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Abstract

Considerable attention has recently been focused on the development of farm management practices that utilize the total resource potential of animal wastes. In addition to the fertilizer value of manure, energy in the form of bio-gas can be generated from manure wastes by an anaerobic digestion process. The purpose of this economic analysis was to evaluate the feasibility of producing energy from the anaerobic digestion of dairy-cow manure. Anaerobic digestion systems were rationally designed for several farm management practices on Vermont dairy farms. These designs were sized to accommodate dairy herds of 20, 50, 100, and 200 cows for both free- and tie-stall arrangements.

The realistic evaluation of the potential of any energy source must include a cost effectiveness analysis. This 1974 economic analysis, with selected 1977 cost updatings, included considerations of both the total annual financial investment and the unit cost of net energy production. Minimum unit costs of net energy production for 1977 prices are approximately \$0.19 per kwh for the 20-cow operation, but these values decrease with increasing herd size to \$0.05 per kwh for the 200-cow dairy farm. At the present time, the generation of bio-gas from the anaerobic digestion of dairy farm manures becomes economically feasible as an alternate source of energy for dairy farms in excess of 200 cows.

1. INTRODUCTION

Sources of alternative energy, such as wind, animal wastes, sun, etc., are currently being proposed to alleviate the pending fuel crisis. Although these sources afford a possible means of augmenting primary energy supplies, little attention has been devoted to the economic feasibility of these energy developments. The realistic evaluation of the potential of any energy source must include a cost effectiveness analysis.

Interest in farm animal wastes as a source of pollution to both surface and ground waters has emerged over the past decade. Because extremely cheap commercial fertilizers and power were readily available, these wastes were viewed by many farmers as a nuisance and often were treated as materials with little value. More stringent environmental controls, greater numbers of animals per farm, and widespread urban sprawl have produced the problem of the management of manures for many farmers.

With the rapid upward trend in fertilizer and farm energy costs, activity has been generated in the development of systems which can efficiently utilize the fertilizer and the energy potential of cow manure. One technique for extracting energy from cow manure is the anaerobic digestion process to generate bio-gas, a gaseous mixture containing methane with an approximate energy value of 600 Btu per cu ft. The fertilizer potential of the manure appears to be enhanced as a result of the digestion process.

The effects which climate and farm management procedures practiced on Vermont dairy farms have on the feasibility of using anaerobic digestion to produce energy from manure are not known. Therefore, a research project was conducted at the University of Vermont to determine a technically feasible anaerobic digestion system which is compatible with dairy farm management practices in Vermont. This report summarizes the assessment of the economic feasibility of these anaerobic digestion systems as an energy source for Vermont dairy farms. (3)

Although proper designs for a bio-gas system can be developed with existing technology, economic analyses are necessary to establish the cost effectiveness of each system designed to generate an alternative source of energy. The economic determinations in this feasibility evaluation involved the monthly cost for owning and operating each system and the unit cost of the net available bio-gas.

A properly designed anaerobic digestion system that is economically feasible provides the following potential benefits to dairy farmers:

(1) Reduction in cost for farm energy and increase in self-sufficiency for the farm operation,
(2) Provision of greater positive control of animal manure handling to minimize water pollution,
(3) Reduction of insect and odor problems that are associated with the application of untreated manure on the land, and
(4) Greater utilization of the manure in the conservation of energy and nutrients.

2. PROCEDURE

Because dairy farmers practice different farm management procedures, manures from Vermont dairying operations contain varying quantities and types of bedding materials. However, average quantities and characteristics of dairy cow manure were estimated for both tie-stall and free-stall operations on Vermont dairy farms. These 'average' manures form the basis for a generalized economic feasibility analysis of various anaerobic digester designs. Actual values should be determined and used for sizing the design of a bio-gas system for an individual farm.

Various designs were prepared for an anaerobic digestion system for the production and storage of bio-gas. The schematic diagram in Figure 1 illustrates the major components of the manure digestion system. The system was arranged to function with the farm management procedures that are currently practiced on many Vermont dairy farms. Because bedding and waste feed cannot be separated in a practical manner from urine and feces, the digester was sized to accommodate all wastes in the manure. The bio-gas system was designed to maximize reliability, to meet various safety regulations, and to minimize energy requirements for sustaining digester operation.

The outputs of the anaerobic digester system include the following components:

(1) Bio-gas that is generated at an average rate of about 70 cu ft per day for each contributing cow and has an energy value of approximately 600 Btu per cu ft

and

(2) Digested manure that is produced at an average rate of about 150 lb per day for each cow.

The digested manure is a slurry that contains approximately 92 percent of moisture and requires management by liquid-handling techniques.

2.1 DESIGN ELEMENTS

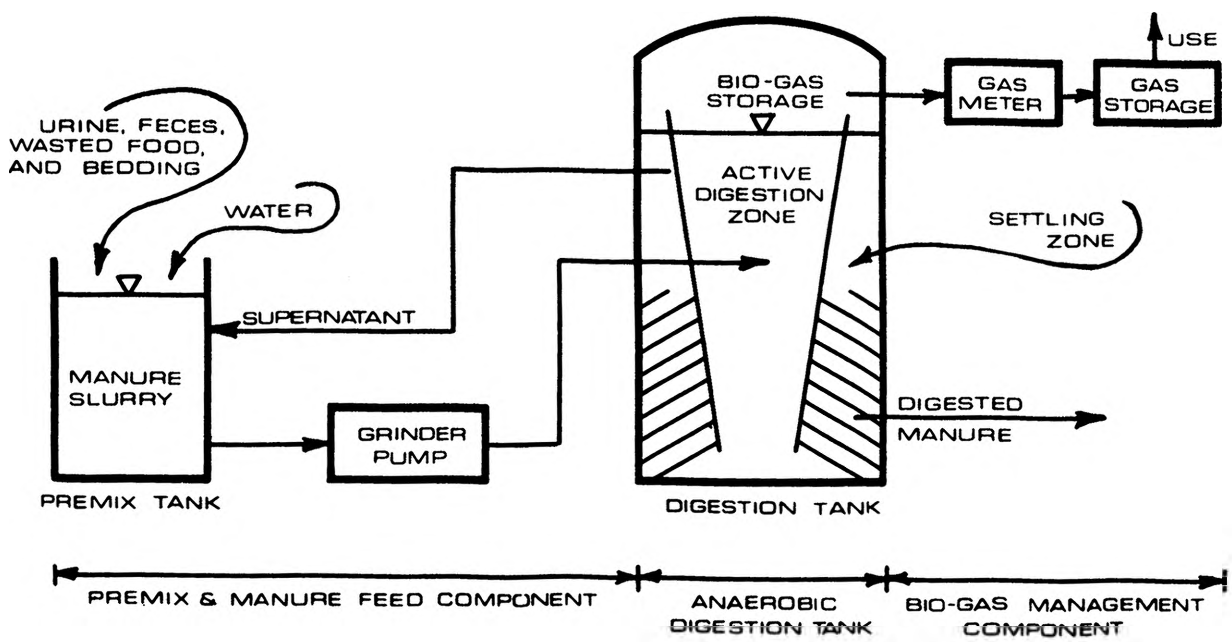
The following components were properly sized for various designs of the anaerobic digestion system:

(1) Premix and manure-feed unit,
(2) Digestion tank, and
(3) Bio-gas handling facility.

System designs were developed for farm operational sizes of 20, 50, 100, and 200 cows with both tie- and free-stall arrangements. In addition, the following design elements were evaluated in the research project:

(1) Digester operating temperature:
   (a) 68 F and
   (b) 95 F; and
(2) Digestion tank arrangement:
   (a) In-ground wood tank, steel top, top only insulated,
   (b) In-ground steel tank, steel top, top only insulated,
   (c) In-ground concrete tank, steel top, top only insulated,
   (d) In-ground wood tank, steel top, fully insulated, and
   (e) On-ground wood tank, steel top, fully insulated.

Designs of the various system components were developed, energy analyses were performed, and economic feasibility studies were conducted for all combinations of varying farm size, herd management, digester operating temperature, and digestion tank arrangements. However, this paper is



SCHEMATIC OF ANAEROBIC DIGESTION SYSTEM

FIGURE 1

limited to the results of the economic analyses. Detailed descriptions of the technical aspects of this bio-gas system study are contained in the complete research report. (3)

2.2 ECONOMIC CONSIDERATIONS

Economic analyses are essential for establishing the cost effectiveness of a properly designed anaerobic digestion system as a producer of bio-gas energy for Vermont dairy farms. The selected economic feasibility evaluations include the following cost determinations:

(1) Monthly cost for construction, maintenance, and operation of the bio-gas system and
(2) Unit cost of the net bio-gas that is available as a source of energy for use on the farm.

The monthly cost indicates the magnitude of the investment that is required for owning and operating a bio-gas system for average conditions on a Vermont dairy farm. On the other hand, the unit cost of the net available bio-gas reflects the comparative economic utility of this alternate source of farm energy. Cost calculations were based on the yearlong operation of the digester and on the daily processing of all manure from the dairy herd.

Detailed estimates were prepared for the initial cost and for the annual maintenance and operational costs of each alternative design. (5) The initial or construction costs were then expressed as annual capital costs that are based on an interest rate of 9.5 percent and the following selected economic lives for the various capital items in the bio-gas system:

(1) Twenty years:
  (a) Excavation
  (b) General electrical,
  (c) Premix tank, and
  (d) Digestion tank (bottom, sides, steel roof, interior cone, and insulation); and
(2) Ten years:
  (a) Pump-grinder,
  (b) Piping and valving,
  (c) Digestion tank (piping and fittings),
  (d) Digester heating system (controls, boiler, and hot water piping), and
  (e) Bio-gas management system (compressor, gas meter, gas-feedback system, piping, valving, and fittings).

Annual maintenance costs were assumed as 1 and 2 percent, respectively, of the initial cost for components that have 20- and 10-year economic lives.

Operational costs include insurance, taxes, labor charges, and electrical and water expenses. Insurance premiums were computed at $17.50 per year per $1000 of initial cost. Taxes were based on a typical tax rate of $60.00 per year per $1000 of assessed value, which is assumed as one-third of the initial cost.

Water usage was charged at $5.00 per month for 20- and 50-cow operations, at $7.50 per month for a 100-cow farm, and at $10.00 per month for a farm with 200 cows. The cost of electricity was selected at $0.03 per kwh. Farm labor charges were established at $2.25 per hour and were assigned to operation of the bio-gas system in accordance with the following schedule: 1.5, 2.0, 2.5, and 3.0 hours per day, respectively, for 20-, 50-, 100-, and 200-cow farms.

Both annual and monthly costs were utilized in the various cost effectiveness evaluations. Although annual costs are usually employed in economic studies, financial transactions for dairy farms are

TABLE 1 - Summary of Economic Analyses for
68 F In-Ground Wood Tank, Steel Top, Top Only Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	499.23	689.65	1002.19	1704.36
Maintenance ($/month)	52.46	70.20	99.85	167.69
Operational ($/month)	274.28	365.53	538.80	786.67
Total Cost ($/month)	825.97	1125.38	1640.84	2658.72
Total Cost ($/year)	9911.64	13,504.56	19,690.08	31,904.64
Total Cost per Cow ($/cow/month)	41.30	22.51	16.41	13.29
Total Cost per Cow - 1977 ($/cow/month)	45.43	24.76	18.05	14.62
Net Gas (Btu/year)	165.5×10^6	465.9×10^6	991.7×10^6	2078.7×10^6
Net Gas (kwh/year)	4.85×10^4	1.37×10^5	2.91×10^5	6.09×10^5
Gas Cost ($/kwh)	0.204	0.099	0.068	0.052
Gas Cost - 1977 ($/kwh)	0.224	0.109	0.075	0.057

TABLE 2 - Summary of Economic Analyses for
68 F In-Ground Steel Tank, Steel Top, Top Only Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	560.25	715.98	932.73	1389.46
Maintenance ($/month)	57.73	72.47	93.85	140.49
Operational ($/month)	294.02	374.06	516.30	684.67
Total Cost ($/month)	912.00	1162.51	1542.88	2214.62
Total Cost ($/year)	10,944.00	13,950.12	18,514.56	26,575.44
Total Cost per Cow ($/cow/month)	45.60	23.25	15.43	11.07
Total Cost per Cow - 1977 ($/cow/month)	50.16	25.58	16.97	12.18
Net Gas (Btu/year)	147.0×10^6	431.4×10^6	937.0×10^6	1991.7×10^6
Net Gas (kwh/year)	4.31×10^4	1.26×10^5	2.75×10^5	5.84×10^5
Gas Cost ($/kwh)	0.254	0.111	0.067	0.046
Gas Cost - 1977 ($/kwh)	0.279	0.122	0.074	0.051

normally conducted on a monthly basis.

3. RESULTS

The application of exisiting technology permits the generation of bio-gas from dairy manures. Because of freezing winter conditions in Vermont, systems designed to receive manure from free-stall operations do not generate bio-gas in excess of these amounts that are required to heat the digesters during the cold months. However, the production of bio-gas in quantities that are sufficient for use as an alternative energy source is potentially feasible for digesters which receive manure from tie-stall operations and which operate at temperatures of 95 F or less. Therefore, the economic analyses were only performed for bio-gas system designs of various construction arrangements for digester operating temperatures of 68 and 95 F and for tie-stall operations involving 20, 50, 100, and 200 cows. All cost determinations are based on yearlong operation of the tie-stalls, so that manure is collected and added to the digester daily.

The cost data represent 1974-price conditions, except for certain indicated summary values which are also expressed in 1977 dollars. A multiplying factor of 1.1 was utilized for the three-year inflation adjustment. (4)

3.1 MONTHLY SYSTEM COSTS

To determine the financial commitment that is required for a bio-gas system, the total monthly cost was calculated for the selected design conditions that are potentially practical in the Vermont environment. The total cost per month represents the amortization of the initial capital investment and the necessary maintenance and operational charges.

The total monthly costs are summarized in Tables 1 through 6 for selected system designs. Summaries of the economic analyses are presented for all digestion tank arrangements with an operating temperature of 68 F, while only the design with the lowest monthly cost is summarized for the bio-gas systems that operate at 95 F. The bio-gas system that involves the lowest monthly cost to the dairy farmer is the 95 F in-ground wood tank, steel top, top only insulated arrangement, as shown in Table 6, for all dairy herd sizes that were investigated with tie-stall operation. Economies of scale are clearly indicated by the decreasing total monthly cost per cow with increasing size of dairy herd. These investments range from \$11.07 to \$39.48 per cow per month for dairy farm operations of 200 and 20 cows, respectively, in terms of 1977 costs.

3.2 ANNUAL UNIT COSTS OF BIO-GAS

The economic feasibility of the various system designs is conveniently evaluated by determining the unit costs of the net energy that is available for use on the dairy farm. These unit cost values on an annual basis are presented in Table 1 through 6 for selected design alternatives with the tie-stall arrangement. Those designs that yield the minimum unit costs of net energy are:

(1) For 20- and 50-cow operations - 68 F in-ground wood tank, steel top, fully insulated (Table 4);
(2) For 100-cow operation - 68 F on-ground wood tank, steel top, fully insulated (Table 5); and
(3) For 200-cow operation - 68 F in-ground steel tank, steel top, top only insulated (Table 2).

For 1977 prices, these minimum unit-cost designs range from \$0.188 to \$0.051 per kwh in the unit cost of the net available bio-gas for the 20-cow and the 200-cow dairy operations, respectively. These unit costs represent the conditions of system operation throughout an average

TABLE 3 - Summary of Economic Analyses for
68 F In-Ground Concrete, Steel Top, Top Only Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	642.62	1013.81	1395.82	2121.13
Maintenance ($/month)	64.85	98.20	133.85	203.69
Operational ($/month)	320.72	470.53	666.29	921.67
Total Cost ($/month)	1028.19	1582.54	2195.96	3246.49
Total Cost ($/year)	12,338.28	18,990.48	26,351.52	38,957.88
Total Cost per Cow ($/cow/month)	51.41	31.65	21.96	16.23
Total Cost per Cow - 1977 ($/cow/month)	56.55	34.82	24.16	17.85
Net Gas (Btu/year)	161.9×10^6	459.2×10^6	981.1×10^6	2061.6×10^6
Net Gas (kwh/year)	4.74×10^4	1.35×10^5	2.87×10^5	6.04×10^5
Gas Cost ($/kwh)	0.260	0.141	0.092	0.064
Gas Cost- 1977 ($/kwh)	0.286	0.155	0.101	0.070

TABLE 4 - Summary of Economic Analyses for
68 F In-Ground Wood Tank, Steel Top, Fully Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	543.12	770.69	1251.44	1908.16
Maintenance ($/month)	56.25	77.20	121.38	185.29
Operational ($/month)	288.49	391.77	619.52	852.70
Total Cost ($/month)	887.86	1239.66	1992.34	2946.15
Total Cost ($/year)	10,654.32	14,875.92	23,908.08	35,353.80
Total Cost per Cow ($/cow/month)	44.39	24.79	19.92	14.73
Total Cost per Cow - 1977 ($/cow/month)	48.83	27.27	21.91	16.20
Net Gas (Btu/year)	212.5×10^6	551.8×10^6	1128.2×10^6	2295.2×10^6
Net Gas (kwh/year)	6.23×10^4	1.62×10^5	3.31×10^5	6.72×10^5
Gas Cost ($/kwh)	0.171	0.092	0.072	0.053
Gas Cost - 1977 ($/kwh)	0.188	0.101	0.079	0.058

TABLE 5 - Summary of Economic Analyses for
68 F On-Ground Wood Tank, Steel Top, Fully Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	535.89	753.80	1099.39	1847.87
Maintenance ($/month)	55.63	75.74	108.24	180.08
Operational ($/month)	286.15	386.30	570.28	833.17
Total Cost ($/month)	877.67	1215.84	1777.91	2861.12
Total Cost ($/year)	10,532.04	14,590.08	21,334.92	34,333.44
Total Cost per Cow ($/cow/month)	43.88	24.32	17.78	14.31
Total Cost per Cow - 1977 ($/cow/month)	48.27	26.75	19.56	15.74
Net Gas (Btu/year)	202.8×10^6	536.7×10^6	1099.9×10^6	2250.0×10^6
Net Gas (kwh/year)	5.94×10^4	1.57×10^5	3.22×10^5	6.59×10^5
Gas Cost ($/kwh)	0.177	0.093	0.066	0.052
Gas Cost - 1977 ($/kwh)	0.195	0.102	0.073	0.057

TABLE 6 - Summary of Economic Analyses for
95 F In-Ground Wood Tank, Steel Top, Top Only Insulated
1974 Cost Data Except As Noted
Tie-Stall Operation

	20-Cow	50-Cow	100-Cow	200-Cow
Expenses on Initial Investment ($/month)	433.96	582.03	799.81	1283.69
Maintenance ($/month)	46.32	61.23	82.37	131.35
Operational ($/month)	236.97	331.28	439.52	596.04
Total Cost ($/month)	717.75	974.54	1321.70	2011.08
Total Cost ($/year)	8613.00	11,694.48	15,860.40	24,132.96
Total Cost per Cow ($/cow/month)	35.89	19.49	13.22	10.06
Total Cost per Cow - 1977 ($/cow/month)	39.48	21.44	14.54	11.07
Net Gas (Btu/year)	57.3×10^6	207.9×10^6	485.0×10^6	1093.5×10^6
Net Gas (kwh/year)	1.68×10^4	6.09×10^4	1.42×10^5	3.20×10^5
Gas Cost ($/kwh)	0.513	0.192	0.112	0.075
Gas Cost - 1977 ($/kwh)	0.564	0.211	0.123	0.082

year.

Although the 95 F in-ground wood tank, steel top, top only insulated arrangement requires the lowest monthly expenditure for a bio-gas system, the lower operating temperature of 68 F increases the net available energy during the year. As a result, the unit cost of net available energy is reduced with bio-gas systems that operate at 68 F.

If the investment in a bio-gas system can be programmed, then only dairy farms of the 200-cow size begin to provide the opportunity for generating bio-gas at a unit cost that approaches the present charge for electrical energy in Vermont. The unit costs for bio-gas produced with the 20-, 50-, and 100-cow dairy operations exceed the present prices of electricity and of various petroleum sources of energy.

4. CONCLUSIONS

Various design, energy, and economic recommendations were developed in the study of bio-gas systems for Vermont dairy farm generations. (3) However, the following conclusions generally pertain to the results of the various economic analyses.

(1) The low temperatures that are experienced during the winters in Vermont have an overriding influence on the feasibility of bio-gas generation for use as an alternate energy source. Uninsulated digesters do not produce enough bio-gas during the winter to maintain the required operating temperature.

(2) Well insulated anaerobic digestion systems that are designed to accommodate dairy manure from free-stall operations do not produce enough bio-gas to sustain digester operation during the freezing winter months.

(3) Digester systems that are well insulated and designed to receive manure from tie-stall operations generate excess bio-gas during the cold weather that is expected in Vermont.

(4) The lowest unit costs for net available bio-gas range from $0.188 to $0.051 per kwh in 1977 dollars, respectively, for the 20-cow and the 200-cow dairy operations.

(5) At the present time, only dairy farms of the 200-cow size approach the economies of scale for generating bio-gas at a unit cost that closely approaches the present charge for electrical energy in Vermont. The unit costs for bio-gas produced with the 20-, 50-, and 100-cow dairy operations exceed the current prices of electricity and of various petroleum sources of energy.

Other evaluation studies have provided similar findings in regard to the economic feasibility of bio-gas systems as an alternative energy source. The production of bio-gas from hog manure is presently not economical in comparison with current prices for fossil fuels and on an operational scale of 100 to 500 animals for farms in the southwestern portion of Ontario, Canada. (1)

Another economic study involved the anaerobic digestion of dairy cow manure in the State of Washington. (2) Economic feasibility is only realized when the size of the dairy herd reaches approximately 400 cows. This finding is in reasonable agreement with the results that are presented in this report for dairy farms in the Vermont environment.

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6. BIOGRAPHIES

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