experimentally to aid in the drying of bedding material. Later on the excess heat would be used in conjunction with an alcohol plant to distill ethanol for use as tractor fuel. The initial system cost was approximately \$100,000 and there was still a number of problems with the system. I felt that this facility was a good example of the problems that you can get into if the influent manure slurry is too dilute. Also, the problems of sludge removal and scum buildup were obvious. We left the next morning (July 19, 1981) for Ithaca, New York to visit the research farm at Cornell University.

2.3 Cornell University Agricultural Research Farm

On July 20 (Monday), 1981 we arrived at Cornell University to meet with Mr. Bobby Cummings, Research Support Specialist at the research farm in Harford, New York. We found out that Mr. Cummings father had passed away and a young Graduate student was to conduct the tour in his absence. Cornell University had built both a complete mix bio-reactor and a plug flow bio-reactor. Most of the thrust of research at Cornell was being conducted by Dr. W. J. Jewell, Professor and centered around the development of an economical small scale bio-reactor. The plug flow biodigester was in operation but the engine/generator set that was on order had not arrived. The biogas was being used to operate a hot water system with the excess flared. Their basic system arrangement consisted of gutter scrapers (barn floor cleaners) that were chain driven and scraped the manure to one end of the barn where a hydraulic ram pump pushed the manure into one of either two biodigesters. The plug flow biodigester was similar to the one at Mason-Dixon farm except that it had sloped sides instead of being a complete rectangular (septic tank) box. The tapered sides eliminated the "dead spaces" where sludge would collect and also helped to decrease the construction cost somewhat. Still no method was provided to clean the bottom of the biodigester without disturbing the normal operation of the plant. Manure from about 65 dairy cows was pumped into the digester daily and the effluent overflowed into a holding tank from where it was pumped into manure wagons each week for spreading onto the fields. The biogas was going to be scrubbed (nearly 1% by volume of hydrogen sulfide was present in the biogas) in an iron-sponge scrubber and then used as fuel in an engine generator. The scrubber was then under construction and we were able to see some of the packing material. While we were at the Mason-Dixon farm we found out that they were not scrubbing hydrogen sulfide from the biogas and did not believe it to be necessary. Talks with officials at Cornell University led to the recommendation to use a scrubber and that only time would tell how much damage would be done to the engines in use at the Mason-Dixon farm. The plug flow biodigester at Cornell had been in operation for only a few months and the design was based on a much smaller pilot bio-reactor. We were not able to meet with Dr. Jewell as he was tied up in a meeting. Later in the day we drove up to Tully, New York to visit the Agway Farm Research Center.

2.4 Agway Farm Research Center

We arrived at the Agway Farm Research Center (AFRC) at 2:00 PM and met with Mr. Stan Weeks. Agway is a private research center made up of supporting member farms and is geared mainly to improving techniques for use in dairy farming. The biodigester had just been built and was based on the design at Pennsylvania State University. At the time of our visit, the system was not in operation and no biogas had yet been produced. The system was designed to process manure from 200 cows and was due to go into operation within three months. The facility was going to produce electricity for sale to the local utility, but the engine/generator unit had not yet been installed. AFRC had contracted with Anaerobic Energy Systems, Inc. of Bartow, Florida to provide the gas handling/storage and cogeneration equipment. The biogas produced would be used to generate 15 Kw of electricity during the onpeak hours of the day and provide heating for the biodigester with excess heat to the dairy barns. The system at AFRC had several modifications from the Pennsylvania State University biodigester. The basic system operation consisted of gutter scrappers to collect the manure (just as at Cornell University) and then pumped into the biodigester by a hydraulic ram pump. Suction lines were placed in the biodigester to draw off sludge that could buildup on the floor (Penn State used augers--see next section). The roof of the biodigester was fixed and could not float as did the one at Pennsylvania State University. This feature allowed the biogas pressure to be higher and of a more useful range. There was the provision to compress and store biogas produced during the evening hours for use in the engine/generator during the main power use period in the daylight hours. This way the generator could meet the full electrical load at AFRC. AFRC had been pumping raw manure into a covered pit to help in conserving the nutrient levels in the manure before it was spread onto the fields (this was another part of their ongoing manure management program). Since the addition of the biodigester, they had installed a bypass and two shutoff valves in the manure transport line to allow them to pump to either the biodigester, the covered pit, or to both. This was an important feature should the biodigester be shutdown for long periods of time. The method used for agitation was not described and we found that many of our detailed questions went unanswered due to certain information considered to be proprietary by the officials at AFRC. We now prepared for our final stop at Pennsylvania State University on the next day.

2.5 Pennsylvania State University Research Farm

On the morning of July 21 (Tuesday), 1981 we arrived in State College, Pennsylvania and had an appointment to see Dr. Sverker P. E. Persson of the Agricultural Engineering Department. Dr. Persson co-authored the report that I had used as the basis of my conceptual design and project proposal. We first drove to the university research farm to see the biodigester that had been taken out of operation for an extended period. This allowed us the opportunity to see the details of construction of the facility. The basic system operation consisted of gutter scrappers to collect the manure in the barns and a hydraulic ram pump to transport the manure to the

biodigester (typical of the two facilities seen the day before in New York). The bio-reactor had a floating roof that could store varying levels of biogas. They had experienced leaks in the roof and had to use a hypalon liner to seal off the gas leaks (the hypalon corrected the leak problem). Researchers at the university had installed several temperature sensors at different locations within the bio-reactor to record temperatures. The slurry was agitated by means of a gas recirculation system that bubbled gas up through diffusers in the bio-reactor floor. This method of agitation was satisfactory to maintain a well mixed slurry with even temperatures throughout. The biogas was utilized to heat an auxiliary boiler to provide heating to the bio-reactor, any excess was flared. Experiments were being conducted on gas appliances and high compression gas engines to gather information on the utilization of biogas and improve operating performances. The biogas had not been scrubbed at Penn State because it was used only to provide fuel for boiler heating, however the hydrogen sulfide caused components of the boiler to corrode. Dr. Persson took us to see the boiler and gas pump that had been taken out of service for repair. He stated that in a permanent installation a scrubber should always be included.

Alan Cleek asked about details of insurance for such a facility (methane is highly flammable). Dr. Persson stated that the need for good ventilation was necessary in the generator building to keep pockets of methane from collecting. If handled properly the gas was rather safe (officials at Cornell also expressed this attitude and had conducted an extensive study of the gas itself). Dr. Persson stated that the digester should be at least 100 feet from the barns and other structures. He also stated that the system should be described as basically another type of manure management system as far as insurance was concerned and was willing to accept a phone call from our insurance agent to explain safety details of these systems. Details of the sludge clean-out auger was discussed, this feature allowed for removing sludge from the bottom without interruption of normal digester operations. Before departing that afternoon we stopped to see a pilot alcohol plant in operation at Penn State and spoke with Dr. Garth (excess waste heat from the engine/generator can be used to distill alcohol for tractor fuel).

An enormous amount of information and photographs was gathered on this trip. The aspects of theory, design, construction, startup, operations, maintenance, and cost was discussed in detail. This information would hopefully allow us to build a plant in which all systems were optimized to provide the best performance possible. I now began the process of developing a detailed design of the project so that construction could proceed.

2.6 Project Site Description

The farm chosen for this demonstration project is the Cleek Dairy Farm (CDF) located near Kingsport, Tennessee. CDF has 300 acres under cultivation and 350 acres in pasture in Sullivan County, Tennessee. The main crops raised are corn, alfalfa, and rye which is used as feed for part of the some 200 dairy cows (Holsteins) owned. This farm represents a medium sized southeastern dairy farm. The dairy

operations consist of the following main areas: power equipment maintenance & storage buildings, milking parlor, cattle loafing barn, cattle feedlot, and calf barn. The cows kept in the cattle barn are milk cows and are free to move to the adjacent feedlot area for feed. A mixture of high moisture corn silage, alfalfa, rye, and high protein supplement are fed to the milk cows each day. The main feed silo supplies silage to a lazy susan feeding trough that is operated by electric motor driven equipment and is controlled by timers. A computerized feeding system meters the appropriate feed rations to select cows that are premium milk producers. The milk cows are confined to the loafing barn/feedlot areas except when they are herded to the milking parlor twice daily (or during illness). The type of bedding material used in the loafing barn is wood shavings and approximately 60 tons is required per year (bedding is changed out twice each month). The annual amount of chemical fertilizer used is about 58 tons (consisting of ammonium nitrate, phosphate, urea, potash, and diammonia) at an approximate cost of \$190 per ton.

The farm is milking approximately 125 cows and has about 75 "dry" cows in the replacement herd which grazes in the pasture. The original manure management system consisted of collecting manure from the barn and feedlot areas by a tractor scraper and dumping this into a pit that measures 20 feet in width, is 60 feet long, and slopes to 12 depth at one end. The pit was designed to hold about a three month supply (54,000 gallons) for 45 cows. The pit was able to hold a two month supply for the current number of cattle and as one can see the farm had outgrown the original system. The manure handling system thus became a very cumbersome problem. Every two months when the pit became full the manure had to be loaded into a manure spreader to be hauled to the fields. Even in cold wet weather, the manure must be hauled and disposed of. Also, in the three colder months the replacement herd is brought into the feedlot area to protect them from the elements and to provide adequate levels of feed (dead grass has a low nutrient content). This means that for three months of the year there is manure from 200 cows that must be disposed of. This effort is very labor intensive and also environmental concerns from residents that live near livestock farms is beginning to become more of an issue. The fertilizer value of manure often is not utilized because the disposal period does not coincide with the growing season and raw manure tends to aid in weed growth. Raw manure also contains many harmful pathogens that can affect both animal and human health. Each of the aforementioned factors can become a significant expense in farm operations cost.

2.7 Project Layout

After our return from the research trip, the final project siteplan was established. The location (as can be seen in figure 2) was in the flat bottom land near the barn and feedlot area. Each project structure was layed out and a survey was made. The USDA Soil Conservation Service was notified of the proposed location. Their staff came to the site to take soil samples of the location to determine whether the groundwater or nearby creek would be affected and to approve of the site chosen for the effluent holding pond. Their findings proved satisfactory and the holding pond location was

approved. The holding pond was designed by Mr. William Thurmond and the construction of the holding pond was supervised by Mr. Carl Milsap both with the USDA. Ground breaking and construction began in early August 1981. As can be seen in diagram , each major structure is layed out in a logical fashion dependent on the purpose of each. The manure collection pit is located near the barn and feedlot (source of manure) so that the present farm practices are not drastically changed. The effluent holding pond was located where the soil would best support the purpose of the structure (as determined by the soil conservation service) and where enough land area was available. The biodigester was located approximately 120 feet away, mainly due to the location of the effluent holding pond to allow for gravity overflow at the bio-reactor outlet and to avoid altering present access roads. The cogeneration building was located beside the biodigester in order to house the bio-reactor heating/monitoring, gas handling/purification, and cogeneration subsystems. The design of each of the required systems and subsystems will now be addressed. See figure 3 for layout of project structures.

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GENERAL LAYOUT OF
PROJECT SITE.

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3 BIODIGESTER DESIGN

3.1 Design Basis

The basic design requirement was to provide for a capacity to process manure from 200 cows maximum to 125 cows minimum. The average weight of the milk cows is approximately 1200 pounds and each cow at this weight produces about 100 pounds of manure per day. This computes to from 10 (wet) tons to about 6 1/4 (wet) tons per day of manure (@ 100 pounds/cow-day times the # of cows) or to a maximum volume of 326 cf/day and a minimum volume of 204 cf/day (based on a raw dairy cow manure density of 61.4 pounds/cf @ 13% solids). Since CDF uses approximately 5 tons per month of bedding material (@ 30% moisture), this equates to 330 pounds per day (wet) of additional solids that must be added to the manure for disposal. This in turn increases the solids content of the manure to 14.2% (after taking into consideration the moisture content of the wood shavings). Also, because of the layout of the feedlot area (having a slope of several degrees) there is liquid loss due to runoff and some loss due to evaporation. The loss due to runoff will be corrected by constructing a runoff ditch to the collection pit and losses due to evaporation are negligible. Based on this figure the new maximum volume is 331 cf/day and the new minimum volume is 209 cf/day. The design calls for a slurry input to the bio-reactor of 12% solids content maximum, which sets the high volume of dilution water required at approximately 390 gallons/day (52 cf/day) and the minimum dilution water requirement is 315 gallons/day (42 cf/day). The total bio-reactor input volumes are; 383 cf/day maximum and 251 cf/day minimum. The minimum slurry retention time chosen for the bio-reactor design is 20 days (for maximum throughput) and the maximum retention time (based on a minimum throughput from 125 cows) is 30 days. The maximum volatile solids (VS) input to the bio-reactor is 1600 pounds/day and the minimum VS input is 1000 pounds/day (based on a VS content of 8 pounds/cow-day). The expected biogas production is 7.5 cf/pound of VS input to the bio-reactor per day. This equates to a maximum biogas output of 12,000 cf/day and a minimum biogas output of 7500 cf/day. With biogas having a heating value of approximately 600 BTU's/cf this is a maximum of 7.2 million BTU's/day and a minimum of 4.5 million BTU's/day. The maximum electrical power output (at 95% system availability) is 20.25 kw/hour and the minimum electrical power output is 12.65 kw/hour. The maximum amount of recoverable waste heat in the form of 195 degree Fahrenheit water is 137,500 BTU's/hour and the minimum amount is 122,000 BTU's/hour. The biodigester heating requirements are; winter maximum (for manure from 200 cows) 128,000 BTU's/hour and the summer minimum (for manure from 125 cows) 27,000 BTU's/hour (based on a low ambient temperature of 10 degrees Fahrenheit and a high ambient temperature of 80 degrees Fahrenheit). The operating temperature of the bio-reactor is the mesophilic level (95 degrees Fahrenheit). The biodigester is to be insulated so that there will be a temperature drop of no more than 2 degrees Fahrenheit/24 hours. The biodigester is designed with a fixed roof (gas collector) to provide a working biogas pressure range of 3 to 8 inches of water. A minimum volume of 1380 cf (volume of roof and top two feet of tank) is provided for biogas storage to allow for fuel gas surge capacity in the system. The

cogeneration system is designed to follow the biogas production cycle over the complete 24 hour period and to utilize all the biogas continually for electricity and hot water production (there is no compressed gas storage). The cogeneration unit is designed to dump excess heat not required by the biodigester via a thermostatically controlled radiator system. Agitation of the slurry is to be provided by recirculating biogas under pressure through diffusers in the floor of the bio-reactor. Equipment to monitor the temperature at various locations inside the bio-reactor is provided as well as equipment to monitor the pH. Conventional solid state controls are incorporated in the design to maintain the various subsystems at their proper operating levels. Utility paralleling equipment is designed per the requirements of the local power company. The feedstock collection pit is designed to hold a minimum of one day's volume of manure from the maximum input of 200 cows. The effluent holding pond is designed to hold a minimum of 6 months of processed effluent (based on a manure throughput from 200 cows) and rainwater. Provisions are included in the design of the holding pond for ultimate disposal of the effluent by an irrigation system. The design details of each system and subsystem will now be discussed. See figure 4 for process flow diagram.

3.2 System/Subsystem Descriptions

As was mentioned in section 1.5 there are four systems and five subsystems that were included in the design of the biodigester cogeneration plant (refer back to section 1.5 for their listing). Figure shows the block flow of each system and subsystem. The experimental plant was designed and constructed around the farm operations and utilizes existing supplies of water and electric power. The plant requires nothing that is not normally found on a dairy farm and provides products that can be readily used or processed by normal farm techniques. Each system and subsystem is described below.

3.2.1 Manure Collection and Handling System

CDF uses a tractor to scrape manure from the concrete floors of the barn and feedlot. This method of manure collection is typical of most southern livestock farms. In order to avoid altering the present farm practices, a manure collection and handling system had to be designed to accomodate the present system. I chose to design a below ground feedstock collection pit with a transport pump located on the base floor and a large metal hopper that expands up and out from the pump to the top of the pit walls at the ground surface. The pit is a square structure (one side includes an offset that is used as a manway) with it's base resting on solid rock (approximately 86 inches below ground). The concrete base slab is 4 inches thick (with about 2 inches of gravel underneath) except for the perimeter of the slab underneath the walls of the pit, which is 6 inches thick (see figure 5). The walls are standard concrete blocks laid to a height of 80 inches (i.e. 10 - 8 inch blocks high) and are poured full of concrete. A sump is located on one side of the pit floor and was made by using a 5 gallon plastic bucket as the sump liner. The pit's overall dimensions were based on the fixed height of the pit as determined

BIO-DIGESTER/COGENERATION FLOW DIAGRAM

by the actual location of the bedrock and the dimensions of the pump chosen to transport the manure. Since the pit height is 80 inches (top of floor slab to top of walls at grade) and the pump's height is 24 inches, this leaves only 56 inches total height for the collection hopper. The design basis requires at least an one day storage of manure and dilution water from the 200 cow maximum volume. This volume of 383 cf (from section 3.1 above) along with the fixed height of the hopper and the inlet size of the pump (which is also the bottom opening dimensions of the hopper), sets the top opening dimensions of the hopper (see figure 6). By using the following formula the dimensions of the hopper are verified:

$$\text{Volume} = 1/2 [\text{Area of Top} + \text{Area of Bottom}] \text{ times Height.}$$

$$\text{Volume} = 1/2 [(12.67 \text{ ft} \times 12.67 \text{ ft}) + (1.5 \text{ ft} \times 2 \text{ ft})] \times 4.67 \text{ ft}$$

$$\text{Volume} = 381.6 \text{ cf}$$

This gives a fixed area of the top opening of 12.67 feet square (152 inches square). With this becoming the inside dimensions of the pit, then by adding the width of the standard blocks (8 inches) the outside dimensions of the pit are determined to be 14 feet square (see figure 7). The hopper is to be constructed of 1/4 inch flat carbon steel plate with no surface coating on the inside and with the outside primed and painted. A 10 inch by 5 inch slot is to be cut into the top of the appropriate two sides (i.e. the sides with a bottom opening length of 1 1/2 inches) where an "I" beam is to be located (see figure 6). (Also, two blocks were left out of the appropriate sides of the pit walls for same reason).

The pump chosen to transport the manure is a King model 451, 10 inch solid piston ram pump driven by a hydraulic powerpack. This ram pump was chosen over a rotary impellor (chopper type) pump due to it's rugged design and high reliability as proven at several of the installations we visited on our research trip. Officials at Cornell University stated that there was one time when a calf was born dead and had been kicked into the path of the barn's gutter scraper. Before anyone had time to reach the animal, it had fallen into their ram pump hopper and went on through the ram pump only to get clogged at a valve. No rotary impellor pump could take such punishment without damage, but the ram pump remained undamaged. Ram pumps can handle bedding material as well as up to 15% solids content without clogging. A rotary impellor pump would clog under a high solids content and thus has a lower reliability for this use. Chopper pumps produce fine manure particles which tend to settle out at varying levels, this increases the buildup of scum. The ram pump will be used to pump manure approximately 120 feet to the biodigester against a head of 15 feet (the ram pump's capacity is up to 250 feet depending on the total head). A flapper valve is attached to the ram pump outlet to prevent backflow into the pump. A 12 inch diameter pvc sewer pipeline is used to transport the manure to either the biodigester or holding pond (by using a "Y" connection) depending on the setting of two 12 inch guillotine shutoff valves. This feature allows for manure to be diverted to the holding pond during times when the biodigester is down for maintenance (see figure 8). The ram pump is operated by a hydraulic power pack rated at 5 HP, 240 VAC, single phase. The ram pump can move manure at a rate of 250 cf/hour,

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Blocks poured full of concrete
for added strength.

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Materials: $\frac{1}{4}$ " steel plate or
 $\frac{1}{2}$ " salt treated plywood
with $\frac{1}{16}$ " fiberglass lamination.

which means that it must operate for about 1 1/2 hours per day (at the maximum manure throughput). As was stated earlier, a manway is provided for access to the ram pump and underneath the collection hopper for maintenance. A standard 6 foot aluminum ladder is used in the manway and a removable grating covers the opening when access is not required. A small shed is to be erected above ground and is located over the manway. This shed will provide shelter for the hydraulic power pack, electrical power distribution panel, and lighting. A power pole is located just outside of the shed near the electrical panel to supply electrical power to each load. A standard commercial sump pump is located in the sump at the pit floor to keep water pumped out from around the ram pump and the discharge ties into the current drain tile system of the farm. The sump pump's capacity is 20 gallons per minute @ 3 feet lift and is rated at 1/6 HP, 120 VAC, single phase.

In order to allow the tractor greater access to dumping manure into the pit, a unique steel grating will be used. The grating was designed to support the full weight of the tractor and operator, so that the tractor can be driven over the pit to scrape manure into the hopper (see figure 9). The design includes a standard "I" beam (W10 x 30) placed across the middle of the pit to reduce the load span on the tractor grating. The grating is designed into two (14 feet by 7 feet) sections that welded together (all welds are to be full penetration butt-welds for structural soundness) can each be removed and is to be constructed of 20 members of rectangular steel tubing (6 x 4 x 0.188) welded together. Each member is 14 feet in length and is spaced 4 inches apart with the 6 inch side standing upright (see figure 9). The tractor being used is a John Deere type 2040 with a weight of 6500 pounds (including manure scraping attachment). The grating design was based on load calculations using 7000 pounds (500 pounds extra for operator) and a span of 6 1/3 feet for each side (see figure 10). A water spraying line is provided to supply dilution water to the pit. The line consists of four spray nozzles that spray water onto the grating. The line size of 3/4 inches is enough to provide water at a rate of 5 gallons per minute, which with a dilution requirement of 390 gallons (@ maximum throughput) means it will take about 1 1/3 hours to supply this amount. A shutoff valve is included to allow the operator to open the water line at the beginning of the collection period and then shutoff the waterflow when scraping and pumping is complete (the current timeframe for scraping manure to pit and herding all cattle out of feedlot area equals with the total pumping time of 1 1/2 hours).

3.2.2 Bio-Reactor System

As was stated in section 1.4, the continuous stirred tank reactor (CSTR) was chosen for the design of this biodigester. This type of bio-reactor has greater environmental control of the slurry and produces a higher amount of biogas than the plug flow reactor. The bio-reactor is designed from a typical precast concrete stave silo. The base slab of the bio-reactor is designed to be 12 inches thick (with 2 inches of gravel underneath) except around the perimeter underneath the tank walls, which is to be 18 inches thick to support the bearing load of the tank walls. The foundation is reinforced with a cross mat of #6 rebar and the foundation rest upon solid rock. The area of the foundation was determined to be 490 square feet at a radius of 12.5

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Top View

CLEEK DAIRY FARM
Sullivan County, TN.

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feet. This was set by the dimensions of the tank required, based on the volume needed. The tank walls are designed from solid precast staves, each being 4 inches thick. The concrete staves are maintained in their circular arrangement by a series of tight steel bands. The height of the tank walls is 20 feet and the center point diameter of the tank is 24 feet. The tank size was based on the maximum volume of slurry input (from 200 cows) and the minimum set retention time. With a maximum input volume of 383 cf/day and a minimum retention time of 20 days, the calculated holding volume required is 7660 cf. Concrete plaster (gunite) is to be applied to the inside of the tank walls to seal the cracks between each stave. Since the tank is to be heated, then some method of insulating the structure is needed. This will be done by using two layers of 2 inch thick expanded polystyrene sheets (Styrofoam) on the inside of the walls. Metal wires will be provided as the walls are erected to help support the insulation and a layer of metal lath (wire mesh). The metal lath is installed over the insulation and then a second layer of concrete plaster is applied onto the metal lath to serve as an internal seal from the slurry. The amount of insulation used on the walls was determined from data provided by Penn State University and is shown in table 3. From the insulation thickness the usable storage volume and slurry height can be calculated. The tank center point diameter is 24 feet (i.e. center line from wall to wall), subtracting half of the 4 inch thickness of each wall gives an inside wall diameter of 23 feet 8 inches. Now subtracting the 4 inches of insulation of each wall gives a final usable inside diameter of 23 feet. The total working volume of the tank (@ 23 feet diameter & 20 feet height) is 8310 cf. The required slurry height needed to maintain a retention time of 20 days based on the working volume is 18 feet. The effluent pipe from the tank must thus be located so that the level of slurry in the tank remains at 18 feet. The effluent pipe will exit the tank 6 feet from the foundation, will turn and go up to a height of 18 feet from the foundation where the line will set the slurry level of the tank and then return back down to the 6 feet level before discharge to the holding pond (see figure 11). The slurry height in the tank leaves a freeboard of 2 feet which when added to the usable volume contained beneath the tank roof gives the total gas collector storage volume. The tank roof is designed as a fixed sealed roof and is made from a standard bolt-together steel silo roof normally used for sealed storage of high moisture corn silage. The tank roof is a cone that envelopes a useful volume of 549 cf, which when added with the volume of the top 2 feet of the tank gives a total gas collector storage volume of 1380 cf. The inside of the tank roof is to be coated with a bitumastic coal tar to seal the joints and protect the hardware from the corrosive nature of the raw biogas. The outside of the tank roof is to be insulated with 2 inches of spray-on polyurethane foam insulation which is then painted to protect it from deterioration from sunlight. The polyurethane also acts as a sealer to stop gas leaks and a coating of spray-on hypalon may be applied prior to application of the polyurethane if the gas leaks are serious. An access manhole is provided as a part of the roof as well as a pressure/vacuum relief valve to alleviate excessive variances in the tank pressure. A safety ladder and catwalk is provided to allow access to the crow's nest atop the tank roof where the manhole is located. Also, an access manhole is designed in the tank's side to facilitate easy maintenance of the tank when required. A wall penetration is provided in the side of the tank which accomodates the passage of the gas, heating,

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$$F_b = 0.60 F_y \quad \sigma_{\text{allowable}} = 0.60 F_y$$

$$\text{where } F_y = 36 \text{ ksi}$$

$$\sigma_{\text{allowable}} = (0.60) (36 \text{ ksi}) = 21.6 \text{ ksi}$$

For structural tubing size 6 x 3 x $\frac{1}{4}$ we find

$$S_y = 4.0$$

$$M = \frac{PL}{4} = \frac{(2\frac{1}{2} \text{ kips}) (6.33 \text{ ft.}) (12 \text{ in./ft.})}{4} = 47.48$$

$$\sigma = \frac{MC}{I} = \frac{M}{S_y} = \frac{47.48}{4.0} = 11.87$$

$$\sigma = 11.87 < 21.6$$

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BIOMASS ENERGY CONVERSION PROJECT

sampling pipelines, and temperature sensor conduit. The penetration was designed as a frame with reinforcement bars, which replaced two staves and allowed passage of the various pipelines and conduit. Once all of the pipelines and conduit are installed, the penetration is poured full of concrete (see figure 12). The influent to the tank enters at a level that is three feet above the tank floor. This level was determined as a result of the differences in elevation between the collection pit foundation and the bio-reactor tank foundation (the latter with an elevation some 3 feet lower). The actual location of bedrock set the foundation level at about 10 feet below ground. This placed 1/2 of the tank below ground and 1/2 above ground. This was taken into consideration in the tank heat loss calculations shown in table 3 below.

Table 3. Bio-reactor heat losses.

Maximum Heat Losses (Winter Season)					
Component	Material	Area	Ambient Temp.	Coef.	Heat Loss
Floor	12" Concrete	415 sf	53 degrees F	0.50	8726 BTU/hr
Wall below -ground	4" Concrete + 4" Insul.	722 sf	42 degrees F	0.07	2604 BTU/hr
Wall above -ground	4" Concrete + 4" Insul.	722 sf	10 degrees F	0.07	4238 BTU/hr
Roof	1/16" Steel + 2" Insul.	602 sf	10 degrees F	0.55	28145 BTU/hr
Minimum Heat Losses (Summer Season)					
Component	Material	Area	Ambient Temp.	Coef.	Heat Loss
Floor	12" Concrete	415 sf	53 degrees F	0.50	8726 BTU/hr
Wall below -ground	4" Concrete + 4" Insul.	722 sf	65 degrees F	0.07	1516 BTU/hr
Wall above -ground	4" Concrete + 4" Insul.	722 sf	80 degrees F	0.07	748 BTU/hr
Roof	1/16" Steel + 2" Insul.	602 sf	80 degrees F	0.55	4970 BTU/hr

(Heat Transfer Coefficients From Penn State University Bulletin 827).

All calculations were based on maintaining a bio-reactor temperature of 95 degrees Farenheit. The temperature of the tank floor was estimated to remain at 53 degrees Farenheit year round at a depth of 10 feet below ground.

BIOMASS ENERGY CONVERSION PROJECT

Digester Wall
Section 6,A-A

Piping Systems
Wall Penetration

3.2.3 Biogas Handling & Purification Subsystem

The biogas pressure from the bio-reactor will vary from 8 inches of water column to 3 inches of water column depending on the volumetric production of biogas. The biogas takeoff line is sized to carry the maximum flowrate of biogas with a loss of no more than 1/2 inch of water column pressure. A 1 1/2 inch cpvc schedule 80 pipeline takes raw biogas from a high point under the tank roof and out of the bio-reactor through the pipeline & conduit penetration. The cpvc piping was used because of it's resistance to attack by the hydrogen sulfide portion of the biogas. Also, cpvc was used instead of pvc because of the temperature of the biogas (95 degrees Farenheit). The pressure of the biogas as produced in the bio-reactor is so small (being less than 1/2 psig) that there should be no problem in using cpvc pipe for this purpose. In fact, cpvc schedule 80 pipe is commonly used as the main biogas line in almost all agricultural biodigesters constructed to date. Once the takeoff line exits the bio-reactor the raw biogas flows through a flame check to prevent any possible back flame from getting to the bio-reactor and causing an explosion. The pressure drop through the flame check is 1/2 inch of water column. Now the raw biogas goes to a pair of scrubbers in series. The raw biogas contains a measureable amount of hydrogen sulfide and mercaptans as can be seen in table 4, below.

Table 4. Raw Biogas Composition.

Dry Basis		Wet Basis	
Component	Percent by Volume	Component	Percent by Volume
Water	00.00	Water	24.50
Methane	61.10	Methane	46.13
Carbon Dioxide	35.28	Carbon Dioxide	26.64
Nitrogen	2.52	Nitrogen	1.90
Hydrogen Sulfide	0.65	Hydrogen Sulfide	0.49
Mercaptans	0.11	Mercaptans	0.08
Ammonia	0.09	Ammonia	0.07
Hydrogen	0.08	Hydrogen	0.06
Oxygen	0.08	Oxygen	0.06
Carbon Monoxide	0.07	Carbon Monoxide	0.05
Inerts (trace)	0.02	Inerts (trace)	0.01
	100.00		100.00

(From "Fuel Gas Production From Biomass", CRC Press, 1981 & Hamilton-Standard Final Report # DOE/ET/20009-T1).

The raw biogas is sent through a two-pass iron sponge scrubber to remove the corrosive hydrogen sulfide. The iron sponge (oxidized iron filings on wood chips) reacts with the hydrogen sulfide to form iron sulfide and water. Approximately 95% of the hydrogen sulfide is removed and the expected bed life of the iron sponge is 1 year. The bed material can be rejuvenated one time by unpacking the material and spreading it in a 5 inch deep layer on the ground to become exposed to the air. However, the material must be thoroughly soaked with water

upon removal because this is an exothermal process that could generate enough heat to ignite the wood chips. Each scrubber vessel is to be constructed of fiberglass to resist corrosion from the biogas and the iron sponge bed depth is to be 3 feet. The biogas will travel through each scrubber in a downdraft flow pattern. This equalizes the biogas flow through the bed material. The pressure drop through each scrubber is to be no more than 2 inches of water column. The bed material must remain moist and is shipped at about 45% moisture content. The biogas is saturated with moisture (as can be seen in table 4) and has a dew point of approximately 154 degrees Fahrenheit. The moisture level of the bed material should be about 40% and this is easily maintained by the biogas flow. A set of moisture traps are included to remove excess condensate from the scrubbers. Once the biogas has been cleaned of the hydrogen sulfide it is passed through a water bath/condensate trap to remove any particulates that may have been added from the wood chips in the scrubber(s). The biogas then goes to a gas cooler just above the water bath that cools the biogas to about 75 degrees Fahrenheit. The cooler consist of a series of passes of pipe over which forced air passes from an electric motor driven fan. An explosion proof motor rated at 1/3 HP was used to drive the fan. A thermostat controls the fan motor to keep the desired temperature level. This removes more of the moisture in the biogas an lets the condensate drain back into the water bath/condensate trap. The biogas now flows through a gas filter to remove any fine particulates present in the biogas. This will keep the instruments downstream of this point free of contaminants. The pressure drop through the water bath and gas filter is 1/2 inch water column each. At this point the biogas is free from the corrosive portion of the gas and is rather dry. It could now be scrubbed of carbon dioxide, leaving mostly just methane which could be compressed and stored. This feature is expensive due to the high cost of a methane gas compressor and the cost of the water scrubbing or membrane gas separation equipment. This will not be done initially, but provisions will be provided should carbon dioxide removal be desired in the future. The "cleaned" biogas is now ready to be utilized and passes on to the biodigester slurry agitation subsystem, heating subsystem, and utilization subsystem.

3.2.4 Biodigester Slurry Agitation Subsystem

The biogas now flows by a series of pressure switches that controls an electric governor on the cogeneration unit. The biogas pressure range is now 0 to 3 inches of water column depending on the volumetric biogas production rate. Further details of the pressure switches will be discussed in section 3.2.8 (Biogas utilization/ electrical power generation system). The biogas now passes to a gas pump (vapor blower) which raises the inlet pressure by 8.5 psig. This pressure is required for recirculation of the biogas through diffusers in the bio-reactor to agitate the slurry. A pressure of 7.8 psig is required to overcome the slurry at 18 feet of head. The gas pump also provides a more useful working gas pressure and raises the temperature of the biogas to a point above that at which it was cooled, thus keeping any additional condensate from forming. A DeLaval model 75 vacuum pump was used as the gas pump and required a motor rated at 2 HP and 1750 RPM. An explosion motor was used to drive the gas pump due to the flammability of the biogas.

The gas recirculation method of slurry agitation was used in the Penn State bio-digester and was shown to be an effective way to agitate the slurry while using relatively little power when compared to mechanical agitation systems. Proper agitation of the slurry in the bio-reactor is required for maintaining an even temperature distribution throughout and to keep surface scum broken up. Biogas from the gas pump flows to a tee from where two globe valves are used to balance the biogas between the recirculation system and the utilization system. The portion of the biogas required for recirculation flows to a manifold from where it splits into four paths each controlled by a throttling valve and each has a check valve. The biogas flows to four diffusers located near the floor of the bio-reactor from where it rises upward through the slurry to provide agitation (see figure 13). The throttling valves are used to balance the flow equally to all four diffusers or to increase the flow to any particular diffuser. The portion of the biogas that is not required for recirculation flows on to the utilization/electrical power generation system (see section 3.2.8).

3.2.5 Biodigester Sludge Removal Subsystem

Over some period of time, the bio-reactor will develop a buildup of sludge at the bottom of the tank. This sludge will eventually begin to affect the retention time of the bio-reactor and thus must be removed. There are several methods that can be used for sludge removal. The method chosen by Penn State was by using an auger in the base of the bio-reactor (controlled by hydraulic gates) to remove sludge when required. Since their bio-reactor was located on a hillside then the auger could be installed in the floor of the tank and exit on the downhill slope. Since our project site was located in flat bottom land with no hills and the tank base was located on bedrock some 10 feet below grade, then a sludge auger could not be used. It was decided that two sludge drawoff lines would be used from which a sewage vacuum lift pump could be used to remove sludge from the tank floor (see figure 14). Each line is of 3 inch cpvc pipe with 3 inch ball shutoff valves and a capped outlet. Water pressure can be applied to either line if necessary to cleanout a clogged line or to mix and dilute the sludge prior to removal. The buildup of sludge should not require a plant shutdown for 2-3 years under normal operating conditions. The dilution level of the input slurry and the proper amount of agitation will mainly determine the amount of sludge buildup.

3.2.6 Biodigester Monitoring Subsystem

In order to keep a close check on the biodigester, a means of monitoring the various parameters affecting it's performance is required. A slurry sampling line is provided at the bio-reactor so a pH measurement can be made periodically. An instrument conduit is provided where temperature sensors are located at various points inside the bio-reactor. The conduit exits the bio-reactor at the tank wall penetration and the sensor(s) cables are connected to an instrument panel. The temperature sensors not only give the bio-reactor temperature but by spacing them at various points throughout the tank and comparing their readings, an indication of how well the agitation system is working can be observed. The temperature and pH readout

FUEL GAS HANDLING SYSTEM

BIOMASS ENERGY CONVERSION PROJECT

equipment is mounted in a standard 19 inch rack. A chart recorder is included to allow for monitoring of these parameters over a long period of bio-reactor operation. Circuit diagrams for both the temperature and pH readout equipment was found in the "Sourcebook of Electronic Circuits" by John Markus (see bibliography). Two commercial gas leak detectors are included to detect biogas/propane leaks inside the cogeneration equipment building.

3.2.7 Heat-Recovery and Biodigester Heating Subsystem

The biodigester tank heating system is partially a part of the gas utilization system. The heating system consists of a heat panel located inside the center of the bio-reactor; an exhaust heat exchanger located on the engine portion of the cogeneration unit; an oil cooling heat exchanger also located on the engine; a main heat exchanger from where recovered heat passes through the primary side and the utilized heat passes from the secondary side to the heat panel; an auxiliary boiler which is tied in with the secondary side of the main heat exchanger and heat panel; and an accessory circulation pump, expansion tank, heat dump radiator, thermostats, thermometers, and valves. The heat required by the bio-reactor is found as being the heat loss from the bio-reactor plus the heat needed to warm the incoming mass (raw manure) up to the 95 degrees Fahrenheit level in the bio-reactor. From calculations in a previous section the bio-reactor maximum heat loss is 43,713 BTU/hr and the minimum heat loss is 15,960 BTU/hr. We can calculate the heat needed to warm up the incoming raw manure and dilution water by the following calculation:

$$Q_m = M_m C_p (T_1 - T_o) \text{ for 200 cows (Winter)}$$

$$Q_m = (970 \text{ lbs/hr}) \times (0.95 \text{ BTU/lb-F}) \times (95\text{F} - 10\text{F})$$

$$Q_m = 73490 \text{ BTU/hr (maximum)}$$

And similarly we get a figure of $Q_m = 8978 \text{ BTU/hr (minimum)}$ as calculated for 125 cows @ 80 degrees Fahrenheit ambient temperature for summer operation. With these figures we find the maximum and minimum total heat values needed to operate the bio-reactor as:

$$Q_{tmax} = (43,713 \text{ BTU/hr} + 73,490 \text{ BTU/hr}) \times 1.09 \text{ (line loss factor)}$$

$$Q_{tmax} = 127,752 \text{ BTU/hr}$$

$$Q_{tmin} = (15,960 \text{ BTU/hr} + 8978 \text{ BTU/hr}) \times 1.08 \text{ (line loss factor)}$$

$$Q_{tmin} = 27,183 \text{ BTU/hr}$$

This is a large variation in heat requirements and as can be expected there will be a great amount of excess heat available during the warmer months for other uses. The heat available from the engine water cooling system, the oil cooling system, and the exhaust heat-recovery system is 137,500 BTU/hr (maximum). Since there is much more excess heat available during the warmer months than can presently be utilized, a diverter valve is installed with the exhaust heat-recovery system to shut off this system when required. With the exhaust heat-recovery

system shut down the available heat is 55,000 BTU/hr. A heat dump radiator is included with a capacity to reject approximately 30,000 BTU/hr. All heat-recovery data was calculated from heat rejection information provided by the engine manufacturer, White Engines. During startup of the plant and when the cogeneration equipment is down for maintenance, an auxiliary boiler is used to provide the necessary heat to the bio-reactor. A Burnham model P-205W boiler rated at 130,000 BTU/hr was selected and can be run from either the biogas or backup propane fuel source. The heat panel was designed from data contained in the Penn State bulletin. The size was determined as:

$$\text{Area of Heat Panel} = 0.003 \text{ sqft/BTU/hr} \times 128,000 \text{ BTU/hr}$$

$$\text{Area of Heat Panel} = 384 \text{ square feet}$$

From this a panel area of 24 feet by 18 feet was designed which would serve the dual purpose of heat panel and dividing wall (based on Penn State theory that the bio-reactor should be divided into two stages). The area of heating tubes required was determined as:

$$\text{Area of Heating Tubes} = 0.0017 \text{ sqft/BTU/hr} \times 128,000 \text{ BTU/hr}$$

$$\text{Area of Heating Tubes} = 218 \text{ square feet}$$

From this a heating tube area of 12 feet by 21 feet was designed and will use a tube spacing of 8 inches which will require 8 - 21 foot galvanized 3/4 inch diameter pipes. The design has four parallel paths with valves to control the flow and balance the temperature at the heat panel. The wall is designed from standard 8 inch reinforcing wall blocks with the tubes located in the slot where the rebar is normally placed. The wall is to be poured full of concrete and blockouts left at the top for overflow from the primary stage to the secondary stage. Encasing the heat pipe in concrete helps to avoid caking of the slurry to the pipes. The basic operation of the system consists of circulating the cooling water of the engine through the oil cooler, then the exhaust heat exchanger, then into the main heat exchanger, and finally into the heat dump radiator (if necessary) before returning to the engine. A thermostat controls the electric motor driven fan of the radiator when it is necessary to dump excess heat. The heat panel surface is maintained at approximately 108 degrees Fahrenheit and the slurry is kept at 95 degrees Fahrenheit. Hot water is produced on the primary side of the main heat exchanger at 195 degrees Fahrenheit. The water temperature on the secondary side of the main heat exchanger is maintained at 150 degrees Fahrenheit with a 10 degree return drop from the bio-reactor heat panel. Water is recirculated to the heat panel at a rate of 10 gpm. Maintenance of the engine will be scheduled during the warmer months at which time the auxiliary boiler will be used to maintain temperature in the bio-reactor.

3.2.8 Biogas Utilization/Electrical Power Generation System

Biogas is best utilized as it is produced in some stationary manner. Since all modern farms today use large amounts of electricity (such as; milking machines, feeders, building heating, sterilizers, hot water heaters, shop equipment, lights, electric fences, etc.) in

their operations, then I have chosen to produce electricity from our fuel source. Since the methane to be used is a high octane fuel, then a special high compression gas vapor engine has been chosen to utilize the fuel. The engine will be a 50 HP (full load) model with a special natural gas carburetion system and a gas pressure regulator. A pressure relief valve and flare unit will be provided to vent off any excess gas that cannot be utilized due to the set capacity. The engine speed and load will be controlled by an electronic governor which will be tied into a series of pressure switches in the fuel line. As the pressure reaches some high level then the governor will set the engine at full throttle. When the pressure reaches some lower level, then the governor will set the engine to some intermediate level or to idle. This will control the load to utilize all of the gas produced and still keep the engine going during low gas production levels so that the bio-reactor tank heating is maintained. An engine performance monitoring system has been designed to monitor the following; battery voltage & amperage (alternator recharging), coolant level, coolant temperature, oil pressure, oil level, and engine RPM. Safety shutoff switches will be connected to shutdown the engine for; low oil pressure, low oil level, high coolant temperature, low coolant level, and engine overspeed. A series of fault indicator lights will tell which subsystem is at fault and help to troubleshoot the problem. These engine shutdown components are necessary in an unattended continuous operating system.

The engine is coupled to an induction generator which is used to produce an AC current. The induction generator was chosen over a synchronous generator in order to keep the cost of utility parallel interface and safety relay equipment down. Such components are costly (like a synchroscope, etc.). The only disadvantage to using an induction generator is the fact that it cannot operate as a stand-in generator should the utility power be lost. The utility that the project will interface with (Kingsport Power Company, part of the American Electric Power System) has a fine record of service and power downtime is minimal, so having standby capability was judged as not truly necessary. The 50 HP engine will drive a 25 KW, 240 VAC single phase induction generator with a power factor of 90%. The generator will be monitored with the following metering; voltage meter, ampere meter, watt meter, frequency meter, and watt-hour meter (for power output/time measurement). The following utility safety interface relays will be used to take the system down should the utility lines go out (to protect servicemen); over/under voltage relay, over/under frequency relay, phase over current relay, phase to ground fault trip relay, and a shunt trip circuit breaker. Arrangements with the utility will allow their servicemen to shutdown the generator if they need to work on the lines at other times. Since the project will be co-generating with the local utility, as more power is produced than is needed on the farm the watt hour meter will turn backwards by that amount. When the farm used more power than it is producing, the balance, will be made up by the local utility. The net monthly effect will be payments from the utility to the farm since the farm will produce more power than it consumes each month (averaged). This method of selling excess power produced by small co-generators is part of the Public Utilities Regulatory Policy Act (PURPA) of 1978, which states that a utility must buy excess power from a small generating facility at the utilities avoided cost. The act is administered in each state by the Public Service Commission. Presently no buy-back rate has been established by the TPSC, but they

are reviewing it for our case. The Tennessee Valley Authority has established such rates and these rates are used in my economic analysis. See figure 15 for generator control panel diagram.

3.2.9 Effluent Slurry Storage and Disposal System

Once the biomass (manure) has been processed in the bio-reactor then some method of disposing of the effluent slurry is needed. As stated earlier the farm presently uses a manure spreader to dispose of the raw manure. Since effluent is produced every 1-2 days (depending on the influent loading rate) then a daily routine could be to haul away the effluent using a manure spreader. This would be very time consuming and some means would be needed to temporarily store some of the effluent during very muddy days (or for other delays) when the manure spreader could not be used in the fields. Since the processed effluent is high in nutrients and the biodegradation process has already taken place (leaving only 6% solids content), then the effluent could be used as a fertilizer and irrigated. I have decided to design the system for a 1 year storage capacity and to dispose of the effluent by irrigation during the spring of the year. A dike pond has been designed to collect the effluent slurry and rain water for a one year period. The pond will then be drained each year (several times if necessary) by using an irrigation pump and traveling gun spraying system. Since the leftover effluent is still high in nitrogen content as well as other nutrients and the biodegradation process has already taken place, then the plants (crop) will be able to readily absorb the nutrients. The odor of raw manure has also been reduced to an insignificant level. The irrigation system will be sized to handle the volume of effluent to be disposed of within a reasonable period (to be determined later in coordination with the farm operator). The detailed design of the effluent holding pond structure has been designed by agricultural engineer, Mr. William Thurmond of the Soil Conservation Service. The detailed holding pond design and soil data taken is included in appendix 2.

3.2.10 Electrical/Control Building

A building was required to house the various subsystem components to protect them from the weather and maintain a controlled environment. The building was designed to house the following equipment:

- A.) Engine/Generator Skid
- B.) Generator Control Cabinet
- C.) Bio-reactor Monitoring Equipment
- D.) Auxiliary Boiler Skid
- E.) Hydrogen Sulfide Scrubber Tanks
- F.) Gas Recirculation Pump and Equipment
- G.) Cleanup Sink and Cabinet
- H.) Other various small components

The structure is approximately 24 feet wide by 36 feet long with an 8 foot high ceiling. A typical wood frame and truss structure was designed with steel siding. The structure is insulated and has interior walls in a 24 foot by 24 foot portion, the remainder being uninsulated.

- A. (27) UNDERVOLTAGE SENSING RELAY
 B. (59) OVERVOLTAGE SENSING RELAY
 C. (FUS) UNDERFREQUENCY SENSING RELAY
 D. (FOS) OVERFREQUENCY SENSING RELAY
 E. (51) OVERCURRENT RELAY
 F. (AM) AMMETER
 G. (FM) FREQUENCY METER
 H. (RTM) RUN TIME METER
 J. (VM) VOLTMETER
 K. (VAS) AM-VM SELECTOR SW.
 L. (WM) WATTMETER
 M. TACHOMETER
 N. FAILURE LIGHTS
 P. (GRS) RESET BUTTON
 Q. (52) OUTPUT CIRCUIT BREAKER

1. (FUL) "UNDERFREQUENCY"
 2. (FOL) "OVERFREQUENCY"
 3. (RPL) "REVERSE POWER"
 4. (GFL) "GROUND FAULT"
 5. (VUL) "UNDERVOLTAGE"
 6. (VOL) "OVERVOLTAGE"

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KATO ENGINEERING
 RELIANCE ELECTRIC

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A drain system is provided in the floor that ties into the farm drain tile system. A sink is provided with running water for cleanup inside when slurry samples are taken. The building electrical distribution system provides power to the various subsystem components and lighting. A garage door is provided for access to the slid mounted equipment (see figure 16).

3.3 Product and By-Product Output

The biodigester produces on an annual average basis the following primary products:

861.2 million BTU/yr of 195 degree Farenheit hot water

120,492 KWhr/yr of 240 VAC single phase electricity

The biodigester requires on an annual average basis the following energy inputs:

801.7 million BTU/yr of hot water for slurry heating

27,060 KWhr/yr of single phase electricity

This gives a primary product average net annual output of:

59.5 million BTU/yr of 195 degree Farenheit hot water

93,432 KWhr/yr of 240 VAC single phase electricity

The biodigester also produces an effluent that is good for use as a soil conditioner and fertilizer. The quantity produced is listed below:

16,706 lbs/yr ammonium nitrogen

5,138 lbs/yr phosphate

11,744 lbs/yr potash

The effluent from the biodigester comes out at approximately 6% solids and is high in nutrients. The solids portion could be separated and used as bedding or even protein rich refeed (for beef cattle only) or food for fish farms. This may be done at some later date after additional research has been conducted on the suitability of recycled solids for use as refeed.

BIOMASS ENERGY CONVERSION PROJECT

NOTE: Not to scale.

4 PROJECT ECONOMIC ANALYSIS

4.1 Cost Estimate

The demonstration plant design is based on capacity for handling waste from a maximum of 200 fourteen hundred pound Holstein dairy cows. This has resulted in the following set of cost figures representing the capital cost of the plant:

Manure Collection and Handling System Includes; 14 ft. by 14 ft. square by 8 ft. deep manure pit made with concrete blocks, man- hole, ladder, hydraulic ram pump, steel hopper, grating, 260 ft. of 12 inch PVC pipe, two-12 inch valves, sump pump, water tank, shed, etc. (exclud- ing labor).	System Cost \$ 11,678.83
Biodigester (Bio-reactor) System Includes; 24 ft. diameter by 20 ft. high reactor vessel made of precast concrete staves, with sealed roof, insulation, epoxy sealer, divider wall, gunite, etc. (including labor).	System Cost \$ 14,990.98
Biodigester Slurry Agitation Subsystem Includes; CPVC recirculation manifold, 4 gas diffuser lines, one gas pump, drain trap, etc. (exclud- ing labor).	System Cost \$ 3,228.48
Biodigester Heating and Heat Recovery Subsystem Includes; Auxiliary boiler, main heat exchanger, recirculation pump, piping, tank heat panel, mixing valve, thermostat, etc. (exclud- ing labor).	System Cost \$ 2,878.30
Biodigester Monitoring Subsystem Includes; Electronic thermometer & sensors, pH meter & sensor gas leak detector & alarm unit, rack mount cabinet, etc. (exclud- ing labor).	System Cost \$ 443.97
Biodigester Sludge Removal Subsystem Includes; Piping, valves, standoff brackets, etc. (excluding labor).	System Cost \$ 250.00

Biogas Handling and Purification Subsystem Includes; Piping, valves, two scrubbers, gas compressor, regulators, gages, storage tanks, etc. (excluding labor).	System Cost \$ 2,028.77
Biogas Utilization/Electricity Production System Includes; Engine/generator set, engine control unit, generator control unit, gas flare unit, metering, power cable, etc. (excluding labor).	System Cost \$ 15,975.90
Effluent Slurry Storage and Disposal System Includes; Earthen dike pond, pier, piping, irrigation pump, valves, etc. (traveling gun sprayer not includ- ed). (Including labor).	System Cost \$ 2,851.98
Electrical/Control Building Includes; Lumber, steel siding, roof trusses, roofing, interior walls, doors, sink, windows, insulation, wiring, lights, etc. (excluding labor).	System Cost \$ 5,240.52
Construction Labor Includes; Labor to construct systems noted above that excluded a labor cost figure (estimated 750 manhours @ \$8.50 per hour).	System Cost \$ 6,375.00
Total Capital Cost:	\$ 65,942.73

The economic analysis will consist of the following net electricity and by product output basic:

4.2 Electricity Output

Annual gross electrical production (minus plant requirements):
93,432 KWhr/yr

Annual electrical consumption of Cleek farm:
84,000 KWhr/yr

Annual net electrical production for sale:
9,432 KWhr/yr

Annual savings for electrical power production:
 $(84,000 \text{ KWhr/yr} \times \$0.048/\text{KWhr}) + (9,432 \text{ KWhr/yr} \times \$0.017/\text{KWhr}) =$
 \$4,192.00

4.3 By Product Output

Annual ammonium nitrogen produced:
16,706 lbs/yr

Annual phosphate produced:
5,138 lbs/yr

Annual potash produced:
11,744 lbs/yr

Annual savings for by product fertilizer production:
 $(16,706 \text{ lbs/yr} \times \$0.25/\text{lb}) + (5,138 \text{ lbs/yr} \times \$0.25/\text{lb}) + (11,744 \text{ lbs/yr} \times \$0.08/\text{lb}) = \$6,400.00$

Total annual savings from electricity and by product production:
 $\$4,192.00/\text{yr} + \$6,400.00/\text{yr} = \$10,592.00/\text{yr}$

As can be seen, the by product value is worth more than the electricity value. This is not the case for instance in New York state where the electric rates are at \$0.124/Kwhr and in Florida state where the electric rates are at \$0.095/KWhr.

4.4 Maintenance and Operating Costs

It has been estimated that the annual maintenance cost is approximately \$1,750.00. This includes; replacement scrubber material, oils, antifreeze changeout, replacement of worn valves, and engine overhaul. The plant requires a daily check of thirty minutes which can easily be accomplished during typical farm chores.

Based on the above data, the payback on this project is about 7 years. It would cost approximately \$90,000 to have a similar plant built by a turnkey contractor.

5 CONCLUSION

In general, the economics of an anaerobic digester system varies greatly depending on the location, replacement energy cost, capital investment, size, tax rate, and biogas output. The economics is very positive where the fuel that is being replaced by the methane gas is propane (used in grain drying) which currently costs \$6/million BTU. Also, the economics is good where electricity is \$0.06 or greater per kilowatt-hour (as in the lower Southeastern, New England, and Mid Western states). After tax internal rates of return on a system that replaces the aforementioned fuel/electrical costs are running from a low of 7.5% on a 50 cow unit to a high of 24.2% on a 500 cow unit considering fuel savings only. As the size of the unit increases beyond 200 head of cattle, the capital investment increases only at a gradual pace (the main increase in cost is the digester tank due to increased volume). This shows that there is an economy of scale for the plant, the economics looks good for bio-digesters sized for 500 cows or larger. Since electricity costs in the Tennessee Valley Region is much lower than other surrounding areas then the economics of using methane to replace electricity here is only marginally attractive. The main conclusion that I have drawn in this study is that these units should be used on very large dairy farms (i.e. over 200 head) and in geographic locations where the fuel/energy costs are high. If the by-product can be sold as fertilizer (as from a beef cattle feedlot), or separated and used to replace cattle bedding material or to supplement cattle feed, then additional savings can be attained. The economics of our system would look better if the gas production is increased (operation in the thermophilic range increases gas production by 20%) and if the additional capacity of waste heat that could be recovered is used for some useful purpose (as distilling ethyl alcohol for tractor fuel). From the research findings thus conducted and the experience to be derived from this project the following conclusions have been established:

- A.) Reproduction of a similar plant is possible if the appropriate planning is conducted and experience is available.
- B.) The benefits to be derived depends on the actual plant/farm location and size.
- C.) Farms with other animals than cows can produce biogas, however the amount of gas production varies for each different animal type.
- D.) Building construction codes, utility interface requirements, and insurance fees all vary with location and should be considered in the evaluation of such a plant.

Overall, these systems will be able to provide farms with a means to cut manure management costs, lower energy costs, enhance fertilizer value of manure, provide excess heat (hot water), and eliminate odors associated with raw manure. More actual experience is needed however, on operating farms to prove systems viability on private farms. This

project will serve as one such project to demonstrate the feasibility of the system. As the biomass conversion facility is completed and goes into operation, more definitive information on gas production optimization and effluent by product value can be determined. Hopefully further research will be performed by various institutions and the present facility will possibly be used for conducting such analysis (Volume II of the final report will include details of the plant operating procedures and performance and will be issued in June 1984).

APPENDIX 1

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APPENDIX 2
EFFLUENT HOLDING POND
DESIGN DATA

CHARLES CREEK

ANIMAL WASTE STORAGE STRUCTURE
(HOLDING POND)

SULLIVAN COUNTY TENNESSEE

DESIGNED BY: WILLIAM THURMOND
AGRIC. ENGINEER
SOIL CONSV. SERVICE
JULY 1981

SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE

SHEET 1 OF 9

PLAN

APPROX. 600 LINEAR FEET
OF 4" DIA. POLYETHYLENE
PLASTIC DRAINAGE TUBING.
TILE SHALL OUTLET INTO
REEDY CREEK. MIN.
RECOMMENDED TILE
DEPTH SHALL BE 3'-6"
BELOW GROUND SURFACE

SCALE 1" = 64'-0"

DRY TOE SLOPE OF
PLANNED LEVEE

PLAN VIEW SHOWING
TILE DRAINAGE INSTALLATION

SCALE 1" = 64'-0"

ELEVATION MAP

CROSS SECTION A-A

CROSS SECTION B-B

HOLDING POND STORAGE
CAPACITY AT RECOMMENDED
MAX. LIQUID DEPTH OF 6'

$$V = d/6 [A_1 + A_2 + 4M]$$

$$A_1 = 180' \times 140' = 25,200$$

$$A_2 = 156' \times 116' = 18,096$$

$$M = 168' \times 128'(4) = 86,016$$

129,312

$$V = \frac{6}{6} [129,312 \div 27]$$

$$= 4790 \text{ YDS}^3 \text{ OR } 129,312 \text{ FT}^3$$

ANTICIPATED SIX MONTHS
ACCUMULATION VOLUME BASED
ON FOLLOWING

$$1 - 200 \text{ COWS} \times 1.5 \text{ FT}^3/\text{DAY PER COW}$$

$$\times 183 \text{ DAYS} = 54,900 \text{ FT}^3$$

$$2 - 254R \text{ RAINFALL} = 4.9''$$

$$\frac{24 \text{ HR}}{4.9'' \div 12 \text{ IN/FT.}} = 0.4083$$

APPROX. WATERSHED OF RESERVOIR

$$200' \times 160' = 32,000 \text{ FT}^2$$

$$32,000 \text{ FT}^2 \times 0.4083 \text{ FT.} = 13,066 \text{ FT}^3$$

3 - SIX MONTHS RAINFALL
PERIOD

$$\text{ANNUAL R.F.} = 54.65''$$

$$54.65 \div 12 = 4.55 \text{ IN./MO.}$$

RAINFALL MINUS EVAPORATION

$$4.55 - (.75)(.95) = 3.84 \text{ IN./MO.}$$

$$3.84 \div 12 = 0.32 \text{ FT./MO.}$$

$$(0.32')(32,000 \text{ FT}^2) = 10,240 \text{ FT}^3/\text{MO.}$$

$$10,240 \text{ FT}^3/\text{MO} (6) = 61,440 \text{ FT}^3$$

$$129,406 \div 183 = 707.14 \text{ FT}^3/\text{DAY}$$

129,406 FT³

$$129,312 \div 707.14 = 183 \text{ DAYS}$$

MAX. STORAGE

SHEET 7 OF 9

ESTIMATED EARTH EXCAVATION
REQUIRED TO CONSTRUCT HOLDING
POND BASED ON AVG. CUT.
EQUAL 3.8 FEET

$$V = \frac{d}{6} [A_1 + A_2 + 4M]$$

$$A_1 = 171.2' \times 131.2' = 22461.44$$

$$A_2 = 156' \times 116' = 18096.00$$

$$M = 163.6' \times 123.6' (4) = 80883.84$$

$$121,441.28$$

$$V = \frac{3.8}{6} \left[\frac{121,441.28}{27} \right]$$

$$V = 4498 \text{ YDS}^3$$

ESTIMATED REQUIRED EARTH FILL
TO CONSTRUCT HOLDING POND
LEVEE BASED ON AVG. FILL HT. = 4.2'

$$\text{FILL LENGTH} = 740'$$

$$\frac{\text{YDS}^3}{\text{LIN. FT.}} = 3.2$$

$$\text{TOTAL YDS}^3 = (740)(3.2) = 2368 \text{ YDS}^3$$

EMBANKMENT CONSTRUCTION SPECIFICATIONS

THE MATERIAL PLACED IN THE EMBANKMENT
SHALL BE FREE OF SOD, ROOTS, STONES OVER 6"
IN DIA. AND OTHER OBJECTIONABLE MATERIALS
THE FILL MATERIAL SHALL BE PLACED AND
SPREAD OVER THE ENTIRE FILL IN LAYERS
NOT TO EXCEED 8" IN THICKNESS EACH
LIFT SHALL BE COMPACTED BY MIN. OF
FOUR PASSES USING 450 P.S.I. SHEEPFOOT
ROLLER OR EQUIVALENT. CONSTRUCTION
OF THE FILL SHALL BE UNDERTAKEN ONLY AT
SUCH TIMES THAT THE MOISTURE CONTENT OF
THE FILL MATERIAL WILL PERMIT A REASONABLE
DEGREE OF COMPACTION

SPECIFICATIONS AND CLARIFICATION NOTES

NOTE: HOLDING POND AS DESIGNED IS A COMPONENT OF A ANIMAL WASTE STORAGE AND DISPOSAL SYSTEM. ANIMAL WASTE BEFORE ENTERING HOLDING POND IS PROCESSED THROUGH AN ANAEROBIC DIGESTER WHERE METHANE GAS IS TRAPPED AND STORED FOR USEFUL PURPOSES. ANIMAL WASTE IS TO BE PUMPED FROM THE ANAEROBIC DIGESTER TO THE HOLDING POND.

WHEN MANURE SLURRY IN HOLDING POND RISES TO ELEVATION 101.0 IT SHALL THEN BE PUMPED (VIA HIGH PRESSURE IRRIGATION EQUIPMENT) (BIG GUN DISCHARGE RATE 250 G.P.M.) AND SPREAD BACK ON TO ADJOINING FARM LAND

NOTE: EMERGENCY SPILLWAY SHALL BE FIELD DESIGNED FOR HOLDING POND ~ CREST ELEV. SHALL BE 101.5 MIN. BOTTOM WIDTH SHALL BE EIGHT FEET MIN. SIDE SLOPES SHALL BE 2:1

IMMEDIATELY AFTER CONSTRUCTION ALL EARTH EMBANKMENTS AND ANY OTHER DISTURBED AREAS SHALL BE ESTABLISHED IN PERMANENT TYPE VEGETATION

PROTECTION: THE HOLDING POND SHALL BE FENCED TO KEEP OUT CHILDREN AND ANIMALS. KEEP OUT OR OTHER APPROPRIATE WARNING SIGNS, VISIBLE FROM ALL DIRECTIONS, SHALL BE POSTED. THE FENCE SHALL BE NOT LESS THAN FOUR FEET HIGH. THE LOWER THIRTY-TWO INCHES SHALL BE WOVEN WIRE