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B816: An Economic Analysis of a Maine Dairy Farm Anaerobic Digester

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INTRODUCTION

Anaerobic digestion is a method for decomposing organic matter, producing in the process, biogas, which is mostly methane. This process can be used to eliminate or reduce disagreeable and often environmentally harmful characteristics of wastes. Among characteristics the process can effectively eliminate or reduce are odor and high biological oxygen demand. During the autumn of 1984, the University of Maine began operation of an anaerobic digestion unit acquired from Agway, Inc., a large Northeastern agricultural cooperative. This system, installed at the Witter Animal Science Center decomposes animal manures and ultimately produces electricity and hot water. A by-product of the system is a fertilizer with characteristics superior to fertilizers produced from biological wastes that have not undergone a process of anaerobic digestion. In addition to these benefits, farmers who install an anaerobic digestion system may realize significant tax benefits.

An extensive review of literature specifically related to biogas generation from organic materials was conducted. The review covered the general biogas process, on-farm biogas production and the economics of biogas production. Some of the findings are that: digested manure is a better fertilizer than undigested manure; positive net energy production is proven on some sized farms; there are intangible benefits from reduction in odor and pollution; larger size farms (greater than or equal to 150 cow equivalent) should consider anaerobic digestion as an investment; and economic feasibility is dependent on many factors including technical performance, electricity prices or the price of substitutes, and inflation. The results reported in the various papers are sensitive to the assumptions of the underlying models.

Objectives

The research objectives were to: (1) construct an economic-engineering model representing the waste to energy system, (2) quantify the benefits and costs of the system, (3) estimate the cash flows accruing over the lifespan of the system, (4) evaluate the model to determine the net present value of the system, and (5) evaluate alternative scenarios to determine the effect on economic feasibility.

Digester Description

The digester system consists of many components including the digester vessel and associated equipment, other structures, living bacteria, and organic matter. The purpose of the digester is to decompose the organic wastes and produce energy. The digester vessel at the Witter Animal Center is a poured concrete, cylindrical container measuring 28 feet high and 24 feet in diameter. Its volume is roughly 70,000 gallons and it is air and water tight.[1] It is within this vessel that the anaerobic decomposition of organic matter and biogas production take place. Biogas is roughly 60 percent methane and 40 percent carbon dioxide with some other trace gases.

Adjacent to the digester is a control room which has instrumentation for monitoring the performance of the digester vessel and other equipment, Also in the control room are an engine and generator. Biogas produced in the digester vessel is used as fuel in the engine which turns a 25 kilowatt electricity generator.

The digester receives organic matter through a network of underground pipes and pumps. Underground pipes receive the organic matter from three dairy cattle barns. The barns are equipped with machinery which scrapes the floor under the cattle to collect waste organic matter. Appendix A presents a more detailed description of the system.

Applicability to Maine

There are many organic waste streams in Maine which may be suitable for anaerobic digestion. Farms with large numbers of livestock or poultry could utilize anaerobic digestion. This paper is concerned with

[1] The first digester vessel, made of concrete staves reinforced by exterior steel braces, collapsed after roughly a year and a half. A second digester, made of different material was constructed at no cost to the University and is described in Appendix A.

the utilization of anaerobic digestion on dairy farms which in Maine account for a large portion of total animal wastes.

In their paper "Dairy Farm Indebtedness in Maine," Thurston, Criner, and Reeb estimate that there are roughly one thousand dairy farms in Maine. In their sample of over 300 dairy farmers the number of cows per farm varies widely with the largest farm having over 240 cows. Using the data from their survey, farms are grouped into nine categories according to the number of cows per farm. Table 1 presents the range of cows per farm in each category, the percent of Maine dairy farms expected to be in each category (based on the Thurston, Griner, and Reeb sample) and the estimated total number of Maine dairy farms in each category. Note that 54.7 percent of dairy farms in Maine have between 30 and 60 cows per farm and that slightly over 93 percent of all dairy farms in Maine have less than 120 cows per farm. It is estimated that it would require at a minimum 120 but preferably closer to 200 cow equivalents in order to provide the manure necessary for a digester similar to the one used in this study.[2] It is believed that the cow number values in Table 1 are the number of milking cows which would be less than the number of cow equivalents. Thus some farms in the 120-149 cows per farm category may have 150 cow equivalents. If one includes this size category with the larger farms, then roughly the largest 6.8 percent or 68 Maine dairy farms could potentially use a digester similar to the one at the Witter Farm Center. Future research should examine the possibility of smaller farms using anaerobic digestion, perhaps with different biogas production and utilization systems.

THEORY AND METHODOLOGY

Economic Theory

The issue relative to the economic feasibility of the digester system is whether the cost of the system is more than offset by the reduction in the farm's variable costs. The net change in variable costs associated with the digester system includes the labor, repair, and maintenance costs of the system and the dollar benefits of electricity, fuel oil, fertilizer, and tax payments.

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[2] Cow equivalents are used to standardize herds to adult dairy cow weights. One cow equivalent equals one 1,250 pound adult dairy cow.

Table 1

Size Distribution of Maine Dairy Farms in Terms of Number of Cows Per Farm and the Estimated Number of Dairy Farms in Each Category

Number of Cows Per Farm	Frequency in Sample	Dairy Farms in Category (Percent of Sample)	Estimated Number of Dairy Farms in Maine (Percent of Sample x Pop.)
1-29	48	15.64	156
30-59	168	54.72	547
60-89	54	17.59	176
90-119	16	5.21	52
120-149	11	3.58	36
150-179	5	1.63	16
180-209	2	0.65	7
210-239	1	0.33	3
>=240	2	0.65	7

Note: The total number of Maine dairy farms in each category is estimated by multiplying the portion of farms in each category (as determined by Thurston, Criner, and Reeb) by 1,000 (the estimated number of Maine dairy farms).

The useful life of the system is assumed to be 20 years since the investment is made of components with life expectancy of roughly 20 years. Over its life span the system accumulates benefits and costs. These future benefits and costs are increased over time to reflect general price inflation. The future net benefit is then discounted to present value in order to standardize the value of money over time. The expected inflation rate is derived using the Fisher equation [Fama, p. 269]. The Fisher equation relates real and nominal interest rates where nominal interest rate equals the sum of the real interest rate plus the expected inflation rate.

The nominal interest rate is obtained from the value of treasury bills with a twenty year maturity. The 20 year treasury bill rate is chosen since it has a duration corresponding to the useful life of the digester system. For 82 recent daily yields of 20 year treasury bonds an average yield of 8.50 percent is obtained with a standard deviation of 0.74 percent.[3] A value of 8.50 percent is used for the nominal interest

[3] Wall Street Journal, January 10 through May 27, 1986.

rate in the first analysis. Boejlhe and Eidman state that many economists agree the real rate of interest ranges between three and five percent [p. 137] while another source indicates historic inflation adjusted yields on 20-year Treasury Bonds average two to three percent [Foldessy]. For all but one portion of the analysis the real rate of interest is assumed to be three percent per year.

With the nominal interest rate and the real interest rate one can derive the expected inflation rate over the 20 year term of the system by rearranging the Fisher equation. Using the above values the expected rate of inflation is then about 5.50 percent. For the purpose of this analysis the annual rate of inflation over the 20 year life of the system will be assumed to be 5.50 percent. The inflation factor is derived by multiplying the previous year's inflation factor by the current year's inflation rate Starting with a base year (1985) inflation factor of one.

The borrowing rate is another important parameter of a net present value analysis. This parameter should reflect the minimum acceptable rate of return. The minimum acceptable rate of return is the opportunity cost, or the cost of capital of the invested funds. Opportunity cost reflects three components, the pure time value of money, risk and uncertainty, and inflation. The borrowing rate can be approximated by using the cost of capital.[4] For a dairy farmer desiring a loan to construct a capital investment (like a digester system) he or she would have to endure the prevailing cost of capital for an investment of

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4 For a specific farm the cost of capital may be calculated as the weighted average cost of debt and equity. This weighted average cost of debt and equity is equal to the sum of: (1) the cost of debt capital times the ratio of debt to assets, and (2) the cost of equity capital times the ratio of equity to assets. For a general estimate of the cost of capital this study uses the cost of debt capital as the total cost of capital. It should be noted that the cost of debt capital is theoretically less than the cost of equity capital and using the cost of debt may present a more economically feasible bias in the analysis depending on the degree of leverage for a particular farmer [Barry, Hopkin, and Baker, pp. 112-5].

similar risk and uncertainty. The prevailing cost of capital for Maine dairy farmers in 1986 is roughly 11.5 percent.[5]

Methodology

The basic core of the analysis is based on the economic-engineering method which representation results in a model of some production process or activity. The models couple the technical aspects and cost and price information of the system. For a more detailed discussion of the economic-engineering method see "Design, Construction, and Use of Economic-Engineering Models" by George K. Criner and "Economic-Engineering Methods in Marketing Research" by L.L. Sammet and B.C. French.

In this study the cash flows associated with the digester system are evaluated using net present value capital investment analysis. Of the many different analytical techniques such as internal rate of return, annual rate of return, payback method and discounted net present value, the last technique is of greatest use for this analysis. Kelly and Egarian concluded that the "net present value method for evaluating expected profitability is currently recognized as the most technically correct method of analysis. It features two key variables: Projected cash flows and required rate of return" [p. 43].

The discounted net present value method compensates for the lower value of a future dollar by discounting all cash flows to the present. If the discounted revenues are greater than discounted costs, the project is worthwhile and should be accepted. The general net present value method is represented mathematically by the following formula:

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5 Current (May 21, 1986) cost of debt capital for a farmer with good credit is reported from telephone conversations with bank loan officers: Key Bank, Presque Isle, 11.5 percent for a 20 year variable annual rate (base rate tied to prime rate, roughly 9.5 percent, plus 2 percent charge); Farmers Production Credit, Auburn, 12 percent on a 20 year fixed rate loan; Casco Northern, Presque Isle, 10 and three-quarters percent variable rate, linked to the prime rate with a maximum of 15 years, no loan would be issued for a longer term; Norstar, Lewiston, 10.5 to 11.5 percent variable rate depending on the borrower.

$$NPV \quad \sum_{t=1}^{n} [B_t/(1 + d)^t]$$

where NPV is the net present value of the project, B_t is the net benefit received in time period t, the borrowing rate is d and the final period of the analysis is n. With this method the borrowing rate d, and duration of project, n, are known or assumed, and the revenues and costs are either observed or estimated.

ANALYSIS

The Costs

The costs of an anaerobic digestion system can be broken into four categories which are:

1. Digester and associated equipment
2. Added labor associated with the system
3. Engine repair and system maintenance
4. Miscellaneous

Digester and Associated Equipment

The digester system consists of the anaerobic digester vessel and miscellaneous items. The digester and all associated equipment in this study cost $105,000. It is assumed in this analysis that the farm has a liquid manure handling system in place when the digester is built.

Added Labor and Management

Additional labor is needed to monitor and control the digester system. The contents of the barn reception pits are mixed and the material pumped to the digester twice daily. Additional labor allowance for periodic repairs and maintenance on equipment must be made and are included in the daily labor requirements. Furthermore, management must direct the labor to maintain or change digester feeding rates, digester temperature, retention times, etc.

Stevens and Brodie [p. 38] estimate labor and management time at 333 hours per year for a digester system sized for 200 cows. This amounts to slightly less than one hour per day (55 minutes). For the purpose of this analysis added labor is assumed to equal one hour per day while added management time is assumed to equal fifteen minutes per day.

The wage rates used in this analysis for labor and management are $5.00 and $8.00, respectively. The total cost of labor and management is $7.00 per day or $2,555 annually. In the alternative scenario section of this paper the economic feasibility of the system will be examined using different labor rates from one-half hour of labor and fifteen minutes of management time to one and one-half hours of labor and fifteen minutes of management per day.[6]

Engine Repair and Maintenance

The engine runs almost continuously (8,760 hours per year) and the allowance of replacing the engine annually has been made in the engine repair cost. In this study the engine installed in the control room lasted one year under operating conditions.7 Further research is needed to establish normal useful life of the engine. The cost of a remanufactured engine is estimated at $800 and utilizes some of the farm labor. The used engine is kept for parts or emergency operation.

Maintenance costs on the engine include 23 oil changes per year. At a cost of $11.91 per oil change for new oil and filter this results in a $274 annual cost. Included in the maintenance is the cost of biogas filter replacement each year. Total annual cost for engine repair and system maintenance is $1,074. The labor time required to perform

[6] Conversations with the Witter Dairy Farm supervisor and the Agway Farm Energy Utilization manager indicate a range in added labor estimates from one and one-half hours labor and fifteen minutes management to one half hour labor and fifteen minutes management time per day, respectively. The estimate of one-half hour labor and fifteen minutes management is for a system installed on a typical dairy farm with very efficient labor utilization. The estimate of one and one-half hour labor and fifteen minutes management time is for the digester system at the Witter Animal Science Center. The extra time is due to the extensive monitoring required at a research facility. A farmer who installs this type of system is not expected to perform these tests and the system would require less added labor. Rather than use the very efficient labor time the one hour labor and fifteen minutes management time was used to ensure that if an error was made, it would be on the high side.

[7] The first engine lasted one year and was operated under less than optimal conditions. The remanufactured engine has modifications that may increase performance, such as the engine water pump and cooling system previously driven by the engine itself. The engine is now cooled by digester vessel piping thus freeing potential energy from the engine to generate electricity.

maintenance on the digester system as well as for replacement of the engine is accounted for in the added labor category of costs.

Miscellaneous

This final category includes costs not included elsewhere such as the cost of valves, meters, piping and pumps. Discussions with the dairy farm supervisor suggest that the cost of miscellaneous items is expected to roughly equal $1,500 annually. Future costs for miscellaneous items are projected using the inflation factor.

The Benefits

The two major benefits of the anaerobic digestion system are the value of the electricity generated and the value of the heat energy co-generated. Other benefits such as weed control, possible fertilizer benefit, pollution abatement and plant disease control are briefly discussed but are neither quantified nor included in this analysis. Any tax benefits would need to be examined by individuals contemplating investment in this system. The 1987 tax laws reduce tax benefits such that projects that are feasible excluding tax effects will tend to be feasible once tax effects have been included. Likewise, projects not feasible excluding tax effects will tend not to be feasible with tax effects included.

Electricity

This analysis assumes that the current price of electricity is 8 cents per kilowatt hour.[8] The annual value of electricity produced by this system is simply 8 cents multiplied by the number of kilowatt hours generated each year. In this analysis an electrical production level of 2 kwh per day per cow equivalent will be used. This benchmark is given by Parsons (p. 39) and is reasonable (in fact conservative) based on the digester's performance. Thus the 137 cow equivalents presently at the farm produce 274 kilowatt hours per day for an annual value of $7,759.68 (137 x 2 x 354 x $.08). It is assumed that the digester has 11 non-operating day per year for cleaning, repairs, etc. Future years'

[8] The cost of electricity depends on the utility servicing the area and the application. Bangor Hydroelectric charges most dairy farmers roughly 8 cents per kwh while Central Maine Power Co. charges 9.074 cents per kwh (March 1986).

electrical benefits are derived by inflating the first year benefit by the inflation factor.

Heat Energy

Heat energy is measured by the volume and temperature of hot water being sent to a hot water tank located in the milking center. The hot water being sent to the storage tank is in excess of the heat required to maintain the digester vessel temperature. Total estimated August 1984 through July 1985 heating oil savings due to the digester system (adjusting for heating degree days during the corresponding period) are 4,329.2 gallons.9

The cost of number two fuel oil (the energy source which the cogenerated heat replaces) to be used in the base analysis of this study is 50 cents per gallon. Future nominal oil savings are projected using the inflation factor. Although current oil prices are lower than the price used in the base analysis it is not known how long the low oil prices may last. To account for future variations in oil prices several feasibility analyses, or senarios, are conducted with various oil prices.

Other Benefits

Other benefits such as pollution and odor control and abatement, and reduction in pathogens exist, but are not quantified. Pollution and odor abatement can be achieved with an anaerobic digester. One study indicates that odor is reduced from a "sulfide" or rotten egg odor to a "musty or tarry" odor which is much less undesirable [Feddes, P. 19].

Destroying pathogens is another benefit from anaerobic digestion as reported in the literature. Turner and others state that "anaerobic digestion is a suitable system for reduction of pathogenic organisms in agricultural plant waste material" and "none of the pathogens studied will be present... 10 days after their introduction into a digester" [p. 10].

Benefits such as pollution and pathogen reduction are difficult to quantify and are not computed or analyzed in this study. It is hoped that future research will be better able to quantify and analyze these

[9] See appendix B for a more detailed derivation of the hot water benefits.

factors to determine more precisely their impact on the overall feasibility of the system.

Results of Analysis

This section presents and discusses the results of various alternative feasibility scenarios. The alternative scenarios involve changing various variables and examining the effect on net present value. If the net present value is positive, the system more than pays for itself and is therefore economically feasible and if the net present value is negative, the system is not economically feasible.

The analysis revealed that the feasibility of the system is very sensitive to benefit levels (electricity, and oil savings) and less sensitive to changes in the cost categories, added labor, repair and maintenance and miscellaneous. The analysis was also generally less sensitive to the various inflation and interest (borrowing or discount) rates that were used in the analysis.

The Witter Farm had 137 cow equivalents at the time of this analysis which is considerably under the digester design cow equivalents of 200. What is important about this is that if the Witter Farm would increase cow equivalents to 200 they would not for all practical purposes experience any increases in digester associated costs. If the Witter farm had 200 cow equivalents their electricity production would equal 400 kwhs per day and the oil savings from cogenerated heat could reasonably be expected to increase proportionately (by 200/137). To represent this all but one scenario are conducted which assume 400 kwhs of electricity per day and 6,320 gallons of oil savings per year (the oil savings from 137 cow equivalents adjusted upward to 200 cow equivalents by the factor 200/137).

Table 2 presents a brief description and summary of the various scenarios along with the net present value of each. The first scenario is termed the base scenario and represents the conditions thought most likely to occur. The design level cow equivalents of 200 are used along with the estimated 200 cow equivalent level of heating oil savings (6,320 gallons per year). The electrical price received is 8 cents per kwh and the value of oil savings 50 cents per gallon. A 5.5 percent inflation rate and an 11.5 percent borrowing rate are assumed. The total annual benefits equal $11,328 and $3,160 for electricity and oil, respectively, for a total of $14,488. Total cost per year equals $5,129 for a total annual net benefit of $9,359 ($14,488 minus $5,129). Given these conditions the system is economically feasible as the net present value of the base scenario is $5,127 and the system pays for itself in 19 years.

TABLE 2

Summary of Alternative Scenarios with Description and Net Present Value

Scenario	Description	Net Present Value ($)
Base	5.5% Inflation, 11.5% Borrowing Rate, 50 Cents Oil Price, 400 KWHs Per Day, 8 Cents Per KWHs, and 6,320 Gallons Heating Oil Savings Per Year	5,127
1	Base Scenario Except 80 Cents Oil Price	27,437
2	Base Scenario Except 4% Inflation, 15% Borrowing Rate	-28,361
3	Base Scenario Except 274 KWHs Per Day and 4,329.2 Gallons Heating Oil Savings Per Year	-48,574
4	Base Scenario Except 10 Cents Per KWH and 90 Cents Oil Price	68,198

Scenario 1 varies from the base scenario only with the use of a higher price for oil (80 cents per gallon). This higher oil price improves the economic feasibility of the system with its net present value of $27,437 and 14 year pay back period.

Scenario 2 represents the system where the farmer is a higher credit risk, perhaps due to low equity in the investment or from a poor credit rating. Using a higher real rate of interest, four percent inflation and 15 percent discount rate, the system is not economically feasible since the net present value is negative.

Scenario 3 represents the situation with 137 cow equivalents; 274 kwhs per day and 4,329.2 gallons oil savings per year. With this underutilization the system is not economical. Further analysis revealed that even with a one dollar oil price and 9 cents per kwh the system utilizing 137 cow equivalents is still not economical. Scenario 4 (again using 200 cow equivalents) represents a high energy price situation with 10 cents per kwh and 90 cents per gallon of oil. The net present value under this scenario is $68,198 and the system pays for itself in 10 years.

SUMMARY

An economic-engineering model using the net present value method was constructed to represent the waste to energy system at the Witter Animal Science Center. The analysis revealed that the feasibility is most sensitive to projected benefit levels and less sensitive to other factors. Items included in the model are divided into two categories: benefits and costs. The benefits include electricity and heat production. The costs include added labor, repairs and maintenance, miscellaneous and the capital investment. Future cash flows are discounted to present value using the borrowing rate. For all but one scenario an inflation rate of 5.5 percent and a borrowing rate of 11.5 percent are used. The digester system costs $105,000 purchased and installed. Under the assumptions of the base scenario the system will recover the capital investment in 19 years and has a net present value of $5,127 (and is thus economically feasible).

Limitations of the Research

A limitation of this study is that an extrapolation of electricity production and oil savings (through heat co-generation) had to be made to simulate the results of the system having the design level of cow equivalents. The 200 cow equivalent levels of electricity production and oil savings used appear very reasonable based on observed data (with 137 cow equivalents) and from the literature (Parsons).

The results of the analysis are peculiar to the system found at the Witter Animal Science Center which has unique characteristics. Results from similar digesters may be close to the net benefits of this system. In comparing the results of this study with other systems some changes in the analysis may be warranted. Farmers who wish to pasture their cows a considerable amount would need to analyze the possible improvement in herd health from pasturing and the decline in manure generated energy.

Areas for Further Research

Empirical evidence needs to be obtained regarding the effect on crop yields from the digestion of the manure (compared with undigested manure). Contact with other Universities revealed that while there has been a fair amount of analysis of the composition of digested and undigested manure no work has explicitly compared digested and undigested manure in crop response field tests. Heat savings could be examined further with observed information. Over time additional data may be available from the operating digester. If sufficient data (for a normally operating system) were available, it should be incorporated in the analysis to provide a more accurate analysis.

The economic feasibility of installing digesters on small and medium farms (less than 200 cows per farm) should be explored. Different utilization systems may be economically feasible. Future research should also investigate the effect of installing a digester on a farmer's optimal level of output. Analysis of cost structures indicates that, by installing a digester, average total cost may be lower than without a digester (depending on the level of output). This may have the effect of increasing the profit maximizing level of output.

CONCLUSION

The analysis conducted in this research reveals that a farmer who installs a digester of the type of the Witter Farm would be wise to have the appropriate number of cow equivalents which is 200. The closer the cow equivalents to 200 the better the system is economically. The effects of having more than the design level of 200 cow equivalents is unknown. If one has a digester of the type at the Witter Farm and also has 200 cow equivalents then, according the assumptions and analysis, the system is economically feasible. Thus, some of the largest farms in Maine, those few with greater than 200 cow equivalents, should consider anaerobic digestion of their manure.

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APPENDIX A

DESCRIPTION OF FACILITIES

INTRODUCTION

The purpose of this appendix is to describe the University of Maine's anaerobic digester system. The anaerobic digester system, designed by Agway Inc., consists of many components. It involves structures, equipment, machinery, organic matter and bacteria. In this system there are many flows, which include organic matter, biogas, water, and electricity. For the purposes of description, the system will be thought of as consisting of the following components:

1. Barns, animals, and milking center
2. Anaerobic digester and associated equipment
3. Bacteria
4. Digester effluent storage and disposition
5. Material flows.

Barns, Animals, and Milking Center

There are three barns housing dairy animals for milk production and research. In addition, these animals provide organic matter (manure and urine) for the anaerobic digester. A fourth building houses the milk processing center. These structures will be referred to as the heifer barn, cow barn, research barn, and the milking center. Figure A.1 presents the relative location of these and the other structures.

Heifer Barn

The heifer barn, measuring 78 feet by 105 feet, is one of the main barns in the system. Presently, there are 59 large and 13 small dairy cows, housed in freestalls, which contribute manure and urine to the digester. The heifer barn has a total of 103 freestalls constructed on both sides of alleyways. There are five alleyways, four of which are outfitted with alley cleaners. The fifth, central alleyway is used for feeding. The manure obtained from these animals tends to have a lower moisture content than other manures. Manure is collected by mechanical means and is mixed with manure from other sources before being sent to become digester feedstock.

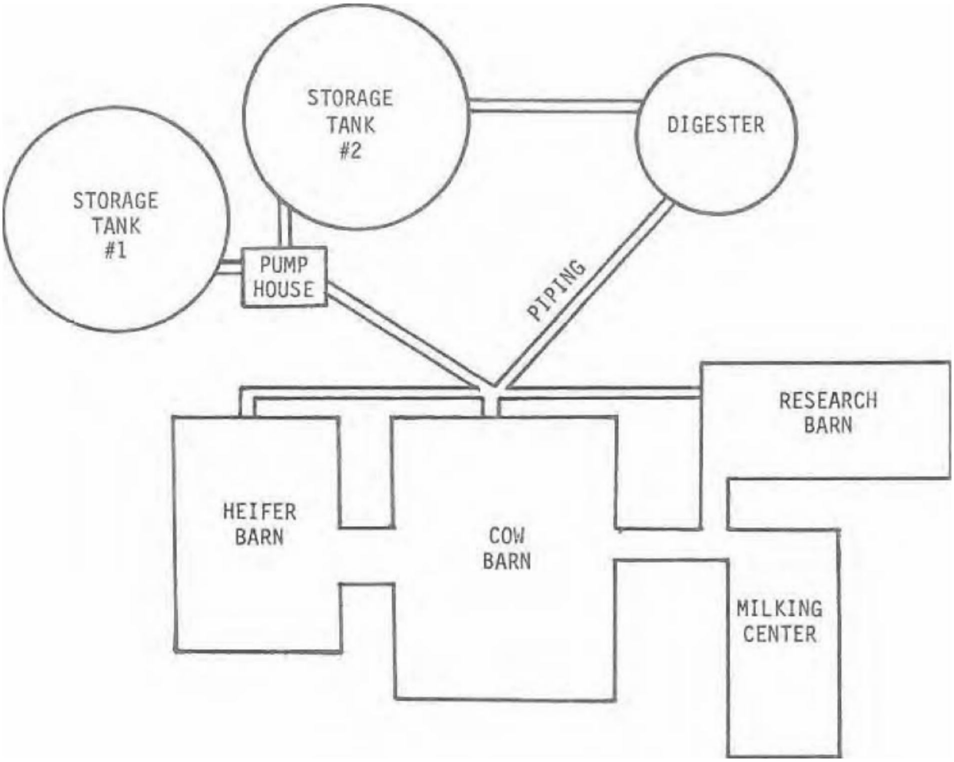

FIGURE A.1: Schematic Diagram of the University of Maine Anaerobic Digester System Showing Relative Position of Digester, Barns, Piping and Other Structures

The heifer barn's reception pit has a 13,100 gallon capacity. A Flygt cutter pump in the pit, has metal blades built in to chop large pieces of organic matter and homogenize the slurry mix. The cutter pump in the heifer barn can be oriented in two directions: First, the pump can be set to circulate material inside the reception pit to create a more homogenized mix. Second, the pump can be set to send slurry through a pipeline to the cow barn reception pit.

Cow Barn

The cow barn is the largest barn in the system measuring 84 by 135 feet. Eighty-seven lactating cows are housed and contribute manure to the digester and milk for the University. The cow barn has 120 freestalls located on either side of five alleyways. Like the heifer barn four alleyways are equipped with alley cleaners, the fifth central alleyway is used for feeding.

The manure handling systems in the heifer barn and cow barn have many similarities and differences. Among the similarities is the fact that animal manure accumulating in alleyways is handled in the same manner as in the heifer barn; two chain loop systems are run with two Badger electric motors to deposit organic matter at the west end of the barn. Differences include a large capacity 15,700 gallon reception pit to handle the larger capacity barn. Also the cutter pump in the cow barn can be oriented in more ways:

1. toward the heifer barn
2. toward the research barn
3. toward the digester
4. toward the storage tanks
5. to slurry the reception pit

Research Barn

The research barn is the smallest barn housing animals in the system, measuring 135 by 50 feet. There are 20 individual comfort type stalls which currently house 23 calves and 13 cows. The manure handling system in the research barn is automated. A trench is located in back of the comfort stalls so that manure falls directly into the trench. In the trench is a conveyor that periodically moves manure to the research storage tank which has a maximum capacity of 17,100 gallons and is the largest underground liquid storage tank at the Witter farm. Material in the research storage tank can be pumped into the cow barn reception pit. Whey, a byproduct of cheese making, has sometimes been stored in the research barn reception pit and is used as digester feedstock in combination with manures. This mixture increases the performance of the digester system and further research on the use of whey is needed.

Milking Center

The milking center measures 120 feet by 50 feet and is adjacent to the barns at the Witter farm. The milking center houses equipment for milking animals, pasteurization of milk, packaging the product, a boiler room, and a backup generator. This equipment provides fresh milk to the university community, and is also a research facility.

Milk Processing

From the milking parlor, milk travels by stainless steel milk line to a pasteurizer. Milk pasteurization requires large quantities of energy since the product must be heated to near the point of boiling. To provide this energy a boiler room is located in the center. The boiler room contains an oil fired furnace which has a maximum output rating of 500,000 BTU's per hour. A 500 gallon hot water storage tank is connected.

In the storage tank is a hot water line which brings heat from heat exchangers built onto the engine in the digester control room. The heat from the digester supplements the heat from the oil burner. Accordingly, the oil burner does not have to work as much to provide the necessary heat. A reduction in the amount of time the oil burner is working directly translates into oil use reductions.

Digester and Associated Equipment

The digester and associated equipment form the centerpiece of the system. Components include the digester, control room, bacteria, and effluent storage. Each of these will be examined in this section.

Digester

The digester is a 28 feet high poured concrete, cylindrical structure with a poured concrete roof. It has a maximum operating capacity of 70,000 gallons and is impervious to air and water. Near the top of the side of the vessel are a pressure release and a vacuum release valve to prevent excessive pressure loads from causing damage to the equipment. If pressures inside the vessel increase too much, a pressure release valve releases biogas to the atmosphere. If a vacuum occurs within the vessel, the vacuum release lets air in to reduce the vacuum. Letting air into the anaerobic container will reduce anaerobic decomposition. Within the digester is a 15 feet high divider wall. This separates the lower portion of the digester into two sections. In the south floor of the digester and on the walls of the divider wall are "S" shaped 1.5 inch pipes. Hot water circulates through this piping in order to maintain the temperature in the digester. Warmed slurry rises over the divider wall and descends on the colder side. This promotes mixing of the organic matter.

A slurry pump is used to promote mixing of the digester contents. The pump, manufactured by Flygt Co., is rated at 500 gallons per minute. The pump is set to start every hour for five minutes and will pump 500 gallons in that time, that is, 12,000 gallons daily or slightly over 17 percent of the digester contents.

Organic matter enters the digester vessel from a pipe on the floor of the vessel container. Material enters the vessel and starts decomposition almost immediately. When the next feeding occurs, more organic matter enters the container and displaces the material already present. An overflow pipe is provided for spent organic matter to flow into storage tanks. At each feeding time the amount of material passing through the overflow pipe equals the amount of matter fed.

Biogas produced from the digester flows via a pipe originating from inside the top of the digester to the control room. Gas produced from the digester flows by the pressure produced in the digester vessel. The gas line from the digester vessel to the control room is located outside the digester vessel and along the outside wall. Heat tape and insulation are attached to the gas line where it is outside to prevent condensation from freezing the gas line in cold weather. Thermocouples and a pressure monitor register temperature and pressure at different points inside the digester and relay this information to gauges in the control room.

Control Room

The control room is the nerve center enabling control and monitoring of the system. The building is located adjacent to the digester and houses filters, the engine-generator combination, monitoring and control gauges and instrumentation.

Filtration

Biogas produced in the digester may be used without further modification; however it is customary to fitter the biogas of impurities. Gas enters the top of the control room and passes through a gas filter manufactured by Nelson Filters Co. of Stoughton, Wisconsin. The filter is designed to remove hydrogen sulfide from the biogas. Hydrogen sulfide, which is toxic, has an abrasive effect on engine components and will result in reducing the time between engine overhauls.

Gas pressure is guaranteed by the installation of a gas pump, manufactured by Rotron Inc. of Saugerties, New York. Total quantity of gas produced is measured by a meter located on the gas line after the pump and filter. The gas meter is manufactured by Dresser Industries.

Engine Generator

The engine is a remanufactured 300 cubic inch Ford gasoline truck motor. The remanufactured engine effectively raises the compression ratio inside the cylinders. A higher compression ratio than that found normally in gasoline spark ignition engines is necessary for efficient burning of biogas in engines. Different carburetion is also necessary for complete combustion. The carburetor made by Impco is the CA100 model.

Linked by direct shaft drive to the engine is an induction generator, manufactured by Marathon Electric Co. of Wausau, Wisconsin. The generator has a rated capacity of 25 kilowatts at 1230 RPM. An induction generator synchronizes operating speed without controls since the generator electric field is controlled by the utility network.

Three heat exchangers are incorporated in the engine unit to recover heat energy. One heat exchanger is located on the exhaust manifold. This water cooled manifold transfers its excess heat to the manifold heat exchanger. A second heat exchanger is found on the exhaust gas pipe. This unit takes heat from exhaust gasses and transfers it to the exhaust heat exchanger. A third heat exchanger cools the cylinder walls. This heat energy, produced by the engine during its operation is in the form of hot water. Heat is sent to where it is needed most (first priority is the digester). When the digester cools down sensors recognize this and send hot water into the heater coils imbedded in the digester. Once the digester's needs are met the next priority is to send hot water to the milking center hot water storage tank for use in the pasteurizing process. If all needs for hot water are met the excess heat is expelled through a radiator to the outside air.

Control and Monitoring

Control and monitoring of the system are made possible by valves, throttles, gauges, meters, and instruments. Control and tracking of engine speed are made possible by a control panel manufactured by Perennial Energy Co. of Dora, Missouri including meters for: total operating hours, revolutions per minute, current kilowatt production, engine oil pressure, engine water temperature, digester pressure, engine manifold vacuum, radiator temperature, and engine oil temperature. Additional monitoring of digester gas pressure and blower pressure is made possible by manometers installed on pipelines in the control room. The manometer is made by Meriam instruments of Cleveland, Ohio.

A unique feature of this installation is a trackertrol device which allows the engine to run at a speed which consumes biogas at the same rate as it is being produced within the digester. This allows for the burning of biogas when it is available, efficiently without the need for costly and inefficient storage facilities. The trackertrol device senses the amount of gas being produced by the digester and sets the engine speed accordingly. The trackertrol device is made by Perennial Energy Co. of Dora, Missouri and is model #300-12. Engine speed can be set manually by disengaging the trackertrol system.

Effluent Discharge

Storage Tanks

There are two 148,000 gallon storage tanks and a pump house incorporated in this system. The two tanks are referred to as the North and South storage tanks. The North storage tank receives digester effluent directly from the digester via the overflow pipe built into the digester. The North storage tank may also receive organic matter from the pump house or from the cow barn reception pit. The South storage tank receives material pumped through the pump house.

The pump house also creates pressure for getting effluent into the discharge point. Material at the discharge point is transferred by flexible hose to a tank truck which enables the organic matter to be spread on fields. The digester effluent spread on the fields is a liquid slurry which is roughly 90 percent water and 10 percent solids. Contained in a 3,000 gallon application per acre are: water, approximately 2,700 gallons, nitrogen, approximately 102 pounds, phosphorous, approximately 54 pounds, potassium, approximately 52 pounds, and micronutrients such as calcium, manganese, magnesium, and other trace elements necessary for plant growth. The material has a pH of about 7, roughly neutral which is a good level (relatively high pH) for the soil and plants.

APPENDIX B

DERIVATION OF HOT WATER BENEFITS

This appendix presents a detailed derivation of the hot water benefits which are co-generated by the anaerobic digestion system. Table B.1 presents heating oil consumption for the Witter Animal Science Center and Bangor, Maine, heating degree days for August through May 1983-84 and 1984-85. The higher the heating degree days the colder it is.

During August through May 1983-84 the digester was not in operation while for the same period in 1984-85 the digester was operational. Notice that the 1984-85 period was colder (8,421 heating degree days) than the 1983-84 period (7,751 heating degree days) in total and for every month except March and May. Even with the colder outside temperature for the 1984-85 August through May period the Witter Animal Science Center used less heating oil (12,700 gallons) than the previous August through May period (15,480 gallons).

TABLE B.1

Gallons of Heating Oil Used at the University of Maine Witter Farm and Bangor, Maine Heating Degree Days for August Through May, 1983-84 and 1984-85

	Gallons			Heating Degree Days		
Month	1983-84	1984-85	Difference	1983-84	1984-85	Difference
August	500	100	400	26	61	35
September	700	600	100	173	343	170
October	600	650	-50	578	633	55
November	1,400	850	550	829	906	77
December	3,600	1,500	2,100	1,273	1,286	13
January	2,250	3,000	-750	1,516	1,680	164
February	2,130	2,200	-70	1,019	1,206	187
March	2,100	2,100	0	1,210	1,126	-84
April	1,500	1,100	400	687	758	71
May	700	600	100	440	422	-18
Total	15,480	12,700	2,780	7,751	8,421	-670

A method to account for heating oil consumption differences due to heating degree day differences before-digester oil consumption was estimated as a function of heating degree days. Using ordinary least squares regression on data for the 12 month period prior to the operation of the digester the following relation between heating oil consumption (GALLONS) and heating degree days (DEGDAY) was estimated:

$$\text{GALLONS } 236.86 + 1.696 \text{ (DEGDAY)}$$
$$(.95) \quad (5.64)$$
$$\text{F-Statistic} = 31.77 \quad R^2\ .76$$

The F-Statistic, coefficient of determination (R^2), and estimated coefficient t-statistic (in parenthesis) are given. The estimation relation is statistically significant at the 95 percent level and the model explains 76 percent of the total variation in heating oil consumption over the twelve month estimation period (August 1983 through July 1984). This relationship was used to estimate what heating oil consumption would have been over the August through May 1984-85 period had the digester system not been in place. Table B.2 presents actual and estimated (without digester) heating oil consumption.

TABLE 8.2

Gallons of Heating Oil Used at the University of Maine Witter Farm, No-digester Estimated Oil Consumption, and Differences, by Month for August Through May, 1984-85

Month	No-digester Estimated Oil Consumption	Actual Consumption	Difference
August	340	100	240
September	819	600	219
October	1,310	650	660
November	1,773	850	923
December	2,418	1,500	918
January	3,086	3,000	86
February	2,282	2,200	82
March	2,147	2,100	47
April	1,522	1,100	422
May	953	600	353
Total	16,651	12,700	3,951

The estimated oil savings due to the digester for the August through May period equal 3,951 gallons when adjusted for heating degree days. This is 1,171 gallons more than the oil savings estimate which did not take heating degree days into account. The actual 1984-85 oil savings need to include oil savings for June and July. During these months the digester oil savings were estimated in the following manner. In the beginning of July 1985 a BTU meter was installed to measure heat sent to the hot water storage tank. The average heat savings for the heat sent to the storage tank for the first half of July 1985 equaled 6.2 gallons per day fuel oil equivalent. Using this daily savings average one can estimate the fuel oil savings for June and July 1985 which was 378.2 gallons. Thus the estimated annual total oil savings equals the August through May 3,951 gallons plus the June and July 378.2 gallons for a total of 4,329.2 gallons.