ENERGY RESOURCE POTENTIAL FROM ANIMAL WASTES IN IOWA

PREPARED FOR IOWA ENERGY POLICY COUNCIL

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SUMMARY AND CONCLUSIONS

With the current world economic situation and the large amounts of energy imported by the U.S., every reasonable avenue for increasing domestic energy production needs to be explored, especially renewable sources currently justified economically. Assessing the potential of animal wastes as an energy source is timely. If economically feasible, energy produced by anaerobic digestion would add to our supply of energy while providing economic benefits to the agricultural segment of American industry.

Anaerobic digestion is a biological process in which organic matter is converted to biogas--a mixture of methane and other gases, primarily carbon dioxide. This process is widespread in nature. Animal wastes, as well as industrial and human wastes, are suitable materials for use in digesters because their value is relatively low while their disposal cost is often high. In Iowa, potential source species for animal waste recovery and digester use are swine, beef cattle, dairy cattle, poultry and sheep.

Methane production from livestock manures is technically feasible. For a methane generation system to be successful, certain requirements must be met including:

- availability of raw materials to meet the production requirement;
- ability to use the gas when produced;
- adequate maintenance and operational control;
- sufficient demand for the gas; and,
- acceptance by potential users.

Animal Waste Inventory

The total waste production by hog, beef cattle, dairy cattle and poultry operations is identified for each Iowa crop and livestock reporting district by type and size of operation. Waste recoverable and suitable for use in digesters with current management practices is estimated to be:

	Iowa Animal Waste	
	Recoverable (1,000 T/yr)	Suitable for digesters (1,000 T/yr)
Hog	14,000	12,000
Beef cattle	33,000	3,000
Dairy	6,000	6,000
Poultry	300	260

Technology

Typical continuous digester systems, designs, construction materials and characteristics are described. The primary factors that influence digester performance--slurry composition, chemical parameters such as pH, temperature, agitation, retention time, solids concentration and loading rate--are discussed. Five companies that produce anaerobic digester systems for farm animal waste application were identified and contacted.

A total of twelve operational on-farm digesters located throughout the U.S. were identified. The type of waste used, the digester size, biogas and by-product uses and the current status are described.

Model Farm Operations

Four representative model digesters were developed on the basis of the analysis of the sizes and types of livestock operations in Iowa. The model farms and operations used for the analysis of the feasibility of biogas production are:

- a 70-sow swine operation farrowing twice a year;
- a 200-cow dairy operation;
- a 200-sow swine operation farrowing weekly or biweekly;
- a cooperative venture comprised of three, 75-cow dairies and six, 70-sow swine operations farrowing twice a year. A truck hauls the wastes daily to the central digester.

The total annual manure and seasonal variations in quantities are estimated.

The economic success of the biogas digester depends in part on matching the biogas production to beneficial uses. Potential uses include direct burning for space heating, crop drying, in stationary engines and engine/generators for production of electricity for own use or sale.

Farm energy demand for the model farms was estimated and compared to the energy produced by the digester. Although the swine digesters fail to provide the total on-farm energy needs in winter, excess energy is produced in the summer. With moderate biogas production levels, the 200-cow dairy digester could provide sufficient energy for on-farm needs year round.

Digester Designs

For purposes of assessing the feasibility of methane production on the model or representative farms, anaerobic digestion systems suitable for each are described. Manure production, design conditions, biogas and by-products production, and investment and operating and maintenance costs are estimated and tabulated in Tables 1 through 3.

Table 1. Characteristics of model digesters

	System 1	System 2A	System 2B	System 3
	70-Sow	200-Cow	200-Sow	Coop.
Manure production				
(lbs/day)	1,160-6,510	21,850	9,750	31,530-63,660
(avg. lbs/day)	3,410	21,850	9,750	45,072
Digester volume				
(ft^3)	1,337	5,660	3,650	13,400
(gal)	10,000	42,300	27,300	100,000
Retention time (days)	17-65	14	21	12-21
Biogas production				
(1,000 ft^3)	1.07-4.01	7.86-20.96	5.46-8.58	17.9-45.9
(avg.)	3,044			29.7
Energy value (mil. Btu/ day @ 600 Btu/ft^3)	1.83 (avg)	4.7-12.6	3.3-5.1	17.8 (avg.)
Digester heating requirement (mil. Btu/day)	0.5	1.2	0.9	2.5
Net energy production (mil. Btu/day)	1.33 (avg)	3.5-11.4	2.4-4.2	15.3 (avg.)
<u>By-Products</u>				
Liquid effluent				
(gal/day)	75-435	1,500	650	4,140-2,390
(50% recovery)	225 avg.			3,125 avg.
Solids				
(lbs/day)	57-330	1,575	460	3,500-6,055
(60% recovery)	165			4,580 avg.

Table 2. Investment and operating costs for on-farm digesters

	System 1	System 2A	System 2B
	70-Sow	200-Cow	200-Sow
Basic system ($) Digester Slurry feed equipment Installation or super-vision startup Solids separation equipment	27-35,000	65-100,000	45-75,000
Engine/generator ($) (size)	6-8,000 (7.5 kW)	25-30,000 (30 kW)	10-12,000 (12 KW)
Gas compression and storage ($)	---	20,000	20,000
Operating costs Labor ($/yr)	2,000	2,000	2,000
Maintenance (annual)	3% of investment	3% of investment	3% of investment
Electricity @ $.06/kWh ($) (kWh/day)	1,095 50	2,400-3,940 110-180	1,100 50
Digester heating ($) (million Btu/day @ $.50/gal propane equivalent)	1,040	2,500	1,872

Table 3. Investment and operating costs - cooperative operation

Capital costs	Gas compression for use at other locations	Electricity generation and sale	Sale of biogas as fuel substitute to nearby facility
	----------dollars----------		
Basic Components ($)	110,000	110,000	110,000
Digester Slurry Feed Eq. Solids/liquids Separation Installation & start up			
Gas compression	35,000		
Engine/generator Tie in (65 kW)		50,000	
Boiler mod. & piping			15,000
Solids/liquids & feed storage	10,000	10,000	10,000
Truck for pickup of manure	50,000	50,000	50,000
Total Capital Costs	205,000	220,000	185,000
Operating costs			
Labor-truck driver & operator (365 days)	47,000	47,000	47,000
Electric power	4,800 (220 KWh/day)	2,000 (90 KWh/day)	2,000 (90 kWh/day)
Maintenance	6,200	6,600	5,600
Digester heating (2.5 mil. Btu/day @ $.50/ gal propane equivalent)	5,200	5,200	5,200

Safety considerations are essential to the continued operation of a digester. Since the biogas produced is highly flammable and potentially explosive, precautions must be taken against fire and explosion in and around the digester. The two most important safety precautions are to avoid explosive mixtures of biogas and air by providing adequate ventilation and to prevent sparks.

A potential limitation, in addition to the collection costs, to the cooperative venture is identified. Diseases may be transmitted via the collection truck. The most serious concern is the possibility of transmitting TGE (transmissible gastroenteritis) among the swine herds. The possibility of transmission of other hog and cattle disease is much less likely. Sanitary procedures could be required that would reduce the possibility of disease transmission, but would increase collection cost.

Cost-Effective Systems

In conjunction with the assessment of the feasibility of the model digester systems, viable uses for the biogas or methane and the by-products are determined. Biogas or methane may be used in many standard boilers and water heaters with only minor modification of equipment, for grain drying, stationary internal combustion engines, and engine/generators for electricity production. The electricity generated may be used on-farm or sold to a utility. The energy produced by the cooperative operation could be used as the primary or a supplemental fuel for adjacent or nearby energy consuming factories or production plants such as a fuel ethanol production facility. For greatest efficiency, it is imperative that the biogas production be matched with the requirements of the energy-consuming unit.

To be cost-effective, the biogas produced must be competitively priced. The biogas would be competing against current propane costs of $5.70 per million Btu in Iowa, natural gas costs of $4.00 per million Btu and Iowa electricity costs averaging $0.06 per kWh.

Two by-products are produced--a liquid effluent and a solids residue. The by-product has fertilizer value essentially equivalent to that of the input manure. The liquid effluent contains over 50 percent of the nitrogen and the major portions of the phosphorus and potassium. The solids residue contains the remaining nitrogen and may be used as a fertilizer and soil conditioner. Other suggested uses are bedding and refeeding to beef cattle. The solids are unsuitable for dairy cattle, as the caloric requirements of a proper dairy cow ration preclude the inclusion of the solids. The solids are not beneficial to swine as they are monogastrics and cannot digest cellulose.

The feasibility of the four digester systems was assessed using a discounted cash flow method. In addition to the investment and operating costs, working capital, inflation rates, cost of capital, taxes and insurance were considered in the analysis. The full cost of biogas produced, which includes labor, electricity, maintenance, insurance, taxes, credit for by-products and the return of and return on the investment are summarized in Table 4.

Since precise biogas production and exact investment costs are unknown, a range of values are provided. Only for the 200-cow dairy under average to high biogas production and low to average investment costs is the full cost of the biogas competitive with propane today.

Barriers and Strategies

There are no environmental regulations dealing specifically with anaerobic digesters. Environmental regulations governing the disposal of digester wastes presumably will be similar to those dealing with manure handling and disposal. Presumably a cooperative operation would be subject to commercial solid waste regulations.

No state policies were identified that would directly prohibit, impede or specifically encourage installation of digesters solely for energy production purposes. However, if odor from a livestock confinement operation becomes a problem, the Iowa Environmental Quality Department requires some method of odor control. Since a digester is one possible control method, obliquely this might be considered a state policy that would encourage consideration of installation of a digester--but not primarily for energy production.

The only tax legislation identified concerns the property tax on alternative energy production facilities. If the energy produced is used by the property owner, the system is exempt from property tax. If some of the energy is sold, the tax would probably be prorated on the basis of the proportion sold, but to date no official ruling has been made.

Two Federal laws provide encouragement for alternate energy systems. The Public Utilities Regulatory Policy Act, among other provisions, stipulates that public utilities must accept power from small parallel electrical energy producers at the utility's avoided cost. These provisions make it possible for a digester owner to sell excess electricity generated to a utility. In Iowa, the digester operator is responsible for the interconnect cost. The operator may use part of the power generated and sell the remainder to the utility. The average price paid by utilities in Iowa is 2.5-3¢ per kWh. The Energy Tax Act of 1978 and the Windfall Profits Tax Act provide for a 10 percent energy investment tax credit for digesters through December 31, 1985, in addition to the permanent business investment tax credit of 10 percent.

State personnel and representatives of digester equipment companies say the only barrier they find to installing digesters is the state of the economy. No specific barriers to commercialization were identified.

Table 4. Full cost of biogas production under varying assumptions

	System			
	1	2A	2B	3
	70-Sow operation	200-Cow dairy	200-Sow operation	Cooperative
	----------------$ per million Btu--------------			
Assumptions				
High biogas yield Low Investment	11.60	4.30	6.45	12.90
High Yield with Electricity Generation	---	---	7.10	---
Average Biogas Yield Average Investment	---	5.90	9.20	---
Average unit with Electricity Generation	---	6.22	---	---
Low Biogas Yield High Investment	---	14.80	13.20	---

Recommendations

Since only very few operational digesters and quite limited operational data are available for small digesters suitable for on-farm use, we recommend first that some type of funding assistance be legislated to provide qualified university personnel and farmers aid in construction and most importantly monitoring of research and on-farm digester facilities. State funding assistance that would allow collection of sufficient technical and economic data could be of the following type:

- Grants
- Low interest loans or loan guarantees
- An extension and/or increase in the Energy Tax Credit beyond that provided by the Federal government.

Given the limited amount of good economic data and a relatively poor historical success rate for anaerobic digestion operations, the EPC should be selective in providing funding assistance. For example, farmer grantees should be solvent established farm operators who possess sound managerial and technical skills. Financial assistance should be given for construction and monitoring of digester and associated waste collection facilities, but not for the livestock and confinement building. Sound engineering and construction are essential, but monitoring of digester performance and costs are vital to an empirical assessment of on-farm digester operation. A stipulation of the funding assistance should be that these operations are a demonstration unit, open to inspection by interested individuals on some reasonable basis.

Examples of the types of data that are needed are:

- material and energy balances;
- the comparative investment and operating costs for underground and above ground digesters;
- optimum size generators for digesters with variable biogas production units; and,
- methods for integrating the digester into the total waste handling system.

Since the primary barriers identified are lack of sufficient detail data and poor economics for the small scale units, we feel recommendations concerning specific laws and bills other than for assistance in conducting research are premature.

After adequate technical, operating, and economic data are available, possible strategies for increasing the interest among farmers and for promoting investment in such facilities might take a variety of forms. We have listed several possible strategies.

- Establish a professional position or positions to coordinate the promotional and developmental activities of on-farm methane generation and act as a technical advisor to qualified groups.
- State sponsored workshops to disseminate information to targeted groups.
- Develop state tax incentive programs through the use of exemptions from certain taxes or through various tax credits.
- Develop grant or other assistance or incentive programs.
- Establish incentive programs for digester components manufacturers.

Conclusions

On the basis of the study, the following conclusions were made:

- Biogas or methane production by anaerobic digestion of animal wastes is technically feasible.
- If the digesters are analyzed totally on the basis of their energy production capabilities, with the investment and operating costs estimated, the operating conditions described and assuming a value equivalent to that for fertilizer for the digester residues, the full cost of production biogas is competitive with propane for the 200-cow dairy only. Even for this representative digester, the feasibility is questionable if the biogas production is less than the average value. If in a specific situation, the investment costs exceed the low to average values estimated, the cost of biogas produced would increase greatly. Only if the price of propane or other competitive energy source increases greatly will the biogas production in the other size digesters be cost effective even with optimum conditions.
- Grants or other incentives that would decrease the initial investment or operating costs would improve the situation.

Limitations

The study conclusions must be interpreted in terms of the limitations to the study. Major study limitations identified are:

- The cost-effective assessment was based on the digester's use as an energy production system. If, however, the value of the digester is in part considered an improved or alternative manure handling and disposal system, then credit can be given for this value and the economics of the digesters might improve.

- Data from working on-farm and small digesters are inadequate.

- The possibility of transmitting the swine disease (TGE) among cooperating swine operations probably precludes a cooperative venture that includes hog operations.

1.0 INTRODUCTION

Today's so-called (and temporary) energy glut is real in that current demand for crude is less than OPEC exporters would like to sell at current prices. That is in marked contrast to the mid-seventies when the "energy crisis" dominated the news media, showed the Western World inordinately dependent on OPEC nations, and resulted in OPEC price increases to approximately $39 per barrel of crude oil, ten times higher than a decade earlier. The price had dropped to $28 per barrel on the spot market by April 1982.

The current imbalance resulted from a combination of circumstances, including the rise in oil prices that helped bring about a major economic recession in the Western World. The recession reduced demand for high priced petroleum fuels as both industrial and private consumers began conservation practices and switched to cheaper fuel.

Such factors as the recovering world economy, increased demand for petroleum fuels in developing countries and the production decline now forecast for many established oil and natural gas fields indicate that the present "glut" is transitory and should not lead to complacency. Another possible consequential factor is the potential explosiveness of the Middle East situation.

It is, therefore, critical that U.S. consumers establish balanced energy use and production programs. Every reasonable avenue for increasing domestic energy production needs to be explored, especially renewable sources currently justified economically. Assessing the potential of animal wastes as an energy source is timely. If economically feasible, energy produced by anaerobic digestion would add to our supply of energy while providing economic benefits to the agricultural segment of American industry.

Anaerobic digestion, a biological process in which organic matter is converted to methane and carbon dioxide in the absence of air, is widespread in nature. It occurs in marine and freshwater sediments, flooded soils, landfills, and animal digestive systems.

At least three primary factors favor anaerobic digestion of animal wastes to produce methane:

- the high cost of energy, increasing the value of methane produced by anaerobic digestion as a substitute for other fuels;

- increasingly stringent environmental regulations increasing the cost of handling animal wastes on farms; and,

- the extensive experience with anaerobic digestion technology as applied to sewage sludge over the last 70 to 100 years.

Anaerobic digestion of many organic materials is a technically feasible way to produce biogas -- a mixture of methane and other gases, primarily carbon dioxide, in approximately 60/40 proportions -- the natural product of anaerobic digesters. Industrial, agricultural, and human wastes materials usually are the best substances for use in digesters because their value is relatively low while their disposal cost is often high. In Iowa, potential source species for animal waste recovery are swine, beef cattle, dairy cattle, poultry and sheep.

Iowa produces more hogs than any other state and in 1980 Iowa ranked third among the states in cattle and calf production and cattle slaughter. Iowa also has significant sheep and poultry industries. Livestock on farms in Iowa by class and by species for January 1, 1971, and for 1977-81 are shown in Table 1-1. The numbers in Table 1-1 indicate that Iowa's potential energy from animal wastes is large.

Some advantages of using animal wastes for biogas production via anaerobic digestion follow:

- Biogas, containing approximately 60 percent methane, has an energy value of 600 Btu per cubic foot (natural gas has 1,000 Btu per cubic foot).

- Organic content of digester residue is reduced and stabilized so final disposal reduces pollution.

- Digester liquid residue is an almost odorless, free-flowing liquid with nearly all of the fertilizing nutrients of the animal waste preserved.

- Neither rodents nor flies are attracted to the residue.

- The separated liquid has nutrient value for fertilizing fields.

- The solids can be used as a compost/soil conditioner, bedding material, or can be dried and fed to beef cattle.

Some disadvantages of anaerobic digestion of animal wastes, particularly for on-farm applications are:

- Equipment is complex and involves high initial investment.

- Daily feeding of digesters at controlled loading rates is desirable and may be difficult to achieve.

Table 1-1. Livestock: Number on farms, by class, by species - January 1, 1971, 1977-81

Specie and class	1971	1977	1978	1979	1980	1981
	------------------------thousand head------------------------					
Iowa						
All cattle	7,403	7,650	7,800	7,200	7,150	7,450
Beef cows and heifers that have calved	1,693	1,903	1,800	1,684	1,746	1,860
Milk cows and heifers that have calved	486	392	380	374	372	378
Beef replacement heifers 500+ pounds	249	199	187	163	186	203
Milk replacement heifers 500+ pounds	156	137	164	126	143	158
Other heifers 500+ pounds	788	1,071	1,170	1,110	980	1,020
Steers 500+ pounds	1,615	1,599	1,778	1,872	1,618	1,683
Bulls 500+ pounds	93	92	92	89	100	104
Steers, heifers, and bulls under 500 pounds	2,323	2,257	2,229	1,782	2,005	2,044
All hogs 1/	16,110	14,200	14,500	15,100	16,200	16,100
Kept for breeding	2,336	2,016	2,161	2,280	2,106	2,095
Market hogs	13,774	12,184	12,339	12,820	14,094	14,005
Under 60 pounds	4,752	4,836	4,936	5,115	5,440	5,672
60-119 pounds	3,623	3,180	3,369	3,500	3,820	3,431
120-179 pounds	2,851	2,303	2,245	2,424	2,819	2,801
180 pounds and over	2,548	1,865	1,789	1,781	2,015	2,101
All sheep	765	388	370	380	408	437
Sheep and lambs on feed	179	70	70	60	68	77
Stock sheep	586	318	300	320	340	360
Ewe lambs	83	38	39	64	60	65
Wether and ram lambs	5	9	10	21	19	22
Ewes 1 year or older	479	260	240	220	250	260
Rams and wethers 1 year or older	19	11	11	15	11	13
All chickens 1/, 2/	14,111	12,080	11,070	10,700	9,600	10,500

1/ December 1, preceding year.
2/ Excludes commercial broilers.
Source: Iowa Crop and Livestock Reporting Service, Iowa Agricultural Statistics, 1981.

- Energy is required to maintain digester temperature for optimum gas production, especially in cold climates.

- High standards of maintenance and management are required.

- Strict explosion-proof standards must be maintained.

- Some chemicals, if present in excessive quantities can inhibit the digestion process. Volatile acids concentration and pH may require monitoring and control.

- Digestion systems will reduce, but not eliminate, the solids content; digested liquid slurry remains a potential pollutant unless properly handled.

It is apparent from published reports that methane production from livestock manures is technically feasible and in some instances economically feasible 1/. For a methane generation system to be successful, certain requirements must be met. The following prerequisites for a successful biogas program were cited by the National Academy of Sciences 2/.

- availability of raw materials to meet the production requirement;

- ability to use the gas when produced;

- adequate maintenance and operational control;

- sufficient demand for the gas; and,

- acceptance by potential users.

A variety of types of digesters and auxiliary systems are reviewed. Factors affecting digester performance for the animal wastes of significance in Iowa (e.g. manures from beef cattle, dairy cows, and hogs) are examined. Another section of this report examines potential uses for biogas produced by the digesters. The economic feasibility of digesters in the size range suitable for on-farm and cooperative ventures in Iowa are investigated. Finally, policies, legislation, tax incentives, and possible barriers to construction and use of small scale rural digesters are discussed.

1/ Hashimoto, A. G. and Y. R. Chen, Economic Optimization of Anaerobic Fermenter Designs for Beef Production Units, Livestock Wastes: A Renewable Resource, the Proceedings of the 4th International Symposium on Livestock Wastes, 1980, pp. 129-132.

2/ National Academy of Sciences, Methane Generation from Humans, Animal and Agricultural Wastes, 1977.

2.0 ANIMAL WASTE INVENTORY

The first step in determining the feasibility of on-farm anaerobic digestion systems is to determine the quantities of wastes available and suitable for use. This section identifies total Iowa livestock waste production, recoverable waste, and recoverable wastes suitable for anaerobic digesters.

2.1 INTRODUCTION

Total waste production is defined as all waste produced by hog, beef cattle, dairy, and poultry operations in Iowa. These four were chosen because they show the greatest potential for energy-resource recovery. Because few sheep are raised in confinement, where they produce recoverable waste, and because data are lacking for turkey operations, sheep and turkeys are omitted from the analysis.

Quantities of recoverable wastes are estimated in the second step. Agricultural engineers indicate that even though waste recovered from a dirt lot can easily be used as crop fertilizer, it probably cannot be put to more sophisticated uses such as anaerobic digestion. Dirt and other impurities can create both biological and physical problems in a digester. Therefore, this analysis identifies two types of recoverable animal waste, hard-surface waste collected from confinement buildings or hard surface lots suitable for anaerobic digestion, and dirt-lot waste not suitable for anaerobic digestion. Finally, although waste produced in pasture areas is useful as fertilizer on the pasture land, such waste cannot be economically used for any other purpose. Thus, it is not considered recoverable.

Some farmers specialize in only certain phases of livestock operations, such as farrow to finish, farrow and sell feeder pigs, or buy feeder pigs and finish for market. Assuming that interregional livestock shipments cancel each other, regional estimates of waste production are not affected by farmers' decisions to specialize. The waste of one animal is simply distributed over more than one farm in the region. However, specialization affects estimates of available and recoverable waste for individual farms and is considered in this analysis.

2.2 METHOD OF ANALYSIS

2.2.1 Total Available Iowa Livestock Waste Production

Total livestock waste production by hog, beef cattle, dairy cattle, and poultry operations is identified for each Iowa crop and livestock reporting district in the state and by type and size of operation. All waste produced during the life cycle of the animal and waste produced by breeding or replacement stock are included. When necessary, adjustments are made to exclude waste from livestock bred and born outside Iowa until they arrive for finishing.

Total livestock waste production is estimated by summing the waste produced during each stage of an animal's development. The waste produced at a particular stage of development is calculated as the number of animals at that stage during the year, times the daily waste production per animal, times the number of days an animal is at that stage. The general form of the total waste (TW) production model is presented below (1).

$$TW_{lrs} = \Sigma_d \, N_{lrsd} \cdot W_{ld} \cdot T_{lsd} \qquad (1)$$

where

TW_{lrs} = Total available animal waste in pounds per year in region r, for livestock operation l, of size s.

N_{lrsd} = Number of head in livestock operation l, of size s, in region r, at stage of development d.

W_{ld} = Pounds of waste produced per head per day for livestock operation l, at stage of development d.

T_{lsd} = Number of days animals are in livestock operation l, of size s, at stage of development d.

2.2.2 Total Recoverable Iowa Livestock Waste

As with total livestock waste production, recoverable livestock waste is identified for hog, beef cattle, dairy cattle, and poultry by type and size of operation for each Iowa crop and livestock reporting district. Two types of recoverable waste are identified, hard-surface waste collected from confinement buildings or hard surface lots, and dirt-lot waste.

Both types of recoverable waste can be estimated by the same model. The recoverable waste model (2) is simply the total waste production model (1) with a recoverability factor. The waste recovery factor is a function of the livestock operation, type of confinement facilities, waste-recovery technologies used, and the farmer's management skills. Obviously these factors vary widely; still logical assumptions can be made to estimate reasonable average values for all the factors.

$$RW_{lrs} = \Sigma_d \, N_{lrsd} \cdot W_{ld} \cdot T_{lsd} \cdot R_{ld} \qquad (2)$$

RW_{lrs} = Total recoverable animal waste in pounds per year for livestock operation l, in region r, of size s.

R_{ld} = Percentage of animal waste recoverable for livestock operation l at stage of development d.

2.3 DATA

Data and assumptions used for analysis are presented in this section. Primary data sources are 1981 Iowa Crop and Livestock Reporting Service publications [1, 2], which are based on 1979 agriculture survey statistics, and the 1978 Census of Agriculture [3]. Area extension agents, farm management specialists, and farmers were consulted regarding typical livestock practices in each area of the state. Also, university extension animal scientists, agricultural engineers, and technical publications were consulted for waste-recovery data.

2.3.1 Hog Operations

Hog production data are given in Tables 2-1 and 2-2. It is assumed that sow conditioning, breeding, and gestation are primarily in pasture areas, while from farrowing through weaning, the sow and litter are housed in a confinement building. After their litters are weaned, the sows are returned to pasture for conditioning to be rebred, and the pigs are placed in confinement and fed until marketed. It is estimated that only 10 percent of all Iowa hogs are finished on dirt lots.

Sows usually are bred twice a year producing 7.5 weaned pigs per litter. If a farmer chooses not to breed twice a year, due to time, weather, or housing-space constraints, his sows can be sold to other farmers as breeding stock. Farmers usually farrow sows only 3 or 4 times, so about 25 percent of breeding stock is replaced per farrowing. Between breedings, boars are usually kept on pasture or in a lot where negligible waste accumulates.

Pigs born outside Iowa and brought in as feeder pigs ("in shipments") produced no waste in Iowa until after weaning. "In shipments" account for 7.2 percent of all hogs marketed from 1976-1980. Thus for each region, the number of hogs in the stages of development from sow conditioning through nursery pigs is reduced 7.2 percent. "Out shipments" of feeder pigs are considered negligible.

2.3.2 Beef Cattle Operations

Beef cattle production data for cow-calf operations in which the calves are kept and fed to market weight are given in Tables 2-3 and 2-4. It is assumed that cow conditioning, breeding, and gestation are primarily in pasture areas. The cow and calf usually remain in the pasture until the calf is weaned. While the calf is still with the cow, the cow is bred for next year's calf crop. The cows remain on pasture while the calves are weaned and brought into a lot for preconditioning and to recover from the stress of weaning. Usually the remainder of the calf's life is spent in the lot where the calf is fed various hay, silage, and grain rations for frame development and finishing. It is estimated that only 20 percent of Iowa cattle are confined for finishing in hard-surface lots.

Table 2-1. Stages of hog development, duration, weight, and daily wet-waste production

Stage	Average weight, lbs	Age, days	Duration, days	Wet-waste production, lbs/day
25% breeding stock replacement inventory	275		182.5	8.9
Sow conditioning	300		24.5	8.9
Breeding			14	
Sow	300			8.9
1 Boar/20 sows	350			11.0
Gestating sow	300		114	8.9
Pigs born		0		
Sow and litter	375	0-30	30	33.0
Weaning		30		
Nursery pig	35	30-67.5	37½	2.3
Growing pig	65	67.5-115	47½	4.2
Finishing hog	150	115-160	45	9.8
Finishing hog	200	160-200	40	13.0
Marketing	240	200		

Source: DPRA estimates.

Table 2-2. Slaughter hogs marketed during 1979 by region and size of operation 1/

Iowa region	Size of operation (Head) 1-99	100-199	200-349	350-499	500-999	>1000 2/	Total
Northwest	53,600	154,100	415,400	381,900	1,078,700	1,266,300	3,350,000
North Central	50,400	134,400	297,600	268,800	710,400	938,400	2,400,000
Northeast	87,000	210,000	408,000	369,000	924,000	1,002,000	3,000,000
West Central	66,700	162,400	403,100	362,500	890,300	1,015,000	2,900,000
Central	51,450	129,850	284,200	279,300	735,000	970,200	2,450,000
East Central	59,850	153,900	376,200	333,450	920,550	1,006,050	2,850,000
Southwest	43,400	112,000	252,000	217,000	415,800	359,800	1,400,000
South Central	52,110	103,062	195,702	155,172	319,608	332,346	1,158,000
Southeast	45,000	99,000	211,500	222,750	661,500	1,010,250	2,250,000
State Total	509,510	1,258,712	2,843,702	2,589,872	6,655,858	7,900,346	21,758,000

1/ Includes 7.2 percent "in shipments."

2/ Disclosure problems prevented the Iowa Crop and Livestock Reporting Service from providing additional data that would allow this category to be further subdivided.

Source: Based on Iowa Department of Agriculture, Iowa Crop and Livestock Reporting Service, Number and Size of Farms in Iowa, 1981.

Table 2-3. Stages of beef cattle development, weight, duration, and daily wet-waste production

Stage	Average weight	Age	Duration	Wet-waste production
	(lbs)	(days)	(days)	(lbs/day)
15% breeding stock replacement inventory	750		365	45
Breeding			30	
Cow	1,000			63
1 Bull/20 cows	1,500			50
Gestation	1,000		270	63
Calves born		0		
Cow & calf	1,250	0-215	215	75
(cow rebred)		65		
Calves weaned	500	215		
Calf preconditioning	500	215-245	30	30
Frame development	500	246-333	88	30
Finishing	750	334-422	88	45
Marketed	1,000	423-510	87	60

Source: DPRA estimates.

Table 2-4. Grain-fed beef cattle marketed during 1979 by region and size of operation

Iowa region	Size of operation (Head) 1-24	25-49	50-99	100-299	300-499	500+	Total
Northwest	10,640	17,480	37,240	147,440	108,680	438,520	760,000
North Central	8,600	10,800	19,200	55,400	38,600	67,400	200,000
Northeast	14,625	17,160	26,325	54,990	30,225	51,675	195,000
West Central	12,705	22,385	39,325	121,000	68,365	341,220	605,000
Central	10,880	18,240	24,000	71,680	45,440	149,760	320,000
East Central	12,285	22,365	34,020	89,775	49,770	106,785	315,000
Southwest	7,560	16,520	22,680	54,880	38,360	140,000	280,000
South Central	4,800	9,750	13,200	19,800	12,225	15,225	75,000
Southeast	8,260	13,860	20,580	45,920	20,020	31,360	140,000
State Total	90,355	148,560	236,570	660,885	411,685	1,341,945	2,890,000

Source: Based on Iowa Department of Agriculture, Iowa Crop and Livestock Reporting Serivce, Number and Size of Farms in Iowa, 1981.

To reflect a "minimum" amount of waste production, estimates for this cow-calf operation are relatively conservative. Large frame steers, fed to a higher market weight, would produce more waste due to their larger size, a slightly longer finishing period, and less efficient conversion. Also, some farmers feed yearling cattle on pasture longer to increase frame size. However, the total time the animal spends in lot confinement is very similar to the assumptions made for this study. Thus, available waste may increase slightly, but recoverable waste should remain about the same.

"In shipments" of feeder cattle are an important facet of the Iowa cattle industry. From 1976-1980, "in shipments" accounted for 61.8 percent of all cattle marketed in Iowa. Thus, the number of cattle in stages of development from breeding through calf preconditioning is reduced 61.8 percent.

Finally, it is assumed a 15 percent replacement herd (raised on pasture) is kept to replace old cows.

2.3.3 Poultry Operations

Poultry production and inventory data are given in Tables 2-5 and 2-6. In small operations, pullets are bought from a hatchery and raised in a brooder house and yard for about six months. At laying age, they are transferred to a confined laying house. After about 11 or 12 months, layers begin to molt and are replaced with a new batch of layers. Large operations use two growing techniques: about half buy pullets, place them in confinement brooder houses, and 6 months later transfer them to a confinement laying house; the other half buy hens "ready to lay" and immediately place them in a confinement laying house. "In shipments" account for a large share, approximately 75 percent, of "ready to lay" chickens, so the total number of chickens at the growing pullet stage for large scale operations is reduced 75 percent. As broilers are raised on litter and their wastes are unsuitable for digesters, they were not considered further in the analysis.

2.3.4 Dairy Operations

Dairy cattle production and inventory data are given in Tables 2-7 and 2-8. Two types of dairy cattle operations are identified: operations of fewer than 30 head are usually pasture oriented, while operations exceeding 30 head are hard-surface confinement oriented. In the small operations, it is assumed dairy cattle spend only 10 percent of their time in the milking parlor. Thus only 10 percent of their waste is considered to be produced in confinement. For the large operations, all of the animal's waste is assumed to be produced in a hard-surface confinement area.

Dairy operators usually replace milk cows 4 or 5 years after they are first milked. Thus, they must keep another 40 percent of dairy stock on pasture for replacement purposes.

Table 2-5. Stages of poultry development, weight, duration, and daily wet-waste production

Stage	Weight, lbs	Age, days	Duration, days	Wet-waste production, lbs/day
Pullets bought		5		
Growing pullet	2.0	5-185	180	0.14
Laying chicken	4.0	186-550	365	0.21
Hens sold		550		

Source: DPRA estimates.

Table 2-6. Hens and pullets of laying age December 1, 1979, by region and size of operation

Iowa region	Size of operation (Layers) 1-399	400-599	600-799	800-1,599	1,600+	Total
Northwest	83,700	21,600	8,100	16,200	1,220,400	1,350,000
North Central	50,875	19,250	6,875	15,125	1,282,875	1,375,000
Northeast	103,680	30,240	8,640	16,200	921,240	1,080,000
West Central	107,160	21,090	11,970	12,540	417,240	570,000
Central	64,750	12,250	5,250	8,750	1,659,000	1,750,000
East Central	87,420	15,345	2,790	19,995	339,450	465,000
Southwest	80,470	12,220	4,940	7,670	24,700	130,000
South Central	41,170	4,140	920	1,150	182,620	230,000
Southeast	88,500	9,000	3,750	15,000	633,750	750,000
State Total	707,725	145,135	53,235	112,630	6,681,275	7,700,000

Source: Based on Iowa Department of Agriculture, Iowa Crop and Livestock Reporting Service, Number and Size of Farms in Iowa, 1981.

Table 2-7. Stages of dairy cattle development, weight, duration, and daily wet-waste production

Stage	Weight, lbs	Duration, days	Wet-waste production, lbs/day
40% replacement inventory	750	365	61.5
Milk cow	1,400	365	115
1 Bull/20 cows	1,500	365	50

Source: DPRA estimates.

Table 2-8. Milk cows on Iowa farms January 1, 1980, by region and size of operation

Region	Size of operation (Head)						
	1-4	5-9	10-19	20-29	30-49	50+	Total
Northwest	216	396	2,916	4,752	10,008	17,712	36,000
North Central	216	336	2,280	4,344	7,704	9,120	24,000
Northeast	404	1,010	9,494	28,886	78,780	83,426	202,000
West Central	306	323	2,091	2,380	4,964	6,936	17,000
Central	270	270	1,095	1,650	3,960	7,755	15,000
East Central	352	440	3,212	5,852	14,124	20,020	44,000
Southwest	248	176	720	704	2,440	3,712	8,000
South Central	442	195	1,105	1,989	3,614	5,655	13,000
Southeast	494	299	1,690	1,508	2,808	6,201	13,000
State Total	2,948	3,445	24,603	52,065	128,402	160,537	372,000

Source: Based on Iowa Department of Agriculture, Iowa Crop and Livestock Reporting Service, Number and Size of Farms in Iowa, 1981.

2.3.5 Waste Recoverability Factors

Previous sections indicate the type of surface used for each livestock operation at each stage of development. During the life cycle of the animal, one or more of the following surfaces may be used: pasture land, dirt lots or hard surface lots and confinement buildings. Agricultural engineers agree that waste produced on pasture land is both physically and economically unrecoverable. Waste produced on dirt lots varies in recoverability, depending on the slope of the lot, percolation rate of the soil, rainfall amount and intensity, and management practices. Agricultural engineers recommend that in a dirt lot, the lower three to four inches of compacted waste and soil should remain undisturbed during waste removal. The compacted layer left reduces the mixing of soil and waste and retards liquid percolation. With all these factors taken into account, agricultural engineers estimate dirt lot waste recoverability as 50 to 80 percent. This study assumes 67 percent; however waste from dirt lots, although recoverable, is unsuitable for anaerobic digester use. Waste produced on hard surface lots and in confinement buildings is estimated to be 95 percent recoverable, with 5 percent lost during transfer and storage operations. These recovered wastes are suitable for use in anaerobic digesters.

2.3.6 Number of Farms Engaged in Livestock Production

Large scale livestock operations may be best suited to energy recovery technologies, because they can take advantage of economies of scale, and because they generate a more uniform flow of recoverable waste. The 1978 Census of Agriculture was used to identify the number of Iowa farms engaged in each size of operation, as shown in Tables 2-9 through 2-12.

2.4 SUMMARY OF RESULTS

Total waste production, recoverable waste, and waste suitable for anaerobic digestion are reported for each livestock operation by region and size of operation. Maximum and minimum daily recoverable waste production levels per animal also are estimated.

2.4.1 Hog Operations

Tables 2-13 and 2-14 present total waste production and recoverable waste for hog operations. Of the 17 million tons of hog waste produced annually in Iowa, nearly 14 million tons is estimated to be recoverable. Assuming that 90 percent of total recoverable waste (Table 2-14) is from hard-surface confinement, total hog waste suitable for anaerobic digestion is estimated to be approximately 12 million tons annually.

Recoverable hog waste is fairly evenly distributed across the state except that the southwest and south-central districts produce only about half as much waste as other districts. As expected, waste production is concentrated in the large scale operations (see Table 2-14).

Table 2-9. Number of Iowa farms marketing hogs by size of operation

Size category (head marketed per farm)	Number of farms
1-24	4,743
25-49	4,273
50-99	7,790
100-199	11,794
200-499	19,342
500-999	9,288
1,000-1,999	3,423
2,000-4,999	775
5,000+	129
Total	61,557

Source: U.S. Department of Commerce, 1978 Census of Agriculture.

Table 2-10. Number of Iowa farms marketing beef cattle by size of operation

Size category (cattle per farm)	Number of farms
1-9	5,296
10-19	5,240
20-49	8,915
50-99	5,506
100-199	3,934
200-499	2,997
500-999	911
1,000-2,499	326
2,500+	83
Total	33,208

Source: 1978 Census of Agriculture, Department of Commerce, Iowa Agricultural Statistics, 1981.

Table 2-11. Number of Iowa farms with poultry by size category

Size category (laying hens) 1/	Number of farms
1-99	7,159
100-399	2,723
400-1,599	544
1,600-3,199	40
3,200-9,999	201
10,000-19,999	120
20,000-49,999	59
50,000-99,999	17
100,000+	4
Total	10,867

1/ January 1 inventory.

Source: 1978 Census of Agriculture, U.S. Department of Commerce.

Table 2-12. Number of Iowa farms with dairy by size category

Size category (milking cows) 1/	Number of farms
1-2	2,544
3-4	370
5-9	673
10-19	1,868
20-49	5,486
50-99	1,749
100-499	186
500+	2
Total	12,878

1/ January 1 inventory.

Source: 1978 Census of Agriculture. U.S. Department of Commerce.

Table 2-13. Estimated annual hog waste production by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-99	100-199	200-349	350-499	500-999	> 1,000	Total
Northwest	43	123	331	304	860	1,009	2,669
North Central	40	107	237	214	566	748	1,912
Northeast	69	167	325	294	736	798	2,390
West Central	53	129	321	289	709	809	2,311
Central	41	103	226	223	586	773	1,952
East Central	48	123	300	266	733	802	2,271
Southwest	35	89	201	173	331	287	1,116
South Central	42	82	156	124	255	265	923
Southeast	36	79	169	177	527	805	1,793
STATE TOTAL*	406	1,003	2,266	2,064	5,303	6,295	17,337

* Totals may not add due to rounding.

Source: DPRA estimates.

Table 2-14. Estimated annual recoverable hog waste by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-99	100-199	200-349	350-499	500-999	> 1,000	Total
Northwest	34	97	262	241	680	798	2,111
North Central	32	85	188	169	448	591	1,512
Northeast	55	132	257	233	582	631	1,890
West Central	42	102	254	228	561	640	1,827
Central	32	82	179	176	463	611	1,544
East Central	38	97	237	210	580	634	1,796
Southwest	27	71	159	137	262	227	882
South Central	33	65	123	98	201	209	730
Southeast	28	62	133	140	417	637	1,418
STATE TOTAL*	321	793	1,792	1,632	4,194	4,978	13,710

*Totals may not add due to rounding.

Source: DPRA estimates.

Daily waste recovery for once-a-year farrowing and finishing on a hard surface lot is 4.2 pounds per pig from a sow and litter, only 2.2 pounds after weaning, but increases to 12.4 pounds by marketing. After the hogs are sold, no waste is recovered for six months until the next farrowing. When farrowing is twice a year, the waste cycle is repeated every six months, but remains uneven. Farrowing every month in a large confinement operation evens out daily waste recovery at 6.4 pounds per pig.

2.4.2 Beef Cattle Operations

Tables 2-15 and 2-16 present total waste production and recoverable waste for beef cattle operations. Although more than 33 million tons of beef cattle waste is produced, only 13 million tons are recoverable. And, only 20 percent of the recoverable waste, less than 3 million tons, is suitable for anaerobic digestion under current waste-management practices.

Recoverable beef cattle waste is concentrated in northwest and west-central Iowa. Almost half of Iowa's recoverable beef cattle waste is produced in those two districts. As one moves south and east through the state, waste production rapidly declines. Cattle operations exceeding 500 head generate about half of all Iowa recoverable beef cattle waste.

Daily recoverable waste produced by feeding a calf to market weight steadily increases from 30 lbs per head at weaning to 60 lbs per head at marketing. The animals may be confined up to ten months, leaving two months during the year when no waste is recovered.

2.4.3 Poultry Operations

Tables 2-17 and 2-18 present total waste production and recoverable waste production for Iowa poultry operations. Slightly more than 300,000 tons of poultry waste is produced and virtually all is recoverable. Only those operations where litter is not used have wastes suitable for anaerobic digestion. Assuming that litter is not used in the large scale chicken (1,600+) operations, an estimated 260,000 tons of poultry wastes suitable for anaerobic digestion are produced annually.

Recoverable chicken waste is produced primarily in northern and central Iowa. Southwest and south-central Iowa produce very limited amounts.

Daily waste recovery for operations that purchase "ready to lay" chickens is 0.20 lb per bird. If a farmer raises his own pullets in confinement, average waste recovery for the entire layer operations is only 0.17 lb per bird, because pullets, producing less waste than layers, reduce the average.

2.4.4 Dairy Cattle Operations

Tables 2-19 and 2-20 present total waste production and recoverable waste for dairy cattle operations. More than 9 million tons of dairy cattle waste is produced, almost 6 million of which is recoverable. All

Table 2-15. Estimated annual beef cattle waste production by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-24	25-49	50-99	100-299	300-499	> 500	Total
Northwest	124	205	436	1,725	1,272	5,131	8,892
North Central	101	126	225	648	452	789	2,340
Northeast	171	201	308	643	354	605	2,282
West Central	149	262	460	1,416	800	3,992	7,079
Central	127	213	281	839	532	1,752	3,744
East Central	144	262	398	1,050	582	1,249	3,686
Southwest	88	193	265	642	449	1,638	3,276
South Central	56	114	154	232	143	178	878
Southeast	97	162	241	537	234	367	1,638
STATE TOTAL*	1,057	1,738	2,768	7,732	4,817	15,701	33,813

* Totals may not add due to rounding.

Source: DPRA estimated.

Table 2-16. Estimated annual recoverable beef cattle waste by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-24	25-49	50-99	100-299	300-499	> 500	Total
Northwest	48	79	168	663	489	1,973	3,420
North Central	39	49	86	249	174	303	900
Northeast	66	77	118	247	136	233	878
West Central	57	101	177	545	308	1,535	2,723
Central	49	82	108	323	204	674	1,440
East Central	55	101	153	404	224	481	1,418
Southwest	34	74	102	247	173	630	1,260
South Central	22	44	59	89	55	69	338
Southeast	37	62	93	207	90	141	630
STATE TOTAL*	407	669	1,065	2,974	1,853	6,039	13,005

* Totals may not add due to rounding.

Source: DPRA estimates.

Table 2-17. Estimated annual chicken waste production by region and size of operation (thousands of tons)

Region	Size of operation (head) 1-399	400-599	600-799	800-1,599	1,600+	Total
Northwest	3	1	-	1	51	56
North Central	2	1	-	1	54	57
Northeast	4	1	-	1	38	44
West Central	4	1	-	-	17	23
Central	2	-	-	-	69	72
East Central	3	1	-	1	14	19
Southwest	3	-	-	-	1	5
South Central	2	-	-	-	8	9
Southeast	3	-	-	1	26	31
STATE TOTAL*	27	6	2	4	277	316

* Totals may not add due to rounding.
\- Indicates less than 1 (thousand tons).

Source: DPRA estimates.

Table 2-18. Estimated annual recoverable chicken waste by region and size of operation (thousands of tons)

Region	Size of operation (head)					
	1-399	400-599	600-799	800-1,599	1,600+	Total
Northwest	3	1	-	1	48	53
North Central	2	1	-	1	51	54
Northeast	4	1	-	1	36	42
West Central	4	1	-	-	16	22
Central	2	-	-	-	65	69
East Central	3	1	-	1	13	18
Southwest	3	-	-	-	1	5
South Central	2	-	-	-	7	9
Southeast	3	-	-	1	25	29
STATE TOTAL*	26	5	2	4	264	301

* Totals may not add due to rounding.
\- Indicates less than 1 (thousand tons).

Source: DPRA estimates.

Table 2-19. Estimated annual available dairy cow waste by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-4	5-9	10-19	20-29	30-49	50+	Total
Northwest	6	10	76	123	259	459	932
North Central	6	9	59	113	200	236	622
Northeast	10	26	246	748	2,040	2,161	5,232
West Central	8	8	54	62	129	180	440
Central	7	7	28	43	103	201	389
East Central	9	11	83	152	366	519	1,140
Southwest	6	5	19	18	63	96	207
South Central	11	5	29	52	94	146	337
Southeast	13	8	44	39	73	161	337
STATE TOTAL*	76	89	637	1,348	3,326	4,158	9,635

* Totals may not add due to rounding.

Source: DPRA estimates.

Table 2-20. Estimated annual recoverable dairy cow waste by region and size of operation (thousands of tons)

Region	Size of operation (head)						
	1-4	5-9	10-19	20-29	30-49	50+	Total
Northwest	-	1	6	10	199	352	568
North Central	-	1	5	9	153	181	349
Northeast	1	2	19	58	1,568	1,660	3,307
West Central	1	1	4	5	99	138	247
Central	1	1	2	3	79	154	240
East Central	1	1	6	12	281	398	699
Southwest	-	-	1	1	49	74	126
South Central	1	-	2	4	72	113	192
Southeast	1	1	3	3	56	123	187
STATE TOTAL*	6	7	49	104	2,555	3,195	5,916

* Totals may not add due to rounding.
\- Indicates less than 1 (thousand tons).

Source: DPRA estimates.

recoverable waste from operations exceeding 30 head (Table 2-20) is assumed to be anaerobically digestible, while only ten percent of waste from operations of fewer than 30 head is suitable for digesters. However, since more than 97 percent of recoverable waste is produced in operations exceeding 30 head, virtually all recoverable dairy waste, 6 million tons, is suitable for digestion.

More than 50 percent of recoverable dairy cattle waste is produced in northeast Iowa. Northwest and east central Iowa also recover significant quantities of dairy waste. As one moves from north to south through Iowa, recoverable dairy waste rapidly declines.

2.5 CHAPTER REFERENCES

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2. Iowa Department of Agriculture. Iowa Crop and Livestock Reporting Service. Number and Size of Farms in Iowa. Des Moines, Iowa, 1981.

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4. Livestock Waste Facilities Handbook. Midwest Plan Service, Iowa State University, May 1979.

3.0 TECHNOLOGY FOR METHANE PRODUCTION BY ANAEROBIC DIGESTION

Methane gas is obtained from waste materials by an anaerobic (absence of free oxygen) digestion process. In essence, the anaerobic process is achieved by placing organic waste materials in a covered container where the quantity of material is reduced as the methane gas is generated. A wide variety of different organic waste materials have been used as the feed materials for anaerobic digestion.

In this section, we discuss the digester systems, designs and characteristics, and the availability and current operational status of digester systems.

3.1 DIGESTER SYSTEMS AND DESIGNS

Digester systems are of two basic types: batch process and continuous feed. The batch type digester is filled with a slurry of organic materials which is left to digest for a specified retention period, after which the digester is emptied and refilled. This system is advantageous where the materials are available only sporadically. Batch digesters require little daily attention. However, gas production is variable in batch systems, starting out at a very low rate and increasing to a peak and then declining again. This is undesirable if a continuous user of the biogas is available. The disadvantage of uneven gas production can be reduced by use of additional digesters filled at regular intervals. However, investment in numerous batch digesters will usually be uneconomic on small farms.

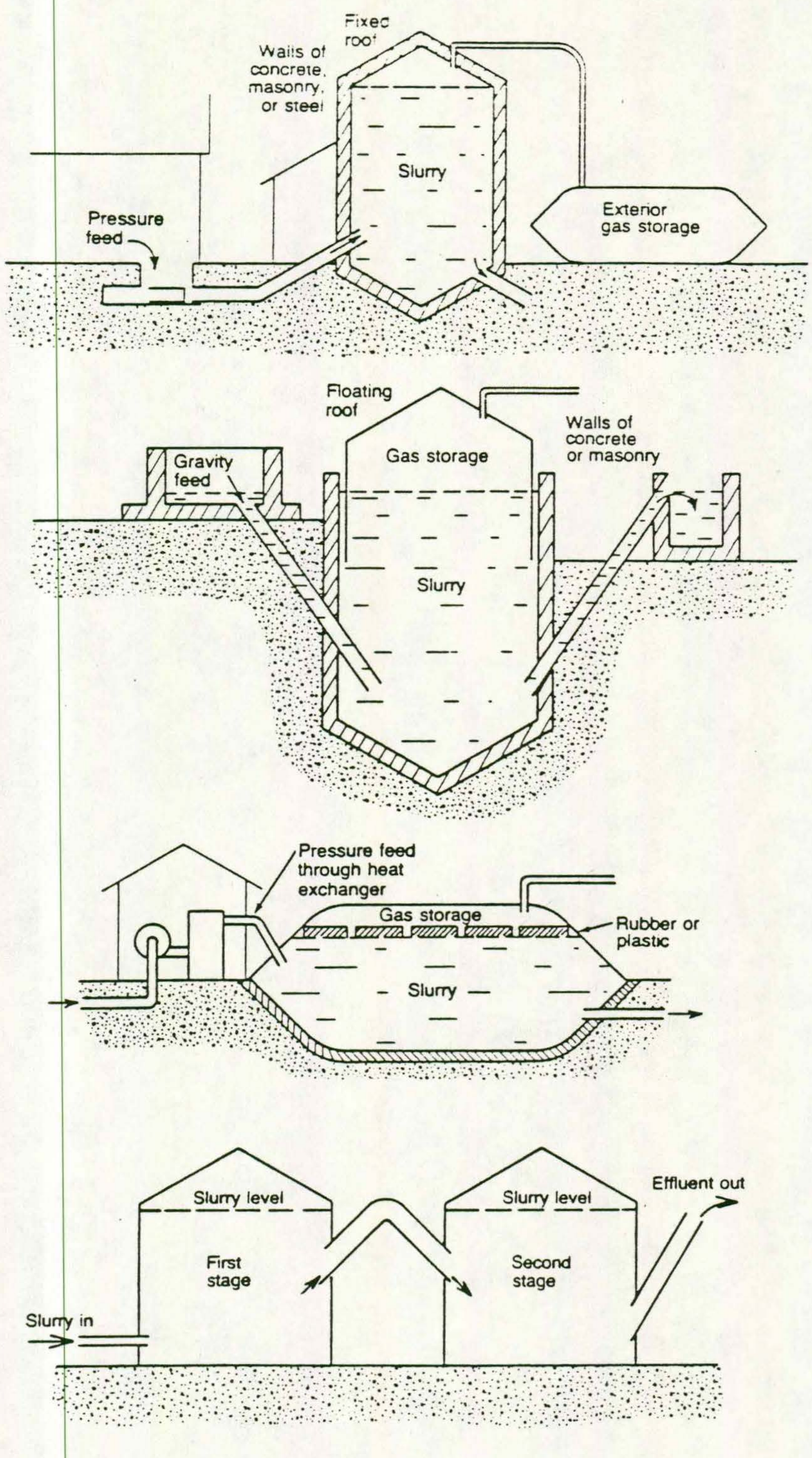
Continuous-feed digesters are better suited to the continuous supply of animal wastes on farms and feedlots. These digesters are loaded on a regular schedule, usually daily, with a fraction of their capacity, and an equal fraction is unloaded. The loading amount is generally the amount of manure slurry produced each day. The size of the digester is then determined by the desired retention time. Retention time in days (usually 10 to 20) times the daily loading volume will determine digester size.

3.1.1 Structures and Structural Components

A wide variety of structures have been used for digesters of animal wastes. Figure 3-1 shows some examples. The variations usually are effects of slurry feed systems and gas storage alternatives. A rigid structure with a fixed roof can be used if an exterior storage system is available for biogas (Figure 3-1a). However, even with continuous use of biogas some gas storage capacity is required in order to account for minor variations in gas production rates. A floating roof design (not unlike many petroleum storage facilities) can incorporate the minimum storage capacity if biogas

Figure 3-1.

TYPICAL DESIGNS OF AGRICULTURAL DIGESTERS



a

b

c

d

Source: Pennsylvania State University College of Agriculture, Bulletin 827, November 1979, "Agricultural Anaerobic Digesters, Design and Operation."

is to be used constantly and continuously. Flexible walled digesters (Figure 3-1c) will also allow some gas storage, and are inexpensive. Use of gravity or pressurized feed systems will determine whether the digester is built above ground level. Pumped feed systems are more expensive and more complex (prone to mechanical failures); however, excavation costs for below ground digesters may be high, depending on site layout and existing topography. One advantage of below ground digesters, even with pumped feed, is the potential for reduced heat losses in cold climates.

The two-stage digester design (Figure 3-1d) was developed based upon the two definite steps is the microbial process of the anaerobic digester: the acid forming and the methane forming stages. It has been suggested that this design should be more efficient, although there seems to be no operating data to support the suggestion. The two stage design may be two separate chambers or one chamber with a dividing wall.

3.1.1.1 Materials for digester construction

Both the gases and liquids (slurries) in digester systems are very corrosive. Mild steel may be used unprotected if submerged in the slurry, but excess thickness is recommended for extended life. Stainless, as well as mild steel, aluminum, copper, and brass all corrode rapidly in a biogas environment, as do most regular or enamel paints. Epoxy paint coatings seem effective for properly prepared (i.e., sandblasted) steel surfaces.

Plastic pipes and pipe fittings, and glass-reinforced plastic sheets are resistant to the corrosive atmosphere of the digester, but some plastics will weaken at the temperatures in the digester (90 to 100°F), so proper structural support is suggested. Wood, when pressure treated with creosote, is quite durable in the digester, as is cement and concrete. In fact, poured concrete and precast concrete panels are the primary construction materials for digesters. Glass-lined steel and fiber glass are excellent, but expensive, alternatives. Wood, too, is often suggested, but no reports of its use are available.

Walls, generally made of concrete, must be reinforced to support the hydrostatic pressures from within. Greater reinforcement is required near the bottom of the digester since this is where the pressure is greatest.

Floors of digesters may be flat or sloped for easy removal of bottom sludge. If the digester will have an agitation system, the sloping of the floor is probably unnecessary, as sludge accumulation will be less substantial.

Roof design will usually incorporate a floating or flexible roof, since fixed roofs are often not permitted for gas-producing structures. Both designs require some sealing system to ensure that oxygen does not enter the digester, nor biogas escape. The flexible roof design can readily adopt a flexible rubber gas sealing material. A floating roof design achieves a seal by immersing the vertical sides of the roof in the digester slurry (see Figure 3-1b). This requires that a corrosion resistant material, such as fiberglass, be used for this part of the roof which is alternatively exposed to the slurry and the biogas environment as the amount of gas contained in the digester varies.

3.1.1.2 Sealing and insulating

Because the digester most often will be maintained at a temperature above ambient (usually 95°F), the digester should be thermally insulated to reduce heating requirements. It has been suggested that insulation be sufficient to keep the digester temperature from dropping more than 2°F if the heating system were inoperative during the coldest 24 hour period of the year. This will require an "R" value of about 8 to 40, depending on local climate; this is equivalent to 2 to 10 inches of expanded polystyrene. Insulation should be added on the inside of digesters, if possible, since rodents, attracted to the digesters warmth, will burrow in outside insulation and reduce its effectiveness. However, inside insulation must be sealed from liquids and gases in the digester by use of concrete plaster or thick polyethylene sheets. Insulation should be applied to, in order of significance: roof and walls exposed to ambient air, walls below ground level, heating pipes and gas agitation pipes (if used). Anywhere significant temperature differences will occur, insulation is necessary.

3.1.1.3 Slurry preparation

The most efficient digestion process will result if manure is fed into the digester as soon as possible after it leaves the animal. Delays in moving manure from animal housing to digester are to be avoided. The slurry preparation area should be kept warm in order to avoid equipment damage. Location within or next to the animal shelter is suggested in order to take advantage of animal heat. This area is one of the most likely trouble spots, according to digester operators, so reasonable access area for all equipment should be planned for.

Water supply will be needed here, for addition of water to manure is essential in order to maintain a constant solids/slurry level acceptable to all equipment used. Mechanical manure collection systems should feed directly into a hopper which feeds the mechanical or gravity digester feed systems. This hopper, and water supply to slurry, help to ensure a mixed and fluid feed to the digester and also reduce the chance of air (which is toxic to methogenic microbes in the digester) being pumped into the digester. Dilution water may also be needed to prevent ammonia toxicity.

An emergency temporary storage area should also be provided for manure, in case of equipment failure.

3.1.1.4 Storage of digester effluent

The required storage area for the digester effluent will depend upon the desired use for this effluent. If the residue were to be spread on fields daily, only an emergency storage area for two or three days effluent would be needed, in case of equipment or weather problems. However, if the residue is to be spread at the best time for land application, then a larger storage area will be needed. In Iowa, the Water Quality Commission recommends that land spreading on snow covered or frozen ground be avoided; thus, storage for several months may be in order.

Separation of liquids and solids may be desirable so liquids could then be distributed as fertilizer by irrigation or other methods. More importantly, it may be possible to recycle some water back into the digester slurry, reducing storage requirements and water usage. Solids storage requires no special facility. These could be spread on fields when desired (as a soil conditioner), used as bedding material, or refed to beef cattle.

3.1.2 Characteristics of Anaerobic Digestion

Many factors influence digester performance. The process of anaerobic digestion is a complex chemical and microbiotic process well understood by scientists in its purist sense, when precise chemical and biological components are known. However, the actual digestion of animal wastes, mixed with bedding materials, uneaten feed, and other unknown contaminates defies precise description. However, a simple flow diagram, such as in Figure 3-2 shows the basic process. Simply stated, two types of anaerobic bacteria, acid-forming and methane-forming bacteria, break down complex organic compounds into simple organics and then into methane, carbon dioxide, and other gases. Because this is actually a complex process acting upon a complex mixture of materials, the actual results of the process vary due to many factors. A number of the most important of these factors influencing methane production are discussed in this section.

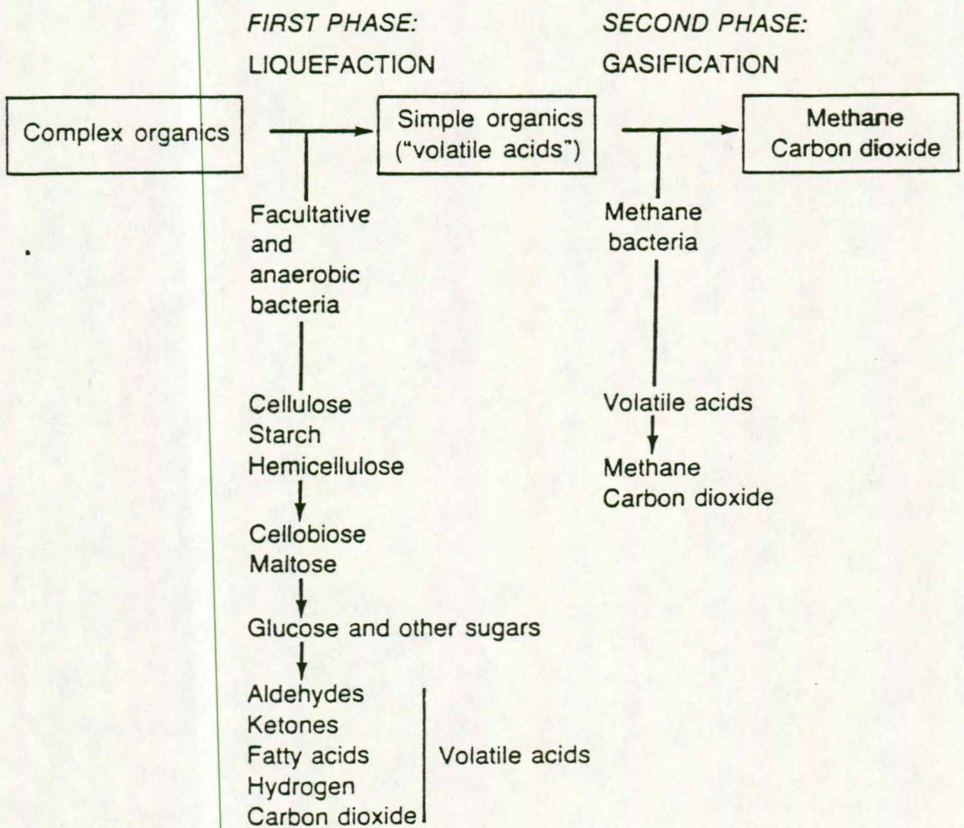
3.1.2.1 Slurry composition

The animal from which the manure comes is a major influencing factor, as the animals diet and digestive system determine manure composition. Beef cattle, dairy cows, swine, and poultry, the four major animal waste producers in Iowa, are represented in Table 3-1. A discussion of some specific factors of manure composition and their influence on digester operation follows.

Manure, as used in this discussion, includes feces, urine, bedding material, wasted feed, anti-slip materials and grit tracked into the barn by animals and workers. The composition of manure will vary for different animals, as well as for each farm. Seasonal changes in farm operation and diet will also affect composition. Major components of manure are water, organic matter, and ash. The organic compounds include protein, starch, fat, cellulose and lignin. Dairy cow manure, for example, have been determined to contain as much as 30 percent cellulose and 20 percent lignin (weight of solids basis). The major element in manure is carbon; other chemicals include nitrogen, oxygen, hydrogen, and minerals.

Figure 3-2.

SIMPLIFIED DESCRIPTION OF ANAEROBIC DIGESTION PROCESS



Source: Pennsylvania State University College of Agriculture, Bulletin 827, November 1979.

Table 3-1. Retention time, loading rate, solids concentration, gas production and size for farm digesters

Manure source	Concentration of input slurry	Retention time	Daily VS a/ loading rate (per unit digester volume)		Daily biogas production: Per unit digester volume		Daily biogas production: Per animal		Digester volume per animal	
	(% TS) b/	(days)	(lb/ft³)	(kg/m³)	(ft³/ft³)	(m³/m³)	(ft³)	(m³)	(ft³)	(m³)
Dairy										
Design c/	13	14	0.5	8	1.9	1.9	53	1.5	28	0.8
Range d/	6-20	10-30	0.13-0.7	2-11	0.7-2.0	0.7-2.0				
Beef										
Design	10	18	0.3	4.8	2	2	38	1.1	19	0.53
Range	5-10	15-40	0.25-0.31	4-5					7-46	0.2-1.3
Swine										
Design	9	21	0.22	3.5	2	2	8	0.23	4	0.11
Range	2.5-11	10-30	0.08-0.31	1.2-5	0.1-2	0.1-2			1.4-14	0.04-0.4
Poultry										
Design	8	40	0.13	2	0.4	0.4	0.15	0.004	0.35	0.01
Range	7-14	20-50	0.11-0.21	1.8-3.4	0.01-0.9	0.01-0.9			0.2-0.4	0.006-0.012

a/ VS = volatile solids (total solids less ash content of 1-2 percent).
b/ TS = total solids.
c/ Value suggested for design of modern high-rate digesters.
d/ VAlues reported by various workers with farm-size digesters.

Source: Pennsylvania State University, Bulletin 827.

The carbon-to-nitrogen ratio can significantly affect digester operation. Carbon and nitrogen are the principal elemental nutrients for anaerobic bacteria. The carbon component is converted into methane, and nitrogen is necessary as food for the bacteria and as a catalyst for the process. However, if the nitrogen content is too high, the process is retarded or stopped. Optimum carbon-nitrogen ratio is believed to be between 16 and 30. The availability of carbon and nitrogen in manures varies for different animal species, with age and diet of the animals, and with manure management.

The carbon content in dairy manure is slightly higher than required for an efficient balance, and swine and poultry manures usually have excess nitrogen. Consequently, adding swine or poultry manure to the dairy manure will increase gas production and the efficiency of solids reduction. However, this is not practical unless the two livestock species are housed on the same farm or a cooperative venture is established that includes both species. Conversely, digestion of swine or poultry manure becomes more effective when material that contains excess carbon (in relation to nitrogen), such as bedding or litter, is added.

Only a fraction of volatile solids in manure can be converted to gas by bacteria. Lignin is practically unaffected by bacteria in a digester, and cellulose is broken down only very slowly. Biological oxygen demand (BOD) value may be used as a measure of biodegradability of the slurry. A BOD to volatile solids (VS) ratio of about 1 indicates that most of the volatile solids can be converted. Dairy manure, for example has a low BOD/VS ratio, about 0.25, whereas swine and poultry manure show higher values. On the basis of volatile solids percentage (of total solids) and the BOD/VS values for dairy manure, as little as 20 percent of the total solids may be available for conversion in the digester.

Based upon some analyses for typical incoming solids, the expected production of biogas (at 60 percent methane) is estimated at 11 ft^3 of biogas per pound of converted volatile solids. Conversion rates are often given relating gas output to the amount of volatile solids fed to the digester (as in Table 3-1). These figures are less than 11 ft^3 per pound because (1) not all volatile solids are biodegradable and (2) not all biodegradable solids are converted in the time that they remain in the digester (retention time).

3.1.2.2 Chemical parameters

Methane bacteria are sensitive to extreme values of alkalinity (pH greater than 7) and acidity (pH less than 7). The optimum pH range is from 6.6 to 7.6. Beyond these limits, fermentation will be retarded, and with continued operation will stop completely. Properly operated cattle-manure digesters will usually stay well within safe pH limits. If the pH of a continuous-feed digester does become too low (too acid), it can be corrected by recycling fresh effluent to the inlet, or by reducing the amount of raw slurry that is fed to the digester, or by neutralizing with calcium (limestone). If the slurry becomes too alkaline, carbon dioxide levels will increase, which will increase the acidity of the mixture, thereby correcting itself.

Small concentrations of sodium, potassium, calcium, and magnesium (up to 200 ppm) have been found to stimulate the digestion process. However, concentration above 5,000 ppm may inhibit methane production.

Although a source of cell nitrogen is required by the methane bacteria, above certain concentrations, nitrogen in the form of ammonia, is toxic. The degree of toxicity as a particular concentration is dependent on other factors such as pH and sodium concentration.

The only digester problem identified to date with animal drugs has been monensin sodium (Rumensin) in beef cattle. Other materials that also may be toxic to microbial life must be prevented from entering the digester. Common among such materials associated with livestock operations are health-related drugs and disinfectant compounds. Generally, dosages normal for disease control will not be excreted in quantities sufficient to affect microbial activity; however, the common practice of disposing of unused materials in the manure gathering system must be avoided.

3.1.2.3 Temperature

The rate of gas production and the rate of solids reduction are very dependent upon temperature (see Figures 3-3 and 3-4). The dual curve maximums in Figure 3-3 correspond to minimum solids reduction times in Figure 3-4. These represent the peak gas production levels in the mesophilic (below 40°C) and thermophilic (above 40°C) ranges. Bacteria which operate in the thermophilic range are very sensitive to changes within the digester, while mesophilic bacteria are more stable. Also, the mesophilic range (peak at 95°F, or 35°C) is easier to maintain, in that it requires less heat.

3.1.2.4 Agitation

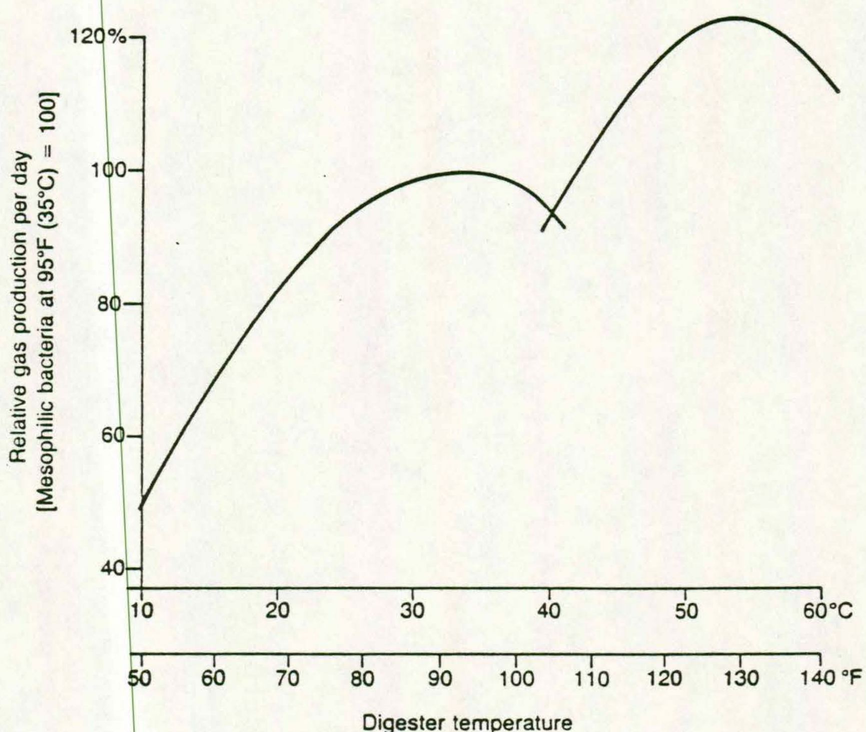
It can also be seen from Figure 3-4 that mixing or agitation of the mixture in the digester can have a significant effect on solids reduction and corresponding gas production rate. Agitation in agricultural digesters can be performed by continuously pumping the slurry around in the digester, mechanical stirring devices, or by bubbling biogas back through the slurry. Additionally, some digesters utilize only the thermally induced mixing from heat exchangers used to maintain digester temperatures.

3.1.2.5 Retention time

The amount of time that the organic material spends in the digester influences the amount of gas produced. Gas production from newly introduced materials is not substantial until about the fourth day, but will continue for several weeks. The period of time that material is actually retained in practice is limited by the economic cost of digester

Figure 3-3.

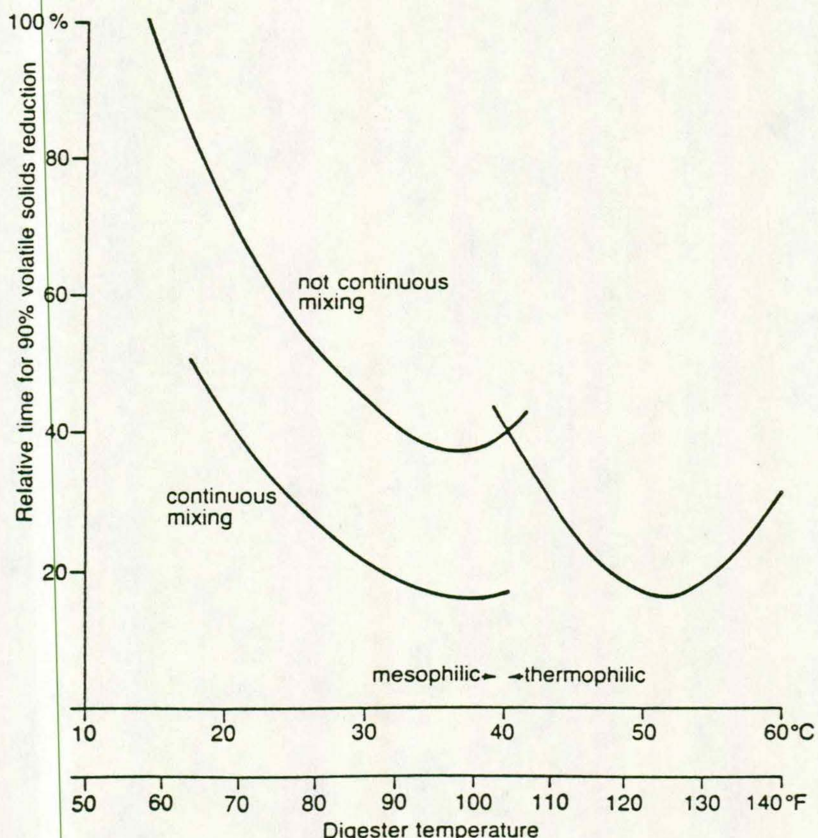
EFFECT OF TEMPERATURE ON GAS PRODUCTION RATE



Source: Pennsylvania State University College of Agriculture, Bulletin 827, November 1979.

Figure 3-4.

EFFECT OF TEMPERATURE ON SOLIDS REDUCTION TIME



Source: Pennsylvania State University College of Agriculture, Bulletin 827, November 1979.

size for the amount of material to be digested. Although total gas produced per unit of volatile solids in the digester continues to increase, a choice must be made to remove the material after a period of time based on the design size of the digester. Figure 3-5 shows the relationship of gas production rate to retention time in two specific examples. From these the declining production rate exemplifies the declining return on investment in longer retention (i.e., requires a larger digester).

With the continuous-type digesters, new organic material is added at frequent intervals in amounts related to retention time. Additions of small amounts avoids the danger of loading shock, such as occurs when cold input reduces digester temperature or when the composition of input material changes. The calculated retention time does not represent actual treatment time for all individual particles of material, but rather an average treatment time.

3.1.2.6 Solids concentration

Water is added to input organic matter to increase the flowability of the input material, which is essential for ease of mixing within the digester and for flow into and out of the digester. Increased dilution is suggested for handling agricultural residue and bedding material in order to avoid clogging pumps. The volume of water added is often as much as the volume of original manure, if bedding or litter are used. Excessive dilution should be avoided, however, in order to maximize the amount of organic material in the digester and to limit the amount of material to be handled.

Some references indicate that anaerobic bacteria will function best with a volatile solids 1/ content in a digester of about 8 percent. However, others indicate wide ranges of effective digester operation (see Table 3-1). In reality, the solids concentration may be determined by equipment used. For example, large centrifugal manure pumps can satisfactorily handle liquid manure with a solids content of 12 percent. However, smaller pumps require that solids content be in the 5 to 8 percent range. Other pumps can handle higher concentrations, such as the ram-type pump used with one test digester which handled a mixture of manure and sawdust bedding with a solids content as high as 22 percent.

3.1.2.7 Loading rate

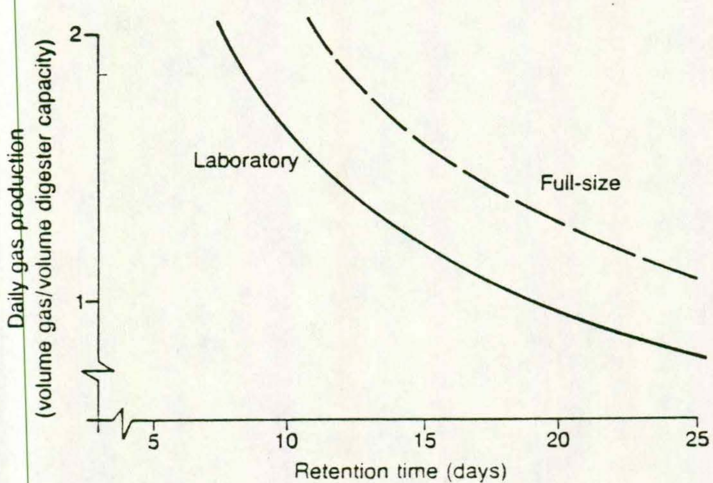
The gas production capacity of a digester is related to the loading rate of volatile solids, which is the amount of material fed to the digester per day per unit of digester volume. A high loading rate is desirable because it means that a given size digester can handle a large amount of manure in relation to its size, which, of course, relates to capital cost. That is, a smaller digester can handle more manure if the loading rate is higher. A

1/ Volatile solids equal total solids less ash.

Figure 3-5.

EFFECT OF RETENTION TIME ON GAS PRODUCTION FROM DAIRY MANURE WITH BEDDING, FEEDING TWICE DAILY

(Laboratory test with 6.8 percent volatile solids concentration; Full-size test with 11.8 percent volatile solids concentration)



Source: Pennsylvania State University College of Agriculture, Bulletin 827, November 1979.

high loading rate results in higher daily gas production and a higher rate of volatile solids reduction, but will give a smaller percentage conversion of volatile solids to gas.

The combination of high solids concentration and short retention time results in high loading rate. So it is that loading rate, retention time, gas production rate, solids concentration of digester slurry, and digester size are related. Table 3-1 shows ranges of variation for these factors on operating digester systems.

3.2 AVAILABILITY OF UNITS

Five companies that produce anaerobic digester systems for farm animal waste application were identified and contacted. These firms are listed in Table 3-2. The company that has been constructing anaerobic digesters for the longest period is Brown and Caldwell of Walnut Creek, California. They have built digesters for municipal sewage treatment plants for 35 years and have over 80 such units in operation producing fuel for boilers and generating electricity. Recently they have constructed anaerobic digesters that use wastes from beef feedlots. At the present time, they do not have a modular design for digesters.

The other four companies have designed and constructed anaerobic digester systems that utilize wastes from dairy, beef and chicken operations. The systems are designed to produce biogas for use for water and space heating, boiler fuel, and cogeneration.

Other uses were also identified. Energy Cycle, Inc. of Ames, Iowa has under construction a digester designed to produce pipeline quality methane. Biogas of Colorado, Inc. designed and installed a digester designed to produce energy for an ethanol distillery. The digester is working well, but the ethanol distillery is currently down.

Perennial Energy Inc. of Dora, Mo. (Ted Landers) sells cogeneration units. These systems provide gas handling for cogeneration (electricity produced by a generator driven with an internal combustion engine) and the interface with the utility. To date, they have sold eight units, seven of the units are on dairy farms, the other is on the University of Missouri, Columbia, Experiment Farm's hog waste digester.

Hamilton Standard Corporation cooperated in a joint venture under a Department of Energy Contract to design, construct and monitor an anaerobic digester at a beef production and processing facility. They are not at present involved in designing or constructing animal wastes anaerobic digesters.

3.3 OPERATIONAL DIGESTERS

A number of contacts have been made in order to assess the number and characteristics of currently operational digesters. To date, we have identified twelve operational on-farm systems. (We identified another

Table 3-2. Known producers of anaerobic digester systems for farm/animal waste application

Company Name & Address	Number of Operating Digesters*	Waste Application	Size Range	Use of Gas	Comments
Energy Cycle, Inc., Ames, Iowa	4 (2)	Dairy (4) Chickens (1) Beef (1)	30,000 gal. to 240,000 gal.	Electricity & Boiler Fuel & Pipeline Methane 1/	• Guarantee gas production rate • Modular designs • Plug flow digester with mixing • Bought patterns from Sheaffer and Roland.
Anaerobic Energy Systems, Inc. Bartow, Florida	2**	Dairy	4,680 c.f. biogas/ day to 9,000 c.f./ day	Electricity With Heat Recovery	• One unit at Agway research center, Tully, N.Y. • Use Fiat Totem Cogenerating I.C. engine • Thermal digester mixing only • Pressurized gas storage units available
Biogas of Colorado, Inc., Arvado, CO	2+	Dairy Beef	50,000 gal. to 150,000 gals. plus?	Water heating Space heating and Ethanol Distillery 2/	• Pressurized gas storage units available
Energy Harvest, Inc., Wash., D.C.	2+	Dairy	20,000 to 60,000 c.f. biogas/day	Electricity	• Subsidiary of Sheaffer and Roland of Chicago
Brown & Caldwell Walnut Creek, CA	85+	Most for Sewage Sludge; Beef	3,000 to 400,000 c.f. Digester Volume	Boiler Fuel and Electricity	• Consulting Engineers have built digester for sewage treatment for 35 years • Do not currently have modular design

* Number in parentheses indicate facilities under construction.
** Company associates helped build and/or operate two others.

1/ Pipeline methane production system under construction.
2/ Ethanol distillery is currently down for extensive repairs.

twelve small digesters that were built but are no longer operating.) In addition, there are experimental units operating such as the one at the Agricultural Experiment Farm at the University of Missouri, Columbia. This digester, utilizing wastes from the University's swine operation, has been operating successfully for over two years.

The characteristics of these on-farm digesters have been summarized in Table 3-3. The location of the digester and the builder are identified. The type of animal waste, the digester size, biogas and by-product uses, and current status of the system are given.

For the most part, these digesters have been operational less than a year. However, the Washington State Dairy Farm, Monroe, Washington and Kaplan Industries of Bartow, Florida have been operational longer. Both of these digesters were designed and built under government grants or contracts (U.S. ERDA and U.S. DOE, respectively) 1/.

The Washington State Dairy Farm's anaerobic digester was built in January 1976 with funds provided by the state Department of Ecology as part of a program to upgrade the farm's manure handling system for purposes of water pollution control. The system was run for 5 months and shut down. In June 1977, the U.S. ERDA provided funds to the Ecotope Group to restart the digester, document the operation and maintenance characteristics of the system, and prepare an operator's manual that would allow the State to operate the system. The operation of the system was taken over by the prison system in September 1979 and has been run since then by prison personnel. The biogas produced is burned in the heating system boiler and in the farm's creamery boiler.

Kaplan Industries, Inc. is a vertically integrated beef packer with a feedlot and a meat packing plant. In 1979, a digester for the facility was funded by the U.S. Department of Energy (DOE) for purposes of demonstrating the technical and economic feasibility of on-farm anaerobic digestion. Hamilton Standard Corporation designed, constructed and monitored the digester under DOE contract. Since February 1981, Kaplan Industries has operated the digestion system as an integrated part of its beef production and processing facility near Bartow, Florida. The anaerobic digester vessels have a capacity of 1,211 cubic meters and are designed to handle the wastes produced by 20,000 head of feedlot cattle. In addition to the feedlot wastes, paunch manure from the packing plant is also added to the digester. The biogas produced is used as a boiler fuel in the packing house during its hours of operation (weekdays) and to generate electricity for Florida Power Corporation in its on-site 440 kW gas engine generator on Saturdays and Sundays. The solids residue are separated with vibrating screens and screw presses. The recovered solids, after composting, are marketed as a specialty fertilizer.

1/ Coppinger, Elizabeth R. and Michael Richter. Operational experience from Three Full Scale Methane Digesters, American Society of Agricultural Engineers Paper No. 81-4537, December, 1981.

Table 3-3. Characteristics and current status of operational on-farm digesters

Name/location (Builder)	Type of waste	Digester size	Biogas use	By-product use	Status
Kaplan Industries, Inc. Bartow, Florida (Hamilton-Standard Corp.)	Beef feedlot	2 - 300,000 gal.	Boiler fuel, for packing plants 5 days a week, week-ends generate elec-tricity for Florida Power Co.	Solids sold as soil conditioner to gardners	Operating thermophilic range since 1980, plan to switch to to mesophilic to reduce diges-ter heating requirements
Washington State Dairy Farm Monroe, Washington	Dairy	2 - 189 m³	Digester heating and creamery boilers	N.A.	Start up Jan. 1976. Operated 5 mo. Restarted Aug. 1977. Operated by prison personnel.
Grieg and Sons Estherville, Iowa (owner-built digester; co-generation system Perennial Energy, Inc.)	1,000- Beef	150,000 gallons 42 kW Co-generation	Cogeneration of electricity with heat recovery	Effluent lagooned, land spread with irrigation equip.	Start up Dec. 1981; currently operating at 2/3 capacity approx. 25 kW, building up to full capacity.
Fairgrove Farms Berrien County, Mich. (Perennial Energy, Inc.)	Dairy 525-Cow	180,000 gallon	Electricity generation with heat recovered for digester heating	Solids for bedding; liquids for irri-gation/fertilizer	Operating since Dec. 1981
Springport, Mich. (Energy Cycle)	Dairy 500-Head	180,000 gallon	Electricity generation with heat recovery	N.A.	Biogas production exceeds re-quirements of 60 kW generator, replacing with 90 kW generator
New York State (Energy Cycle)	Dairy, cheese whey	240,000 gallon	Electricity generation with heat recovery	N.A.	Selling power to Consolidated Edison. Start up Jan. 1982.
Connecticut (Energy Cycle)	Dairy	N.A.	Electricity generation with heat recovery	N.A.	Start up Jan. 1982. Selling power to Consolidated Edison.
Arkansas (Energy Cycle)	Chickens	90,000	N.A.	N.A.	Start up Dec. 1981.
Otter Run Farm Bedford, VA (Anaerobic Energy Systems, Inc. owned and operated)	Dairy 100-head	3,000 cubic feet	15 kW generator heat recovered for digester heating.	N.A.	Start up Spring 1981. Opera-tion stabilized Nov. 1981. Digester is operated by Anaerobic Energy Systems Inc. as demonstration/product development unit.

Continued . . .

Table 3-3. (Continued)

Digester location and contractor	Wastes	Digester size	Biogas use	By-product use	Status
Evan Leefers Carlinville, Illinois (Biogas of Colorado)	Beef 1,000 head	150,000 gallon	Space and water heating, designed for process boiler for ethanol production unit (not operational)	Effluent to lagoon, irrigation spray boom	Have scrubber to remove sulfur. Well automated, labor requirements are minimal. Since ethanol unit is down are flaring biogas in excess of heating requirements.
Mason-Dixon Farm Gettysburg, PA (Energy Harvest, Inc.)	Dairy 800-head	2-producing 80,000 cu. ft. of biogas/day	Generates electricity with heat recovery for own use	Solids for bedding, excess sold to mushroom growers Liquid irrigation/ fertilizer	Start up Aug. 1979. Later enlarged, venting 1/3-1/2 of biogas to atmosphere. No electricity sale.
Sunnytime Foods West Union Iowa (own design, consulting from Biogas of Colo.)	Chickens 160,000	2 - 250,000 gallon	Generating electricity with heat recovery, when generating biogas	Non-digested slurry stored for periodic irrig./fertilizer liquid tank spreaders	Not currently operating as digester. Wastes stored prior to land spreading.
Harold McCabe Mount Pleasant, Iowa (own design)	Hog 80-100 sows	55,000 gallons	Flaring	In process of modifying to reclaim byproducts for fertilizer for own use	In operation 10 years. Installed for odor control.
Iowa State University Beef Farm Ames, Iowa	Beef 40-50 head		Venting - plan to generate electricity	land application	Research unit

Mason-Dixon Dairy in Gettysburg, PA has been operating a digester since August 1979. From wastes produced by the 800-head dairy, 80,000 cubic feet of biogas per day is produced. The biogas is used to generate electricity, the generator waste heat is recovered for the dairy's own use. The digester solids are used for bedding. The excess solids are sold to mushroom growers.

Not all operational digesters have been built by firms specializing in anaerobic digesters. Grieg and Sons of Estherville, Iowa built their digester for both energy production and as an integral part of their manure handling system. A 42 kW cogeneration system was purchased from Prennial Energy, Inc. This digester operates on wastes from 1,000 head of beef cattle. The biogas is utilized for electricity, waste heat is recovered. The effluent is lagooned and land spread with irrigation equipment. The digester was started up in December 1981 and is currently operating at about two-thirds capacity. Full capacity operation is anticipated soon.

A pioneer in digester operation in Iowa is Mr. Harold McCabe of Mt. Pleasant, Iowa. McCabe installed a digester 10 years ago as an odor control measure for hog wastes. For this purpose it has worked well. McCabe is in the process of modifying the system to enable him to reclaim the by-product fertilizer for use on his own land. At the present time he has no plans to capture and use the biogas for energy production; the system is too small to be economical.

However, another owner designed and built digester is not currently producing biogas. Sunnytime Foods of West Union, Iowa has two 250,000 gallon digesters and cogenerator equipment. At the present time, the digesters are being used as storage for the wastes from 160,000 chicken operation prior to using the slurry for irrigation and fertilizer.

Energy Cycle has four operational digesters on dairies in Michigan, New York and Connecticut, and a poultry farm in Arkansas. The dairy digesters are equipped with cogeneration equipment and are producing and selling power to local utilities.

A similar operation was identified at Fairgrove Farm in Michigan. The digester for the 550-cow dairy is cogenerating electricity. The solid residues is being used for bedding and the liquid for fertilizer distributed with irrigation equipment.

Anaerobic Energy Systems, Inc. has constructed a digester on the Otter Run Farm in Bedford, Virginia. This digester is used for product development testing and demonstration. The 100-cow dairy has a 3,000 cubic foot digester. The 15 kW generator is set up for waste heat recovery. The unit was started up in Spring 1981 and was stabilized in November 1981.

In addition to space heating and electricity generation, one on-farm operation was designed to work in conjunction with an ethanol production facility. Evan Leefers of Carlinville, Illinois has a 150,000 gallon digester for his 1,000 head beef feedlot. The digester is operational and is providing heat for the farmhome, farm buildings, and grain drying. However, the ethanol production facility is down. Since there are insufficient heating requirements on the farm to consume all the biogas produced, the excess biogas is being flared. The effluent is stored in a lagoon and land spread with a boom irrigation system.

4.0 MODEL DIGESTER OPERATIONS

For analyzing the feasibility of the sizes of digesters appropriate for on-farm and cooperative use, four model digester systems are defined. These model or representative digesters were selected on the basis of the analysis of the sizes and types of Iowa livestock operations in Section 2. The digester biogas output is then compared to the energy demand of these representative operations.

4.1 DESCRIPTION

Based on the analysis of the various sizes and types of livestock operations that are most prevalent in Iowa and identification of those that have the greatest potential for recoverable waste suitable for anaerobic digestion, four representative types of model digesters were developed. The model digesters chosen for analysis of economical biogas recovery potential are:

- a 70-sow swine operation farrowing twice a year
- a 200-cow dairy operation
- a 200-sow swine operation farrowing weekly or biweekly
- a cooperative venture comprised of three, 75-cow dairy operations and six, 70-sow swine operations farrowing twice a year.

Each operation assumes livestock are housed in a confinement building so that waste can be recovered efficiently and routinely even during severe winter conditions. Waste is scraped, flushed, or pumped from the confinement floor to a holding tank from which the digester is periodically loaded. It is assumed no bedding material, antibiotics, or growth promoters are used in these livestock operations which will interfere with either the mechanical or biological operation of the digestion system.

Daily waste recovery will vary from model farm to model farm since each farm is comprised of different types and/or numbers of livestock. Daily waste recovery can also vary on an individual farm if that farm's livestock operations are not continuous and uniform. Average daily waste production for the model farms is shown in the Figure 4.1.

Waste recovery for the 200-sow operation is essentially continuous given a weekly or biweekly farrowing schedule. Assuming 7.5 pigs saved per litter, approximately 1,500 hogs will always be in confinement. Using an estimate of 6.5 pounds of waste per animal per day, 1,500 hogs will produce 9,750 pounds of waste per day. Using the same assumptions, the 70-sow operation, raising 525 pigs per farrowing, will produce an average of 3,412 pounds of waste per day. However, since farrowing occurs only twice a

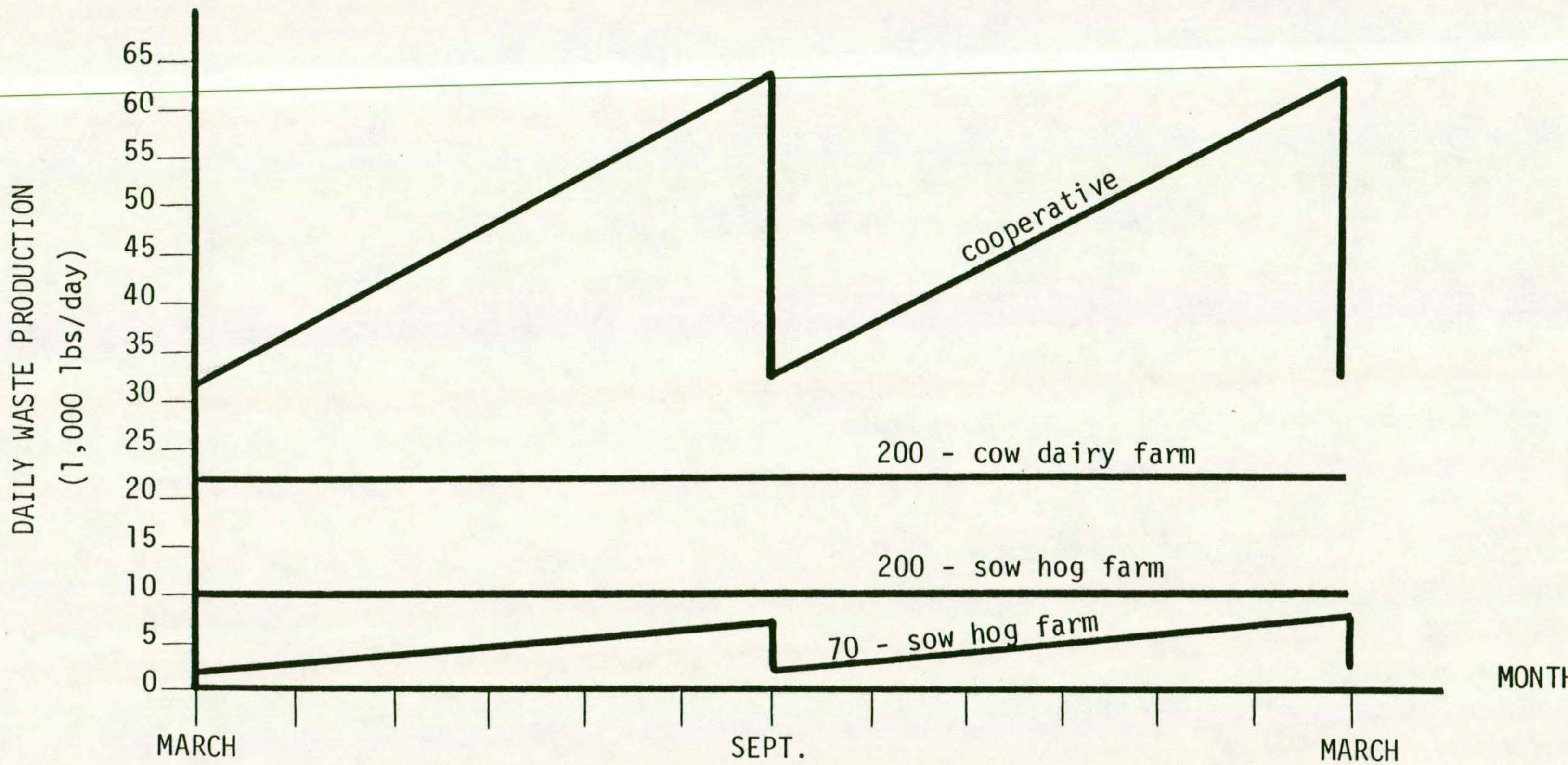


Figure 4.1. Annual variation in average daily waste production

year, total daily waste production ranges from a minimum of 1,155 pounds for a herd of nursery pigs to a maximum of 6,510 pounds for a herd of 200-pound finishing hogs.

The 200-cow dairy herd recovers a relatively constant quantity of waste each day since it is a continuous operation. Assuming 109.3 pounds of waste are recovered daily per animal, 21,850 pounds per day can be recovered from a 200-cow herd.

The cooperative venture consists of a centrally located digestion system which is supplied by waste recovered from both dairy and swine operations. Dairy operations are assumed to be 75-cow herds and swine operations are 70-sow herds farrowing twice per year. In the best case, the cooperative venture is located in a high density livestock area so that transportation costs are minimized. Delaware county in east central Iowa and Sioux county in northwest Iowa are examples of high density livestock areas. The following table gives the number of farms in both counties fitting the cooperative farm size criteria.

Number of Farms by County and Type of Operation

Type of Farm	Delaware County	Sioux County
75+ dairy cows	122	85
70+ sows	260	207
Total	382	292
Ratio of swine farms to dairy farms:	2.13	2.44

It is assumed waste is transported from farms to the cooperative digester daily to maximize energy recovery. A tandem-axle truck with a 3,000 gallon bulk tank which has a payload capacity of approximately 24,000 pounds is equipped with a pump of sufficient capacity to allow the truck driver to pump waste from a temporary holding tank, clean pumping equipment to minimize disease transmission, and drive to the next farm in one hour or less. Assuming a reasonably even distribution of swine and dairy farms throughout our two sample counties, approximately two swine farms will be served for every dairy farm served. This 2 to 1 ratio translates into 6 swine farms and 3 dairy farms being served by one truck per day. These 9 total farms on the average will generate 45,066 pounds of waste, slightly less than double our model truck's payload capacity. Thus, twice a day the driver returns to the cooperative digester to unload the truck and check if the digester is functioning properly.

The driver should design the routes to minimize transportation and handling costs. For example, the driver could define separate pick up routes for swine waste and dairy waste. The 75-cow dairy herds generate 24,581 pounds of waste daily, conveniently filling our model truck for one route. For the other route, the six 70-sow swine herds generate on the average 20,472 pounds of waste per day, not quite filling the truck.

4.2 BIOGAS POTENTIAL

Biogas and methane production potential varies between swine and dairy waste. The following table presents typical daily methane production per 100 pounds of swine and dairy waste.

Waste	Total Solids	Volatile Solids	Biogas	Methane	Btu
Swine	10 lbs	8 lbs	56-88 ft^3	34-53 ft^3	33,600-52,800
Dairy	15 lbs	12 lbs	36-96 ft^3	22-58 ft^3	21,600-57,600

These estimates are based on the following assumptions:

- Swine waste contains 10 percent solid material
- Dairy waste contains 15 percent solid material
- Volatile solids comprise 80 percent of total solids in both swine and dairy waste
- Biogas production from swine waste varies from 7-11 ft^3 per pound of volatile solids added to the digester
- Biogas production from dairy waste varies from 3-8 ft^3 per pound of volatile solids added to the digester
- Biogas generated by anaerobic digestion is 60 percent methane
- 600 Btu are contained in each cubic foot of biogas.

Daily energy production for each model digester depends on the type and number of animals confined on each farm. However, many other factors such as the temperature of the waste and loading rate of the digester influence the variability of gas production. For these reasons, energy production is specified as a range for each model in the following table.

Farm	Million Btu	
70 sows-2 farrowings/yr	0.4-0.6	Minimum-nursing pigs
	1.1-1.8	Average
	2.2-3.4	Maximum-finishing hogs
200 dairy cows	4.7-12.6	
200 sows-weekly farrowing	3.3-5.1	

Cooperative	Million Btu	
3 75-head dairy farms	7.7-17.8	Minimum-nursing pigs
	11.9-25.0	Average
6 70-sow swine farms-farrowing twice per year	18.5-34.6	Maximum-finishing hogs

As indicated above, energy production varies considerably for swine operations farrowing only twice a year. Over five times as much energy potential exists for a herd of market-weight hogs as for a herd of nursery pigs. Uneven energy production inherent in seasonal hog farrowing operations such as these can create serious energy use problems. For efficient energy use, the farm should attempt to schedule its farrowing operations so that peak farm energy production coincides with peak farm energy demand.

4.3 BIOGAS PRODUCTION AND USE

The economic success of a biogas digester depends in part on matching the biogas production to beneficial uses. Potential uses for the biogas are direct burning for boiler fuel, space heating, cooking, crop drying, in stationary engines, and engine/generators for production of electricity.

The biogas produced by the cooperative may be used at an adjacent or nearby energy-consuming facility, such as a factory, a process plant, or a school operated year round, as determined by the site. Alternatively, the biogas could be used to generate electricity for sale to a utility.

4.4 FARM ENERGY DEMAND

Confinement livestock operations are major electrical and thermal energy users in the farm sector. Large energy consuming functions for dairy operations are: milk cooling and refrigeration, ventilation, gutter heating, livestock feeding, and hot water heating. A study conducted for a 200-cow dairy farm in northern New York measured these energy demands 1/. Since northern New York and northern Iowa have very similar annual heating degree days 2/, approximately 8,000 and 7,000, respectively, energy requirements would be expected to be quite similar also. This study found that in mid-December daily energy usage averaged 6.3 kWh per cow while

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1/ Stipanuk, D. M., et al. "Electrical Usage Patterns on a Dairy Operation" Paper No. 79-3506. American Society of Agricultural Engineers. December, 1979.

2/ Annual heating degree days are the sum of negative departures of average daily temperatures from 65°F.

mid-June energy usage was 2.6 kWh per cow. This is equivalent to a December daily energy demand of 4.3 million Btu and a June daily energy demand of 1.8 million Btu for the 200 cow herd 1/.

Swine confinement operations are also large consumers of electrical and thermal energy. Heating and ventilation are the primary energy consuming functions. Annual electrical power required to ventilate a 1,600 head confinement operation in the central Corn Belt is approximately 55,000 kWh 2/. This is equivalent to approximately 0.17 kWh per hog per day or 586 Btu per hog per day. During summer, ventilation is primarily for heat removal, while during winter moisture removal is the major concern. Additional energy is required during the winter for heating farrowing houses and nursery buildings. Approximately 2,100 gallons of LP gas plus 3,700 kWh of electricity are required to operate heater fans and heat lamps from November through February. This is equivalent to 2,144 Btu per hog per day. Thus, total winter ventilation and heating requirements are approximately 2,730 Btu per day per hog. For the 70-sow operation farrowing twice per year, with 525 hogs always in confinement, about 0.31 million Btu are required during the summer, and about 1.4 million Btu are required during the winter. For our 200-sow operation in which 1,500 hogs are always in confinement, about 0.88 million Btu per day are required during the summer, and about 4.1 million Btu per day are required during the winter 1/.

Grain drying is another operation that requires an extensive amount of energy. It is estimated that 0.0175 gallons of LP gas are required to dry a bushel of corn by one point of moisture. Also, 0.25 kWh of electricity are required to operate the blower during drying and aeration during storage 2/. Assuming the moisture content is typically reduced to 9 percent, 15,343 Btu are required to dry each bushel of corn. To dry 20,000 bushels of corn harvested at 24 percent moisture down to 15 percent moisture, a farmer must expend 307 million Btu of energy.

Finally, a diverse set of general farm and household functions are energy consumers. Household functions include activities such as clothes drying, refrigeration, and water heating. General farm activities include heating livestock drinking water, barnyard lighting, and operating welders and other shop tools. Records for a rural electric cooperative in central Iowa indicate that these activities use an average of 1,600 kWh per month or about 0.2 million Btu per day. If the home is electrically heated, this value would be considerably higher.

1/ Note: These Btu conversions from kWh are done at 3412 Btu/kWh. If electricity is to be used for the end-use, then the number of Btu of biogas to deliver one kWh will be about 17,000 at a 20 percent energy conversion efficiency.

2/ U.S. Department of Agriculture and Federal Energy Administration, A Guide to Energy Savings for the Livestock Producer. June, 1977.

4.5 ENERGY BALANCES

A daily energy balance is estimated for the model farms as total daily energy supply, minus total daily energy demand. Daily energy supply is defined as daily energy production potential estimated in Section 4.2, minus daily digester heating requirements. Daily energy demand is the sum of general farm demand and livestock operation demands estimated in Section 4.4.

A daily net energy balance is presented for both the summer and winter season due to seasonal variations in livestock and digester heating requirements. These tables show that during the summer each model farm has the potential to generate enough energy for digester heating and all other farm energy needs. Aside from the cooperative operations, which has no farm energy needs, the 200-cow dairy has the highest net summer energy balance, and thus the most energy for sale to other energy users.

During winter, each model farm is still able to satisfy its digester heating requirements, but since these heating requirements are substantially higher than during summer, energy available for other farm needs is greatly reduced. The 70-sow swine operation must buy almost all of its energy, and the 200-sow operation must buy almost half of its energy needs. However, the 200-cow dairy still sells excess energy, and buys energy only on days which are very cold or when the digester is operating at low efficiency.

Farm energy balance for a 70-sow swine operation
(million Btu/day)

	Summer	Winter
Supply:		
Energy production potential (average)	1.1 to 1.8	1.1 to 1.8
Less Digester heating requirement	0.1	0.9
Total energy available after digester heating	1.0 to 1.7	0.2 to 0.9
Demand:		
General Farm	0.2	0.2
Plus Swine operation	0.3	1.4
Total energy demand	0.5	1.6
Net farm energy balance:	0.5 to 1.2	-1.4 to -0.7

Source: DPRA estimates

Farm energy balance for a 200-cow dairy operation
(million Btu/day)

	Summer	Winter
Supply:		
Energy production potential	4.7 to 12.6	4.7 to 12.6
Less Digester heating requirement	0.2	2.2
Total energy available after digester heating	4.5 to 12.4	2.5 to 10.4
Demand:		
General Farm	0.2	0.2
Plus Dairy operation	1.8	4.3
Total energy demand	2.0	4.5
Net farm energy balance:	2.5 to 10.4	-2.0 to 5.9

Source: DPRA estimates

Farm energy balance for a 200-sow swine operation
(million Btu/day)

	Summer	Winter
Supply:		
Energy production potential	3.3 to 5.1	3.3 to 5.1
Less Digester heating requirement	0.2	1.6
Total energy available after digester heating	3.1 to 4.9	1.7 to 3.5
Demand:		
General Farm	0.2	0.2
Plus Swine operation	0.9	4.1
Total energy demand	1.1	4.3
Net farm energy balance:	2.0 to 3.8	-2.6 to -0.8

Source: DPRA estimates

Energy balance for a cooperative operation
(million Btu/day)

	Summer	Winter
Supply:		
Energy production potential (average)	11.9 to 25.0	11.9 to 25.0
Less Digester heating requirement	0.5	4.5
Total energy available after digester heating	11.4 to 24.5	7.4 to 20.5

Source: DPRA estimates

5.0 DIGESTER DESIGNS

Methane production from livestock manures is technically feasible 1/. In general, an anaerobic digestion system consists of a feedstock holding basin, a digester, a gasholder, and a basin to hold and dewater digester residue. Biogas plants may be simple or complex, based upon material availability, technical expertise, and general economy of the particular country. Biogas plants may be broadly classified as batch or continuous systems; only continuous systems will be considered in this analysis.

5.1 GENERAL DIGESTER DESCRIPTION

In order to maximize methane production optimum conditions for anaerobic digestion must be maintained. The raw materials (animal wastes) should be slurried with water, anaerobic bacteria must be present in sufficient numbers and actively growing, adequate nutrients must be present, strict anaerobic conditions must be maintained, and pH and temperature must be controlled 2/.

An efficient anaerobic digestion process requires environmental control parameters to be set at optimal conditions. These parameters include temperature, complete anaerobic conditions, adequate nutrients, pH, and absence or low concentration of toxic materials. Under equilibrium conditions, a digester will require a minimum of control. However, if any of the control parameters are suddenly changed, the system becomes unbalanced and gas production and waste stabilization decrease. When an imbalance in a digester occurs, the operator must first be able to identify the onset of problem and second be able to determine the nature and cause of the imbalance. Finally, the operator must be sufficiently trained to correct the problem. Therefore, although the systems may be largely automated, labor and maintenance costs are included in the costs of operating the digesters. These costs are in addition to those incurred with the manure handling and land spreading or other disposal operations now practiced on the farm.

1/ Hashimoto, A.G., and Y.R. Chen, Economic Optimization of Anaerobic Fermenter Designs for Beef Production Units, Livestock Waste: A Renewable Resource, 1980, pp. 129-132.

2/ Vause, Kurt H. and Sandra L. Woods, "Anaerobic Digestion of Animal Wastes", Handbook for Biomass Energy Conversion Systems, U.S. Department of Agriculture, 1980.

Schematic diagrams of each of the four representative digesters showing animal shelter, slurry feed tank, digester, biogas scrubbing, solids-liquids separation, and storage are included in Figures 5-1 to 5-4. These schematics are representative and sufficient for the economic analysis, but would not necessarily fit into a particular on-going farming operation. Specific digester types are not specified, nor are internal digester components, such as mixing systems. Actually, detailed engineering designs in this type of study could be misleading as each farmer's operation is unique. If maximum efficiencies are to be achieved, the appropriate engineering design must take into account such factors as the present farming operation, the livestock numbers and specific energy utilization by type.

The design of the biogas digestion systems which accompany this discussion are based largely upon published data and upon data gathered from manufacturers of digester equipment and systems. Sizing of digesters for different systems was based on design Volatile Solids (VS) loading rates, slurry concentrations and retention times provided in the literature 1/. For those systems where manure production varies considerably throughout the year, digester size was determined using high loading rates and short retention times for the maximum recommended loading conditions in order to keep digester size and cost down.

Biogas production rates in the digester systems designed are not certain. Digesters apparently produce biogas at very different rates. Also, manufacturers are very optimistic. For systems with constant loading, alternative biogas production rates are used to analyze the systems under potentially different biogas production levels. For systems with varying loads, production of biogas has been estimated at a rate dependent on volatile solids loading. Daily biogas production varies in these cases due to varying retention times.

System costs generally include manure/slurry preparation, digester with insulation, biogas storage, gas using generator (when electricity is generated), solids/liquids separation systems, and bottom sludge removal systems, controls, installation and start-up. Costs not accounted for include:

- Extensive excavation where topography requires it
- Construction of lagoons or solids storage pits
- Solids or liquids transportation or distribution
- Boiler or furnace cost, where electricity is not generated
- Land cost.

Specific assumptions, digester characteristic and cost estimates are discussed in turn for each of the digesters.

1/ Agricultural Anaerobic Digesters : Design and Operation, The Pennsylvania State University, College of Agriculture, Bulletin 827, November 1979.

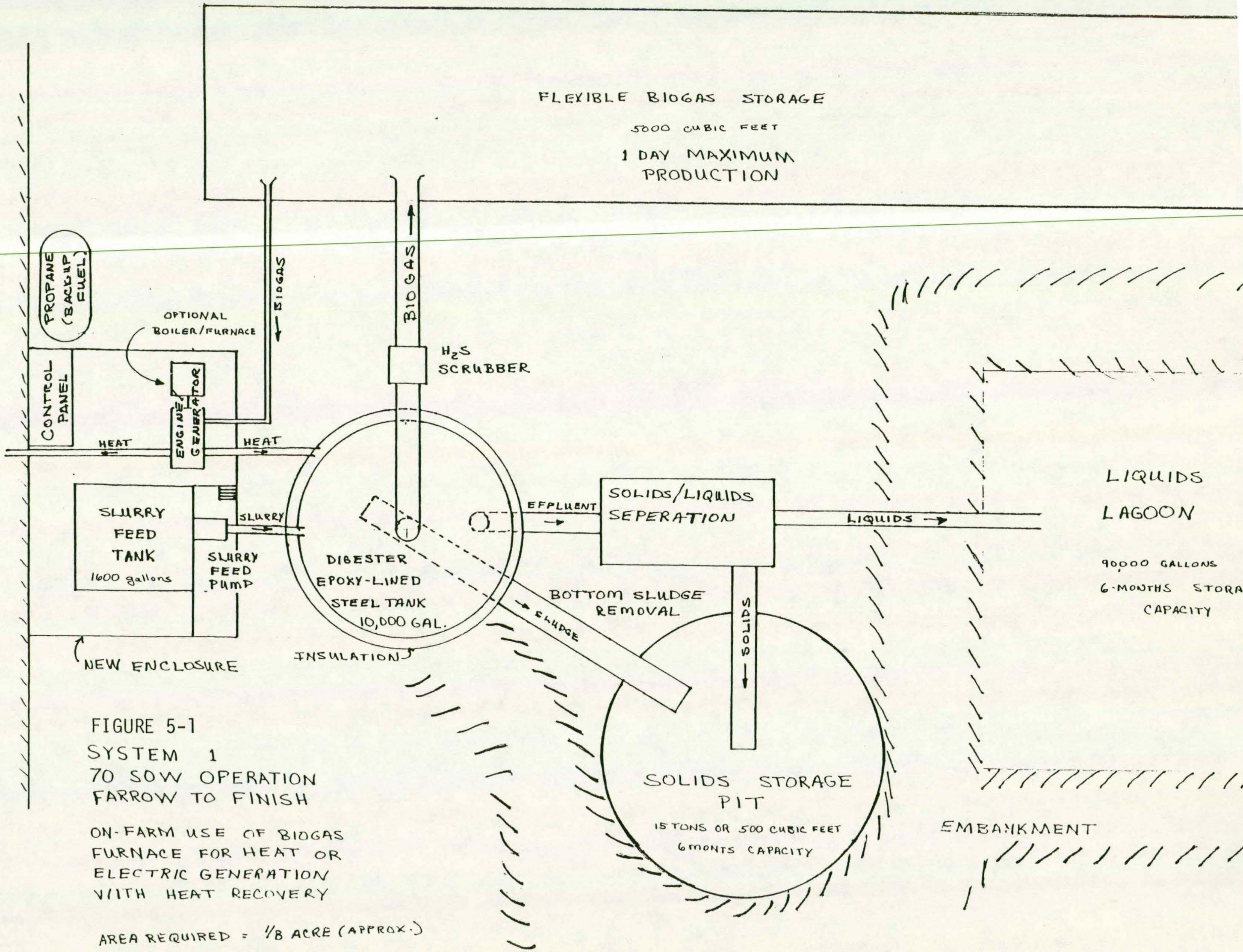
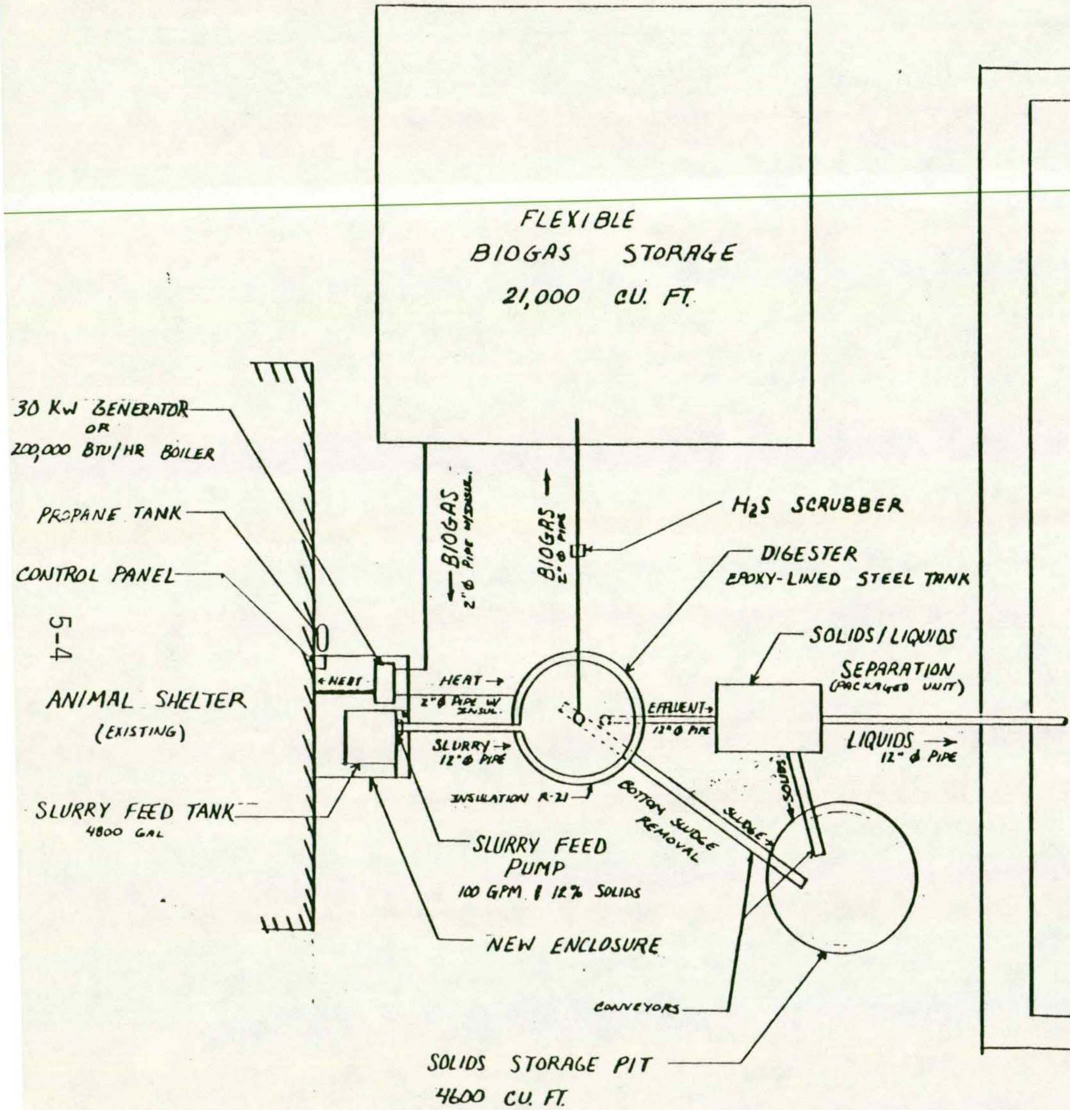


FIGURE 5-1
SYSTEM 1
70 SOW OPERATION
FARROW TO FINISH

ON-FARM USE OF BIOGAS
FURNACE FOR HEAT OR
ELECTRIC GENERATION
WITH HEAT RECOVERY

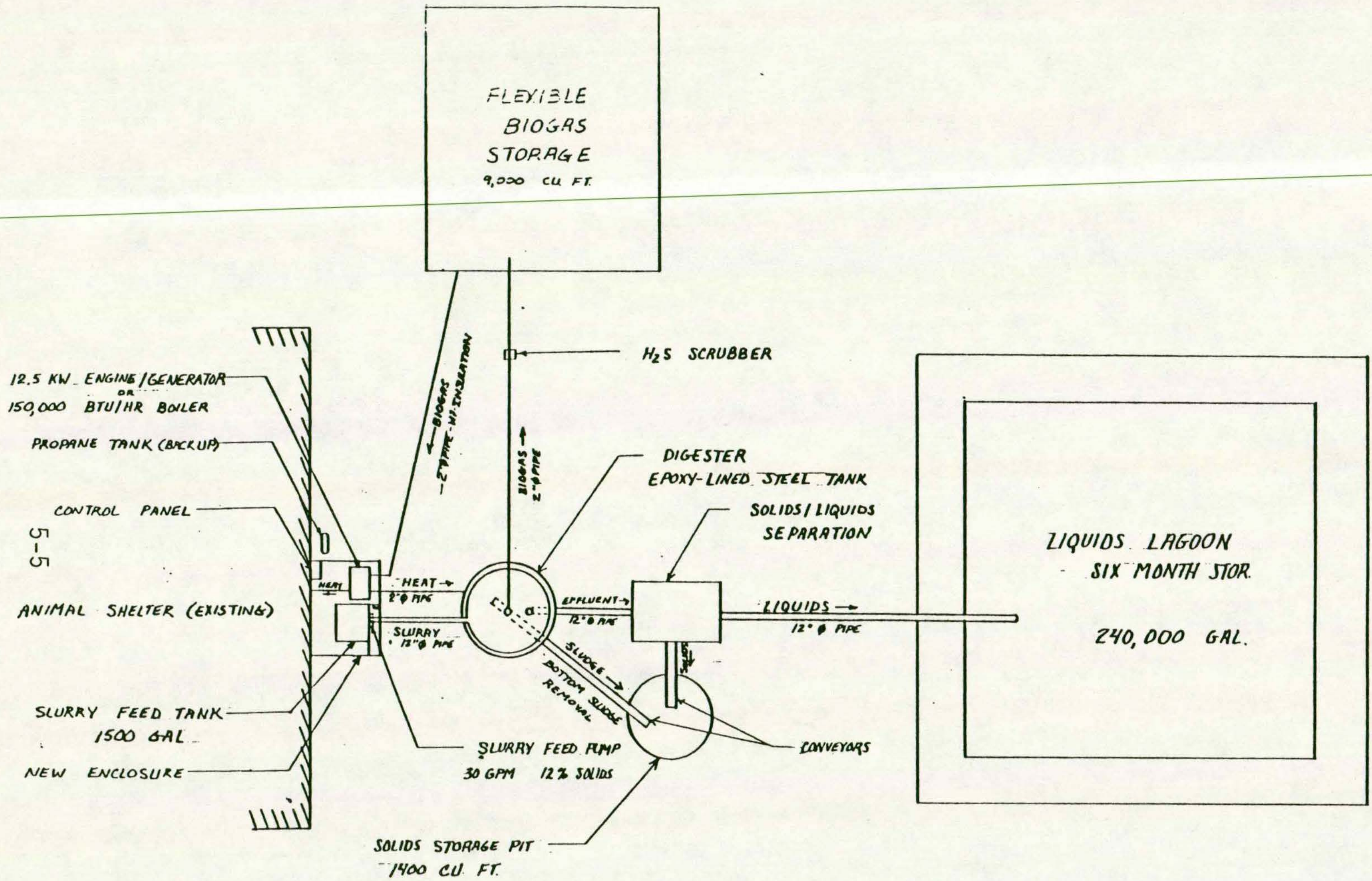
AREA REQUIRED = 1/8 ACRE (APPROX.)



NOTES

- THE DIGESTER TANK IS A STEEL WALLED TANK SURROUNDED BY HEAT EXCHANGER PANELS AND ENCLOSED WITH INSULATION (R-30 OVER HEAT EXCHANGER)
- AREA REQUIRED = 1/2 ACRE

FIGURE 5-2
SYSTEM 2A
200 COW DAIRY. ON-FARM USE OF BIOGAS FOR HEAT OR ELECTRICITY GENERATION WITH HEAT RECOVERY



NOTES

THE DIGESTER TANK IS A STEEL TANK SURROUNDED BY HEAT EXCHANGER PANELS AND ENCLOSED WITH INSULATION (R-30 OVER HEAT EXCHANGER)

AREA REQUIRED • 1/3 ACRE

FIGURE 5-3
SYSTEM 2B
200 SOW OPERATION
FARROW TO FINISH
ON-FARM USE OF BIOGAS
FOR HEAT OR ELECTRIC
GENERATION WITH HEAT
RECOVERY

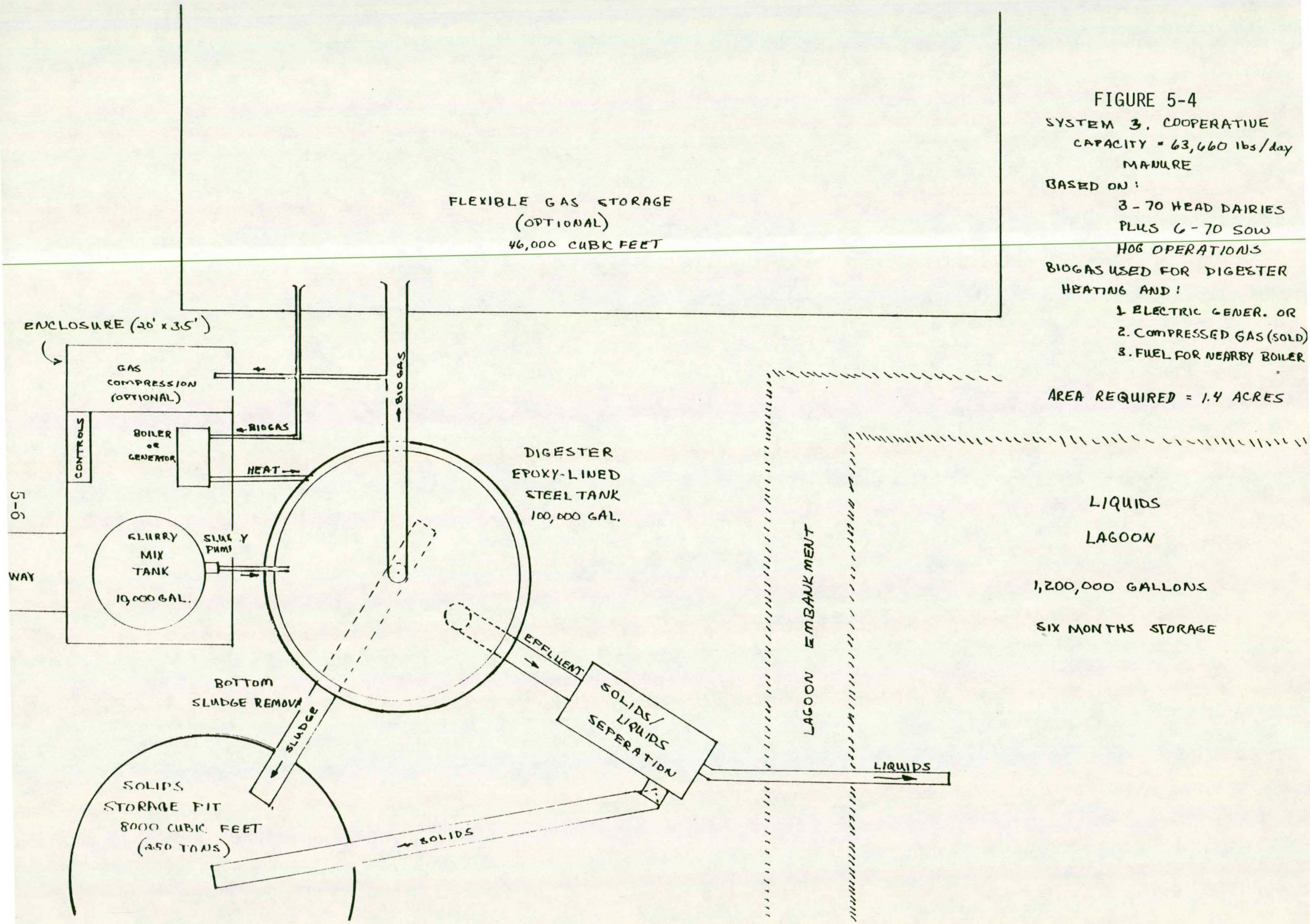


FIGURE 5-4

SYSTEM 3, COOPERATIVE
CAPACITY = 63,660 lbs/day MANURE
BASED ON:
3 - 70 HEAD DAIRIES
PLUS 6 - 70 SOW HOG OPERATIONS
BIOGAS USED FOR DIGESTER HEATING AND:
1. ELECTRIC GENER. OR
2. COMPRESSED GAS (SOLD)
3. FUEL FOR NEARBY BOILER

AREA REQUIRED = 1.4 ACRES

5.2 MODEL DIGESTER DESCRIPTIONS

For purposes of assessing the feasibility of methane production on the model or representative farms detailed in Chapter 4, anaerobic digestion systems suitable for such situations are described. For each of the digesters--70-sow operation, 200-cow dairy, 200-sow operation and cooperative operation--the manure produced, the design conditions, the biogas production, by-products production, and investment and operating and maintenance costs are estimated and tabulated in Tables 5-1 to 5-3.

5.2.1 System 1--70-Sow Operation

The small on-farm digester described below is suitable for a 70-sow operation that farrows twice a year. All hogs are confined on hard surface areas that are suitable for relatively easy and mechanized manure removal. The characteristics of the digester are summarized in Table 5-1. The manure production varies throughout the year (as described in Chapter 4) with the number and sizes of pigs confined. The digester size was based upon the maximum daily manure production of 6,510 pounds. The minimum is estimated to be 1,155 and the average 3,412 pounds per day.

The annual biogas production and the yearly variation are shown below.

Retention Time, Days	Rate of Biogas Production $ft^3/day/ft^3$	TS/Day	Daily Manure (lbs/day)	Number of Days at This Rate	Total Biogas, MCF
< 17	3.0	526	5,260	143	574
17-23	2.5	326	3,260	79	264
23-24	1.75	221	2,210	71	166
34-50	1.25	150	1,500	49	82
50-65	0.8	115	1,150	23	215
				365	1,111

Based on a biogas energy value of 600 Btu per cubic foot, the total annual energy production would be 667 million Btu. Assuming that digester heating requirements are 0.5 million Btu per day, the net energy production is 1.33 million Btu per day or 485 million Btu per year. The range of biogas production is 1,070 to 4,010 ft^3 per day or 0.62 million Btu to 2.40 million Btu per day. If biogas is used directly to heat the digester, enough biogas is available at all times. However, if electricity is generated with biogas, the minimum biogas production corresponds to 37 kWh per day electric generation. Assuming generator heat recovery potential of 50 percent of fuel input or 0.30 million Btu per day. Digester heat may be insufficient when the minimum in manure production occurs.

Two by-products, a liquid effluent with value as a fertilizer and a solids residue with value as a fertilizer and soil conditioner, are produced. Annual liquid effluent production is 82,000 gallons, assuming fifty percent recovery of liquid. Six months storage capacity of 82,000 gallons for the liquid effluent is provided. Annual solids digester residue production is 60,225 pounds or 30 tons.

Table 5-1. Characteristics of model digesters

	System 1	System 2A	System 2B	System 3
	70-Sow	200-Cow	200-Sow	Coop.
Manure production				
(lbs/day)	1,160-6,510	21,850	9,750	31,530-63,660
(avg. lbs/day)	3,410	21,850	9,750	45,072
Digester volume				
(ft^3)	1,337	5,660	3,650	13,400
(gal)	10,000	42,300	27,300	100,000
Retention time (days)	17-65	14	21	12-21
Biogas production				
(1,000 ft^3)	1.07-4.01	7.86-20.96	5.46-8.58	17.9-45.9
(avg.)	3,044			29.7
Energy value (mil. Btu/day @ 600 Btu/ft^3)	1.83 (avg)	4.7-12.6	3.3-5.1	17.8 (avg.)
Digester heating requirement (mil. Btu/day)	0.5	1.2	0.9	2.5
Net energy production (mil. Btu/day)	1.33 (avg)	3.5-11.4	2.4-4.2	15.3 (avg.)
<u>By-Products</u>				
Liquid effluent				
(gal/day)	75-435	1,500	650	4,140-2,390
(50% recovery)	225 avg.			3,125 avg.
Solids				
(lbs/day)	57-330	1,575	460	3,500-6,055
(60% recovery)	165			4,580 avg.

Table 5-2. Investment and operating costs for on-farm digesters

	System 1	System 2A	System 2B
	70-Sow	200-Cow	200-Sow
Basic system ($) Digester Slurry feed equipment Installation or supervision startup Solids separation equipment	27-35,000	65-100,000	45-75,000
Engine/generator ($) (size)	6-8,000 (7.5 kW)	25-30,000 (30 kW)	10-12,000 (12 KW)
Gas compression and storage ($)	---	20,000	20,000
Operating costs Labor ($/yr)	2,000	2,000	2,000
Maintenance (annual)	3% of investment	3% of investment	3% of investment
Electricity @ $.06.kWh ($) (kWh/day)	1,095 50	2,400-3,940 110-180	1,100 50
Digester heating ($) (million Btu/day @ $.50/gal propane equivalent)	1,040	2,500	1,872

Table 5-3. Investment and operating costs - cooperative operation

Capital costs	Gas compression for use at other locations	Electricity generation and sale	Sale of biogas as fuel substitute to nearby facility
	dollars		
Basic Components ($)	110,000	110,000	110,000
Digester Slurry Feed Eq. Solids/liquids Separation Installation & start up			
Gas compression	35,000		
Engine/generator Tie in (65 kW)		50,000	
Boiler mod. & piping			15,000
Solids/liquids & feed storage	10,000	10,000	10,000
Truck for pickup of manure	50,000	50,000	50,000
Total Capital Costs	205,000	220,000	185,000
Operating costs			
Labor-truck driver & operator (365 days)	47,000	47,000	47,000
Electric power	4,800 (220 KWh/day)	2,000 (90 KWh/day)	2,000 (90 kWh/day)
Maintenance	6,200	6,600	5,600
Digester heating (2.5 mil. Btu/day @ $.50/ gal propane equivalent)	5,200	5,200	5,200

The investment and operating costs estimated for this digester are shown in Table 5-2. The investment costs obtained from company representatives for the basic components range from $27,000 to 35,000. If it is desired to generate electricity, generator cost adds $6,000 to 8,000. This cost includes the interface required for connecting and selling to a local utility. Operating costs include labor at $5.00 per hour for approximately one hour per day. Maintenance costs were estimated as three percent of the investment costs. Electricity was estimated at $.06 per kWh, since the Iowa average is $.05 to .07 per kWh. Digester heating cost was estimated on the basis of equivalent energy value of propane at $.50 per gallon. In the financial analysis, the operator was also given credit for the digester fuel, assuming a portion of the biogas was used for digester heating.

5.2.2 System 2A--200-Cow Dairy

The digester for the 200-cow dairy is designed assuming that all cows are confined to hard surface area at all times. The manure production is assumed to remain relatively constant throughout the year at 21,850 pounds per day.

Biogas production estimates vary from 7,860 to 20,960 cubic feet per day, depending on the digester design and operating conditions. Gross energy production is 4.7 to 12.6 million Btu per day. Digester heating will consume 1.2 million Btu resulting in net daily energy production of 3.5 to 11.4 million Btu or 1,280 to 4,600 million Btu per year. By-products produced are 1,500 gallons per day of liquid effluent and 1,575 pounds per day (287 tons per year) of solid residue.

The investment cost for the basic digester components ranges from $65,000 to 100,000. A 30 kW engine generator will cost an additional $25,000 to 30,000. For gas compression and storage capabilities, the investment cost is $20,000.

Operating costs include $2,000 for labor, valued at $5 per hour for about one hour per day year round. Electricity costs vary from a high of $3,940 to $2,400 (110-180 kWh at $0.06/kWh). Digester heating of 1.2 million Btu per day were valued at an equivalent energy value of $0.50 per gallon of propane.

5.2.3 System 2B--200-Sow Operation

The digester system described below assumes that the 200-sow operation has staggered year-round farrowing. All hogs are confined to hard surface areas. Manure production is relatively constant throughout the year at 9,750 pounds per day.

The characteristics of the digester are shown in Table 5-1. The digester volume is 27,500 gallons. Biogas production estimates range from 5,460 to 8,580 cubic feet (3.3 to 5.1 million Btu) per day. The Digester heating requirement is 0.9 million Btu per day. The net biogas production is 2.4 to 4.2 million Btu per day (876 to 1,530 million Btu per year).

Approximately 650 gallons of liquid effluent and 460 pounds of solid residue are produced daily.

The estimated investment cost for the basic digester components vary from $45,000 to $75,000. A 12 kW engine/generator costs an additional $10,000 to 12,000 and gas compression and storage capability costs $20,000.

Labor costs are estimated at $2,000 per year assuming $5.00 per hour and approximately one hour per day for the entire year. Annual maintenance costs for purposes of the analysis were assumed to be 3 percent of the investment. Electricity cost of $1,100 were calculated assuming $0.06 per kWh and requirement of 50 kWh per day. Digester heating costs were estimated on the basis of equivalent energy value of $.50 per gallon for propane. For the financial analysis, it was assumed that a portion of the biogas was used to heat the digester; credit was given for this biogas.

5.2.4 System 3--Cooperative Operation

The cooperative operation was set up to include three 75-cow dairies and six 70-sow swine operations with two farrowings per year, presumably spring and fall. Total manure production varies from a high of 63,660 pounds per day just prior to hog marketing to a low of 31,530 immediately following farrowing.

The characteristics of the digester for this system are summarized in Table 5-1. The digester volume is 100,000 gallons. Daily biogas production ranges throughout the year from 17,900 to 45,900 cubic feet and averages 29,700 cubic feet. The energy value averages 17.8 million Btu per day for a total annual production of 6,500 million Btu. Digester heating requires 2.5 million Btu leaving an average net energy production of 15.3 million Btu per day or 5,600 million Btu per year.

The quantity of the liquid effluent produced depends on digester loadings and ranges from 2,390 to 4,140 gallons and averages 3,125 per day. An average of 4,580 pounds per day of solids or 850 tons per year are produced.

Digester investment and operating costs are summarized in Table 5-3. The capital cost for the basic digester is $110,000. If the biogas is to be sold for boiler fuel or space heating at a nearby facility, an additional $15,000 investment is required. On the other hand, if the biogas is used for electricity generation, a 65kW engine/generator costing $50,000 is required. For all cases a tank truck for pickup of the manure is required. Operating costs consist of labor for the truck driver and digester operator of $47,000. Labor was valued at $8 per hour (average of regular and premium time). Truck driver and plant operator each work 8 hours per day, 365 days per year. Electricity costs were calculated at $0.06 per kWh. Digester heating costs are calculated on the basis of energy equivalent value of propane at $.50 per gallon. Credit was given for biogas for digester heating in the financial analysis.

5.3 OTHER CONSIDERATIONS

5.3.1 Safety Considerations

The use of animal wastes for methane generation in biogas plants involves both public health and safety concerns. Since the biogas produced is potentially explosive, precautions must be taken against fire and explosion in and around the digester. Biogas is no more dangerous than natural gas or propane, however, as with other fuels, it should be used with the care due a material that can attain explosive concentrations in air. The two most important safety precautions are avoidance of explosive mixtures of biogas with air and prevention of sparks. Since biogas can only explode at concentrations from 9 to 23 percent by volume in air, enclosed areas where gas can accumulate are the most dangerous. Small leaks are almost impossible to prevent, therefore, good ventilation of enclosed areas is important. A checklist of safety precautions for biogas plants is presented in Table 5-4.

Safety factors such as shut off valves in the gas handling systems will be provided in a well designed and engineered facility. The safety aspects make it imperative that properly designed and constructed digestion systems be utilized.

5.3.2 Potential Disease Problems

A major potential limitation to the feasibility of the cooperative venture has been identified. Little consideration has been given previously to assessing the economic feasibility of a central digestion facility due to the high cost of transporting animal wastes long distances and to possible disease problems 1/. Animal science professionals and veterinarians agree that the disease problems are real. Diseases that could be transmitted via the waste collection truck's wheels or the suction tube are more serious with hogs than with dairy cattle. One especially serious disease among hogs is TGE, transmissible gastroenteritis. Other hog diseases mentioned were swine dysentery (bloody scours), salmonella infections, and colibacillosis.

Although much less likely, the possibility of transmitting diseases among dairy cattle via the waste collection truck exists. Serotypes of E. coli and salmonella could conceivably be carried from farm to farm by the truck or the driver.

In order to decrease the possibility of transmission of diseases from one livestock operation to another by the manure collection truck, sanitation procedures could be required. One such procedure would be to have the truck drive through a disinfector vat prior to entry to the farm collection point. Alternatively, the waste could be collected at an off site (roadside) pick-up location.

1/ J. R. Fischer, *et. al.*, Transaction of the ASAE, 1981, 1264.

Table 5-4. Checklist of safety precautions for biogas plants

1. Prevent biogas from mixing with air in confined areas. Methane is explosive when mixed with air in proportions of from 5 to 15 percent (by volume).

2. Purge gas lines of any air prior to use.

3. Install flame traps in delivery lines near the point of use (e.g., near cooking stoves). These can range in sophistication from elaborate mechanical devices to simply a plug of steel wool for very small systems.

4. Provide adequate ventilation around gas lines.

5. Install a water trap on gas lines.

6. Protect all gas lines from freezing.

7. Remove any sources of sparks or flames near the digester or gasholder.

8. Install fire extinguishing materials and equipment at or near the digester and gasholder.

Source: National Academy of Sciences, Methane Generation from Human, Animal and Agricultural Wastes, 1977.

Another waste collection method might be considered. The farmer could deliver the wastes to the central digester in his own honey wagon. The waste delivery could be more readily standardized and better sanitation controls could be instituted that would lessen the possibility of disease transmission.

6.0 COST-EFFECTIVE SYSTEMS

In order to determine the cost effective sizes and types of digester systems, first the viable uses for the biogas or methane and the by-products must be examined, the alternative uses for the animal wastes considered, and the value of input materials and products estimated either in terms of their market value or that of competitive products. Next, the cost of producing biogas in a specific digester is calculated. Finally, the feasibility of a specific energy producing system may be assessed.

6.1 OPPORTUNITIES FOR UTILIZATION OF BIOGAS

Biogas has a composition of approximately 60 percent methane and 40 percent carbon dioxide and other gases. The compositions of biogas and natural gas are compared below.

	Biogas	Natural Gas
	percent	
Methane	54-70	96.1-98.1
Carbon dioxide	27-43	0.8
Hydrogen sulfide	1-5	
Carbon monoxide	0.1	
Hydrogen	1-10	
Nitrogen	1-5	1.1-3.2
Oxygen	0.5-1	
Others	trace	

Source: Vause, 1980.

The heating value of biogas ranges from 540 to 700 Btu per cubic foot; the exact value is determined by the methane content. Biogas can be upgraded to essentially pure methane by removing the carbon dioxide. Methane has a heating value of approximately 1,000 Btu per cubic foot.

Biogas can be utilized as an energy source in two basic ways: as the mixture of methane and carbon dioxide as produced or converted into pure methane. Pure methane can be produced from biogas by scrubbing the carbon dioxide and other gases from the mixture. Though gas scrubbing is not particularly complex, the systems require substantial capital investment. Therefore, carbon dioxide removal should only be considered when methane can be sold for pipeline distribution or when substantial storage is necessary. Energy in the form of pure methane can be stored more compactly than in the form of biogas. Biogas has various potential household and farm uses; its use as a vehicle fuel is usually limited by the unfavorable economics of gas storage, i.e., low pressure storage requires very large container volumes while high pressure storage requires expensive compression equipment. Hydrogen sulfide and water can be removed to minimize corrosion and plugging effects, although not all impurities need to be removed for every use.

Biogas can be used directly in boilers and water heaters of many types with only minor modification of equipment. Burner equipment modifications include:

- Enlargement of burner nozzle orifices from the standard natural gas or LP designed orifices. The heating value of biogas is only 30 percent of LP gas and 60 percent of natural gas. LP gas burner orifices should be enlarged by about 70 percent.

- Air supply to the burner should be reduced. Air inlet ports on conventional boilers can be almost entirely closed.

- A separate fuel source, such as LP gas should be used for pilot fuel. This is primarily a precaution should the supply of biogas be interrupted.

In addition, one treatment measure -- the removal of water vapor -- should be provided for biogas before combustion in boilers and water heaters of any type. A system for cooling and heating the gas in combination with condensate traps will facilitate the delivery of biogas to valves and orifices without risk of condensation in these narrow channels. An example of such a moisture removal system is shown in Figure 6-1.

Biogas-fueled engines are common in municipal sewage treatment plants. Many experimental digesters have furnished gas for engines, tractors, trucks, or automobiles. However, a fuel tank that would store sufficient biogas to operate a mobile vehicle will be quite large, so use of biogas as a motor fuel will likely be confined to stationary engines.

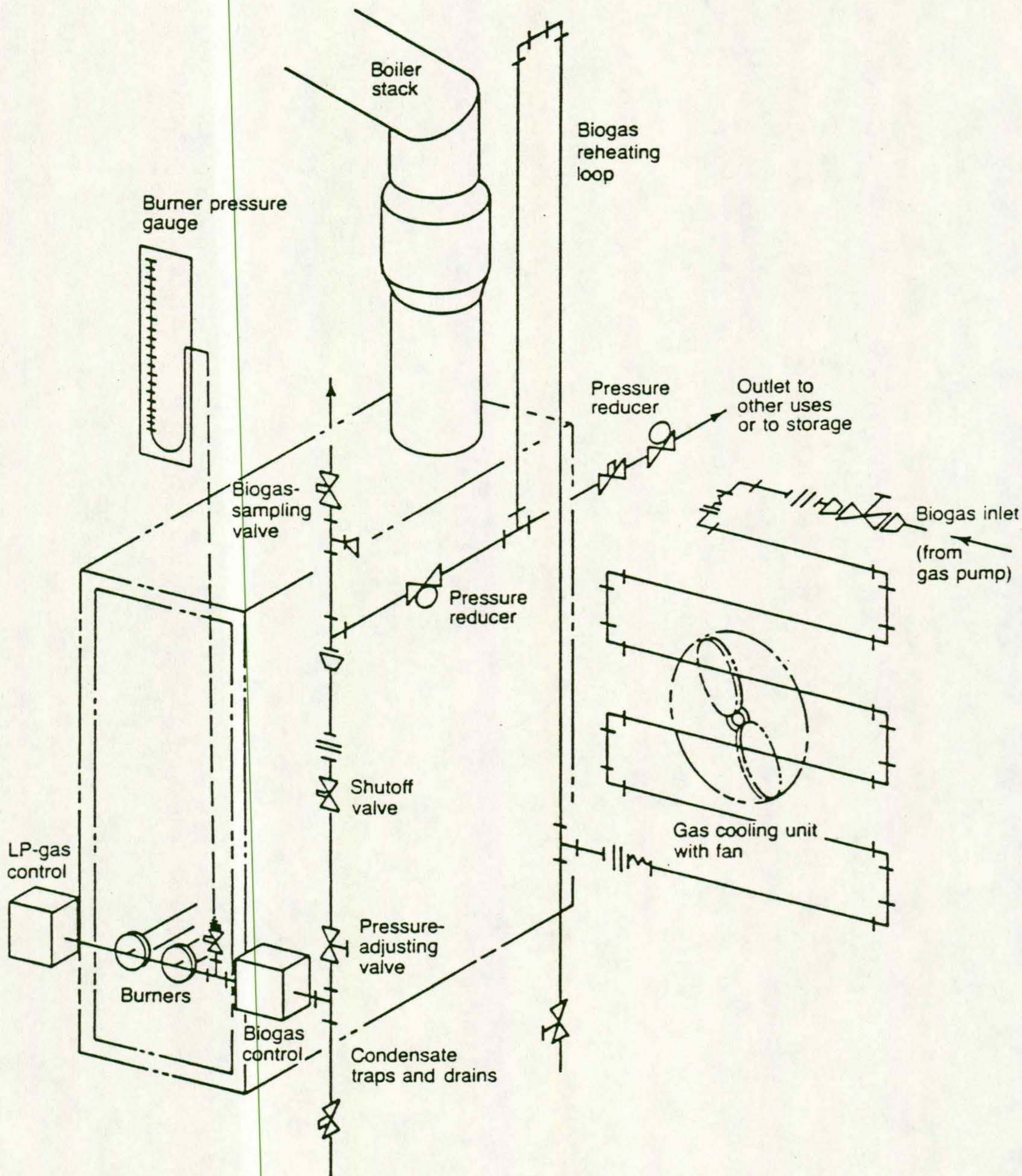
Biogas has a high (100 to 110) octane rating and consequently can be used in high compression engines. However, the high octane rating also means that the fuel mixture must be ignited by a spark or by some other fuel. In spark-ignition engines, biogas alone can be used as fuel. In diesel engines, however, a small amount of regular diesel fuel must be injected in order to achieve ignition of the biogas. In this case, the engine may run on 20 percent diesel fuel and 80 percent biogas.

The heat value per unit volume of an appropriate biogas-air mixture is only 60 percent of the heat value of a gasoline-air mixture, and only 75 percent of the heat value of the fuel mixture used in a diesel engine. Consequently, the maximum power output from an engine operated on biogas will be 20 to 40 percent less than that of the engine operating on liquid fuels 1/.

1/ Source: Pennsylvania State University College of Agriculture, Bulletin 827.

Figure 6-1. SYSTEM FOR

MOISTURE REMOVAL FROM BIOGAS BEFORE COMBUSTION



Source: Pennsylvania State University College of Agriculture, Bulletin 827.

Conversion of a compression-ignition (diesel) engine from liquid fuel to dual fuels, diesel fuel-biogas, is more complicated than conversion of a spark-ignition engine; however, energy conversion should be more efficient with a diesel operation.

The biogas energy uses that will be assessed for the on-farm systems will be limited to direct burning for on-farm space heating and crop drying, use in stationary engines, and generation or cogeneration of electricity for use on farm and for sale to the utilities (see Section 4.3).

The energy use for the biogas produced by the cooperative venture will be limited to use in an adjoining energy consuming unit and sale as electricity. For the size unit considered here, it is anticipated on the basis of a previous study 1/ of a 100,000 head cattle operation that the increased cost of purifying the biogas to the extent required for pipeline quality gas is too great.

With some 65,000 factories of all types, vocational technical schools that operate year round, and other energy consuming units in Iowa 2/, the opportunity to integrate the energy produced from digestion of animal wastes with an existing industrial or other energy consuming facility would appear to be good. New industrial facilities offer additional and perhaps an even better opportunity as the energy produced via anaerobic digestion could be an integral part of the original design of the facility. An example of the success of such cooperation and coordination may be found in a Northern Iowa town with a population of less than 3,000. There, engineers for a manufacturing plant that uses natural gas for heat treating materials have done extensive work through recycling for energy conservation. Similarly, it is likely energy from anaerobic digesters could be adapted if it proved feasible for a site.

Energy from anaerobic digestion of animal wastes might be either the primary or a supplemental energy source. The energy could be utilized by direct burning for space heating, boiler fuel, for generation of electricity, or for cogeneration of both electricity and heat.

The ideal location for the cooperative venture is adjacent to an energy consuming unit. The unit could be a fermentation ethanol production facility. For this type of operation, the energy usage has been estimated 3/ to be 82,000 Btu per gallon of 200 proof ethanol, broken down by operation as follows:

1/ Sailor, Michael K. and Louis A. Light, Biogas: Full Scale Process Design, Am. Society of Ag Engineers, Paper No. 81-4538, December, 1981.

2/ Iowa Development Commission.

3/ David, Milton L., et al. Small-Scale Ethanol Production for Fuels. U.S. Department of Agriculture. 1980.

Operation	Btu/gal of 200-proof ethanol
Cooking	3,600
Distillation	28,000
Dehydration	20,000
Drying	21,000
Miscellaneous	9,400
	82,000

Assuming 80 percent boiler efficiency, 102,500 Btu or 170 s.c.f. of biogas (600 Btu/scf) are required to produce 1 gallon of ethanol; thus, the net energy, 2,700 million Btu/year, produced by an average 200-cow dairy farm could provide sufficient heat energy for production of 90 gallons per day or 22,500 gallons of ethanol per year. (Assumes all energy is used in the ethanol plant; no on-farm energy used.) Even though the digester would be expected to continue operation on a uniform basis 365 day a year, ethanol and many other manufacturing facilities normally do not. For purposes of estimating ethanol production, it is generally assumed that the plant operates 240 to 250 days per year, with planned down time for routine maintenance and repair.

In addition to the heat energy requirement, an estimated 0.5 kWh gal of electrical energy is also needed in an ethanol plant to operate the grinder, augers, mixers, pumps and lights. These energy requirements too could be provided by biogas utilization in a generator.

For a specific site assessment, those involved in the cooperative venture would want to assess carefully the energy required at a particular location and determine definite opportunities for sale of the energy produced--either for direct firing electricity generation or cogeneration producing electricity and using the heat energy produced by the operation.

To be cost effective, the cost of producing biogas in the digester must be no more than the cost of competing energy sources.

In order to determine if the systems analyzed are feasible, the cost of the biogas produced will be compared with that of the price of the energy source it displaces.

If the biogas is to be used for direct heating, the two fuels likely to be substituted for are natural gas and propane. Natural gas prices average $4 per million Btu. (The heat value gives a better basis for comparison than does the volume.) This method of comparison takes into account the fact that natural gas has a heat content of 1,000 Btu per standard cubic foot while that of biogas is about 600 Btu/s.c.f. Propane prices are $5.70 per million Btu ($.50/gallon; 87,200 Btu/gallon).

In Iowa, electricity costs vary from about 4-7¢ per kWh, with an average value of approximately $0.06 per kWh (Iowa Commerce Commission). The value of the electricity produced by burning biogas in the engine/generator will on average be valued at 6¢/kWh if the energy is being used on the farm in lieu of purchasing from a rural electric cooperative or an investor owned utility. If the electricity is to be sold to the utility, then the price the utilities will pay (see Chapter 7.0 for discussion of PURPA) is their avoided cost. The rate paid to small qualifying generators in Iowa is 2½ to 3¢ per kWh. The value of biogas then depends on the competing fuels.

6.2 ALTERNATIVE USES OF ANIMAL WASTES AND DIGESTER PRODUCTS

The conventional use for agricultural animal wastes has been as fertilizer. An approximate analysis of average manure 1/ is 10 pounds nitrogen (N), 5 pounds phosphorus (as P_2O_5) and 8 pounds potassium (as K_2O) per ton of manure. At the current prices 1/ for commercial fertilizer of $.26 per pound of N, $.28 per pound of P_2O_5 and $.13 per pound of K_2O, the value of one ton of manure for fertilizer is $5.04.

This compares favorably with a 1982 value calculated 2/ by Bob Wright of Sperry, New Holland. He estimated that the manure from a 50-cow Holstein herd was in excess of $3,000, even assuming there is some loss between the cow and the crop. The fertilizer value loss can be minimized if the manure is handled as a slurry, stored in a deep pit and knifed into the ground. Since the animal wastes do have a value to the farmer, the feasibility analysis was conducted using a value of $3 per ton for the raw manure. For purposes of the analysis, we also assumed that the liquid effluent had value as fertilizer and the solid residue had value as a soil conditioner. The liquid effluent was valued at $10 per 1,000 gallon and the solids at $2.40 per ton.

In some instance where digesters are located near metropolitan areas, there is a demand by local gardners for the solids as a soil conditioner. In these cases, the solids are priced at up to $75 per ton. In one instance, the solids are being sold to mushroom growers. Should farmers-digester operators find they too are in an unusual situation that would allow them to sell the by-products for a greater value, the by-product credit would be increased. At the same time, there are associated higher costs for drying, selling, bagging and additional equipment.

It has been suggested that the digester solids may be refed to beef cattle. (These solids are unsuitable for dairy cattle as the caloric requirements of a proper dairy cow ration preclude its inclusion. The solids are not beneficial for swine as they are monogastrics and cannot digest cellulose.)

1/ Dr. Larry Murphy, Agronomist, Potash Phosphate Institute, Manhattan, Kansas

2/ High Plain J., Jan. 25, 1982, p. 6A.

Early feeding trials had indicated that digester solids had potential as a protein-rich animal feed. In feeding studies of sheep and steers 1/, it was shown that dried centrifuged solids can be fed at up to 10 percent of dietary dry matter and not alter markedly the utilization of diet components. Major disadvantages of feeding the dried solids are that considerable nutrients were lost by centrifugation and the capital and energy costs required for the installation and operation of the centrifuge and the drying systems are extremely high. With elimination of the drying process, additional nitrogen is retained, but storage of the wet solids would be a problem during both hot and cold weather.

In a recent full-scale feeding trail 2/, the feeding value of the centrifuged digester effluent was only marginal. Both the energy and protein value were less than expected. It is suggested that in part the results may be attributed to the long digester retention time used that may result in more extensive manure degradation. Problems remain to be solved before a value can be assigned to digester solids used for refeeding.

6.3 FINANCIAL FEASIBILITY

Various approaches are used for analyzing prospective investments. These approaches all use much the same data, i.e. revenues and costs; however, the treatment of these data vary. The method used in this analysis is the discounted cash flow, or life cycle costing. The discounted cash flow method is one of the more rigorous in that it considers both the timing of cash flows and the time value of money.

6.3.1 Data Inputs

Most of the required inputs for the financial analysis were discussed earlier in the report. Specifically, plant investment and operating cost, and animal waste and by-product values. In addition, the financial parameters -- working capital, inflation rates, cost of capital and income and other tax factors -- are required. These items are discussed below.

6.3.1.1 Working capital

In addition to the investment outlays for the facility, working capital will be required to finance ongoing operation. Working capital requirements, in general, depend on operating practices with respect to

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1/ Prior, R. L., R. A. Britton and A. G. Hashimoto, "Nutritional Value of Anaerobically Fermented Beef Cattle Wastes in Diets for Beef Cattle and Sheep." Livestock Wastes, A Renewable Resource. The Proceedings of the 4th International Symposium on Livestock Wastes. 1980, pp. 54-60.

2/ Coppinger, Elizabeth R., and Michael Richter, ASAE Paper No. 81-4537. 1981.

inventory prices, accounts payable and receivable. This is particularly important for the cooperative venture. For purposes of the analysis, the working capital requirement was estimated in terms of the investment (approximately 10 percent) rather than raw material and by-product prices due to the lack of established market prices.

6.3.1.2 Inflation rates

During the last 15 years, inflation rates have been sufficiently high to warrant their inclusion in financial analyses. The average rate of general inflation over the past decade has been about seven percent (as indicated by the Implicit Gross National Product Deflator), although the rates have approached or exceeded nine percent in several years. However, energy prices increases have increased more rapidly than the general price level.

For purposes of this analysis, a general inflation rate of 8.0 percent and an energy inflation rate of 11.0 percent were used.

6.3.1.3 Cost of capital

The cost of capital is the value used to reflect the time cost of money. Based on information from bank agricultural officers, a representative capital structure of 80 percent debt and 20 percent equity was established. An interest rate, the cost of debt capital, of 13 percent was used. The cost of equity capital, the return the digester operator gets on his equity capital, was set at 15 percent. The return on equity represents the return a farmer could obtain on an alternative investment. For comparison, one farmer-digester operator used a 20 percent return as one of the criteria for deciding whether to install a digester.

6.3.1.4 Income taxes

An income tax rate representing federal and Iowa income taxes of 25 percent was used for the on-farm and the cooperative ventures. The on-farm digester would be a part of the total farming operation, but it was assumed that the taxes on digester profits would be at the highest (marginal) rate paid by the farmer.

6.3.1.5 Other taxes

Property improvements for energy producing systems are exempt from property tax, if the energy produced is used by the owner. If a portion or all of the energy is sold, the property tax might be prorated; however, no official ruling has been made. In this analysis, no property tax was included.

6.3.1.6 Insurance

As the biogas produced in the anaerobic digester is flammable and potentially explosive, insurance is desirable. None of the insurance companies contacted had established rates for an anaerobic digester. For the analysis, an insurance rate equal to one percent of the investment was included.

6.3.2 Discounted Cash Flow Analysis

The discounted cash flow analysis involves estimating year-by-year investment outlays, the cost components and revenues, reflecting inflation. These values are then discounted back to present values and summed. If the sum of the present values (net present value) are zero or greater, the project is financially feasible; if they are less than zero, the project is not feasible for the assumptions, conditions, and data used in analysis.

For these analyses, the net present value was set equal to zero and the minimum value the product must have for the project to be feasible was calculated. The product value in dollars per million Btu of biogas was calculated. For the values calculated, return to and return on equity were obtained as specified in the analysis; i.e. the owner received 15 percent return on the equity investment.

6.4 FULL COST OF BIOGAS

For the four digesters analyzed, the full cost of the biogas produced was calculated. These values include labor, electricity, maintenance, insurance, income taxes and the return of and return on the investment. The values are summarized in Table 6-1. The results for each digester are discussed in detail below in terms of substitute fuel value. For all four, the fertilizer value only for the raw materials and the digester residues was assumed.

6.4.1 System 1: 70-Sow Operation

For this system, the best situation was assessed, i.e., the lowest investment cost and the highest biogas production rate were used. The digester heating fuel was assumed to have an energy value equal to that of propane at 50 cents per gallon. Under these conditions the full cost of the biogas is $11.60 per million Btu. This fuel cost is equivalent to $1.01 per gallon of propane (87,200 Btu per gallon).

Another analysis was conducted in which no charge was made for the animal wastes and no credits were given for digester by-products (credit was given for biogas used for digester heating). Under these conditions, the full cost of the biogas is $10.50 per million Btu. This is equivalent in energy value to propane at $.92 per gallon.

6.4.2 System 2A: 200-Cow Dairy

The assessment of the best situation (i.e. low investment cost, high biogas yield) for digester 2A yielded a full cost of biogas of $4.30 per million Btu. Biogas at this cost would substitute in energy value for $.37 per gallon propane.

In what probably constitutes more nearly average operating and investment conditions, the full cost is $5.90 per million Btu. For this assessment, the investment cost of $80,000 (rather than 65,000) and a biogas production of 3,440 million Btu per year (rather than 4,600) were used.

Table 6-1. Full cost of biogas production under varying assumptions

	System			
	1	2A	2B	3
	70-Sow operation	200-Cow dairy	200-Sow operation	Cooperative
	----------------$ per million Btu--------------			
Assumptions				
High biogas yield Low Investment	11.60	4.30	6.45	12.90
High Yield with Electricity Generation	---	---	7.10	---
Average Biogas Yield Average Investment	---	5.90	9.20	---
Average unit with Electricity Generation	---	6.22	---	---
Low Biogas Yield High Investment	---	14.80	13.20	---

For this same system, an analysis was performed in which the generator was included. For this case, the full cost of biogas was $6.20 per million Btu. When this biogas is used to generate electricity, the cost is $.11 per kWh.

To provide a full range of cost of biogas production, a third analysis consisting of high investment and low biogas yield was conducted. The cost of producing biogas under these conditions was calculated to be $14.80 per million Btu.

Thus, the ranges of possible digester investment costs coupled with the ranges for biogas production yield a range of costs for biogas produced from 14.80 to 4.30 per million Btu, corresponding in energy value to propane at $1.29 to 0.37 per gallon.

6.4.3 System 2B: 200-Sow Operation

Three investment-biogas production options were examined for this system. For the low investment cost, high biogas production option, the full cost of biogas production is $6.45 per million Btu. The full cost of biogas for the average investment, average biogas production conditions is $9.20 per million Btu.

The full cost of biogas for the high investment, low yield biogas production is $13.20 per million Btu. The corresponding price of propane with an equivalent energy content is shown below:

Biogas ($/mil. Btu)	Propane ($/gal)
6.45	.56
9.20	.80
13.20	1.15

6.4.4 System 3: Cooperative Operation

The cooperative operation consists of the digester and the truck used to collect and haul the manure from the farm to the central digestion facility. Additional labor costs are incurred over that required for the on-farm systems. At a minimum 1½ to 2 employees are required, a digester operator and a truck driver. The analysis, was conducted using the investment and operating costs shown in Table 5-3. The full cost of biogas produced is $12.80 per million Btu. It should be noted that no transportation costs were included for hauling animal waste to the digester nor for hauling liquid effluent or solids to the buyer. If the biogas could be used nearby as a boiler fuel, it would not be competitive with propane until the propane price reached $1.12 per gallon, or with natural gas until its price reached $12.80 per million cubic feet.

6.5 Conclusions

Of the four digester systems selected for analysis, the 200-cow dairy is the most promising. Since the exact biogas production levels to be attained for a specified investment costs are unknown, the best that can be done is to show a plausible range of values. If the operational conditions required to attain the highest level of biogas production can be attained, the biogas produced in the 200-cow dairy is competitive with propane today. The assessment is based on the assumption that there is a use on-farm for the biogas produced. The moderate yield-investment scenario is essentially competitive with propane also.

The 200-sow operation is apparently somewhat small to be competitive at today's energy prices.

None of the digester systems produced sufficient income to pay income taxes. Therefore, the tax credits would be useful only if the farmer-operator had other income tax liabilities against which the investment tax credits could be applied.

The initial analysis using the best of conditions, high biogas yield and low investment costs, resulted in eliminating two of the systems from additional analysis. The full costs of biogas production for the 70-sow system is $11.60/million Btu, and not competitive with other fuels today. The full cost of biogas produced by the cooperative operations exceeds $12.00 per million Btu. Even though considerable economics of scale are shown in the digester component costs, the additional costs for the truck operation and the labor requirements outweigh any economics due to the larger digester.

All of these conclusions are based on the assumption that the digester is being used strictly as an energy producer. The feasibility assessment is based on the energy being used as a substitute for propane or other fuels. If, however, the digester is used as an alternative manure handling and disposal system, a credit could be given based on costs of alternative systems and the economics improve.

7.0 BARRIERS AND STRATEGIES

The technical feasibility of methane production by anaerobic digestion is well established. Large systems, particularly municipal sewage-treatment facilities, have operated many years. But few long-term operating data are available for smaller systems, especially on-farm systems in the U.S. Successful university research experimental operations have provided only limited technical and economic data. In this section, we examine possible incentives and barriers to small digesters that might be used on farms. Constraints include environmental regulations, state or federal policies, and tax considerations. We discuss each in turn. Finally, we discuss possible strategies for accelerating acceptance of economically feasible digesters.

7.1 ENVIRONMENTAL REGULATIONS

The Iowa Department of Environmental Quality is responsible for waste-disposal regulations and recommendations. The Department could exempt on-farm digester residue in a manner similar to that now applied to land disposal of animal wastes. Digester residue from a commercial or cooperative venture might be classified as industrial rather than agricultural wastes, and thus might be regulated. In the following section, current regulations and recommendations for animal waste disposal are summarized.

The Iowa regulations concerning land disposal of animal wastes are currently under the Water Quality section. Solids from a digester spread on land would presumably also come under these regulations, so it is anticipated that farmers who installed digesters would be subject to no additional environmental regulations when digester residue was spread on land. In general, animal wastes have been applied to land for many years. Recent advancements in waste-treatment technology may provide alternative disposal methods, but land disposal is expected to continue to be the primary disposal method.

Crop production as well as the environment is concerned with land disposal of animal wastes because improper or excessive applications can create water pollution problems from runoff of waste materials into streams or leaching into groundwater supplies. And very high application rates (50-60 T/acre per annum) can put excessive salts into the soils so soil structure, plant growth, and crop yields are adversely affected.

Such factors as the chemical composition of waste materials, the rate and frequency of application, crops grown, topography and soil characteristics determine the hazards of waste disposal by land application. Although the manure is modified by the digestion process, the same hazards would presumably exist but to a lesser degree with a digester. The specific recommendations are designed to assure that animal-waste disposal will not increase existing environmental hazards or create new environmental or crop growth problems.

The Iowa Water Quality Commission's Guideline on Land Disposal of Animal Wastes recommends waste application rates for nitrogen and phosphorus (IAC, 7/12/76). The specific recommendations for nitrogen are designed to limit application of excessive nitrogen so contamination of surface or groundwater is not increased. The recommendations deal with specific quantities related to application methods and specific crop-management plans.

When crop nitrogen needs are met through application of animal wastes only, phosphorus application usually exceeds crop requirements. Excessive phosphorus may lead to crop-production problems. Specific recommendations designed to prevent the problem are made on the basis of soil samples.

Other waste disposal recommendations are summarized below.

- Wastes disposal on frozen or snow covered land should be avoided.
- For land subject to flooding more than once every ten years, it is recommended that wastes be incorporated into the soil within 30 days after spreading. Waste applied during peak flood periods (April, May, and June) should be injected or immediately incorporated into the soil.
- For land within 200 feet of a watercourse, it is recommended that the wastes be injected or incorporated into the soil.
- For tilled land with slopes exceeding 10 percent and on floodplains subject to flooding more than once every ten years, immediate incorporation or injection is recommended.
- In the absence of odor control standards, efforts should be made to minimize odor problems.

Regulations regarding disposal of municipal sludges and industrial wastes are contained in Chapter 33 of the Iowa Administration Code. Disposal of these wastes requires a permit. A commercial cooperative animal waste digester presumably would be subject to commercial solid-waste regulations. A digester, as a cooperative venture, would be subject to rules requiring a processing-facility permit. The permit which has design and operating standards, is to be obtained before digester construction begins. So long as the standards are adhered to, the permit is renewed. At the present time, the proposed expansion of Chapter 33 Rules relating to land application of solid wastes is being evaluated. The current regulation exempts farming wastes. The official status of digester residue is undecided.

Certain animal-feeding operations for which a construction permit is required are defined in the Iowa Administrative code, Chapter 20, Animal Feeding Operations 400-20.3(1) to 20.3(4). For these specified animal-feeding operations, a construction permit is required before a waste storage and disposal system is constructed, installed, or modified. Since installation of a methane digester could be viewed as modifying the animal waste storage and disposal system, a ruling on the applicability of the provision should be obtained earlier than the advance notice that is required 90 days before construction starts.

7.2 POLICY AND TAX CONSIDERATIONS

So far as could be determined from personnel of the Iowa Energy Extension Service, the Iowa Development Commission, and the Iowa Energy Policy Council, no state policies or tax legislation prohibit, impede, or specifically encourage installation of anaerobic digesters in Iowa solely for energy production. Iowa Department of Revenue personnel indicated energy producing systems such as solar, wind, biogas and ethanol production facilities are exempt from property tax, if the energy is for owner use. If some of the energy is sold, the tax would probably be prorated on the basis of the proportion sold, but to date no official ruling has been made. Otherwise, digesters are treated the same as other similar type investments. Two Federal laws, discussed below, provide encouragement for alternate energy systems.

7.2.1 Public Utility Regulatory Policy Act of 1978

The Public Utilities Regulatory Policy Act (PURPA) among other provisions, stipulates that public utilities must accept power from small parallel electrical energy producers (wind, hydro, solar, biomass) and buy it at the utility's avoided costs. Those provisions make it possible for a digester operator to sell excess electricity generated to a utility company. Several buy-back rates are possible: less than, the same, or at a rate higher than the customer normally pays.

Iowa has specific statewide rules for interconnecting individual electrical generators with electric utilities. The customer is responsible for the interconnect cost. In exchange, customers can use part of the electricity for their own use and sell the remainder. So, in effect, customers receive a credit for the electricity they produce and use that is equal to what they would have paid the utility. The credit may be estimated on the basis of the coverage statewide electricity cost of 5-7¢ per kWh in 1981.

The rate received by the customer depends on the method of selling to the utility. If the customer simply wants to sell energy to the electric utility company when an excess is produced, with no time of day specified, then the customer is paid on the basis of energy sold only. There is no credit given for utility operating capacity foregone.

If the customer sells on a time-of-day basis, more sophisticated metering and other equipment is required, so the customer is paid on the basis of energy generated and also gets credit for utility generating capacity foregone.

For the rural electric cooperatives (REC) the basic rate payment is what the REC pays its wholesaler. The rates of the six generation/transmission suppliers in Iowa differ, but a customer selling to an REC now would receive an estimated 2.5-3.0¢ per kWh. For investor-owned utilities, the rates are comparable. Interconnection costs vary from approximately $200 to $2,000, depending on the sophistication of the equipment and interface required.

From the point of view of the utility, the most desirable time to purchase electricity is during peak demand. A farmer-digester operator must consider that when determining the option suitable for his operations. If the peak electrical use on the farm coincides with the peak demand of the utility, the farmer is not in a position to sell on a time-of-day basis. That decision should be made by farmers, based on their own individual situations before interconnectors are installed. The decision would be made in consulation with the utility but it helps while planning to know that in all of Iowa the summer peak is 25 percent above the winter peak. However, for rural Iowa, the peak is in the fall and winter.

7.2.2 Energy Investment Tax Credit

Under the Energy Tax Act of 1978 and the Windfall Profits Tax Act, equipment that converts alternate substances such as biomass into synthetic solid, liquid or gaseous fuels are eligible for a 10 percent energy investment tax credit through December 31, 1985. The permanent business investment tax credit of 10 percent continues to apply in addition to the 10 percent energy Investment Tax Credit. So a total investment tax credit of 20 percent may be claimed through 1985.

7.3 STRATEGIES

State personnel and representatives of digester equipment companies say the only barrier they find to installing digesters is the state of the economy. With the current situation, they see little indication that people are investing. The Iowa Development Commission feels strongly that if the economics are favorable, interested investors will be forthcoming. Representatives of the Iowa Development Commission are prepared to assist interested farmers and energy users in setting up joint operations.

Specific barriers to commercialization were not identified. Equipment of proper size for small systems has not been produced on a large scale, so small scale systems are forced to use oversized (and perhaps more expensive) pumps than are required. On the other hand, without evidence that the demand for the smaller-sized pumps warrants large scale production, there is little incentive for manufacturers to produce them.

According to the telephone survey of County Extension Agents conducted for the Energy Policy Council, there are at the present time two anaerobic digesters operating in Iowa (See Table 3-3). One of these systems is using the methane for energy production, the other installed 10 years ago for purposes of odor control flares the biogas. Since only very few operational digesters and quite limited operational data are available for small digesters suitable for on-farm use, we recommend first that some type of funding assistance for research such as grants or other incentives be provided to qualified university personnel or farmers to promote construction and most importantly monitoring of research digesters or on-farm digester production facilities. Sound engineering and construction are essential, but monitoring of digester performance and costs are vital to an empirical assessment of on-farm digester operation. A stipulation of the funding assistance should be that these operations are a demonstration unit, open to inspection by interested individuals on some reasonable basis.

Farmers with operating digesters who were contacted stressed that funding assistance for installation of digesters was definitely secondary. The type of assistance that would be most helpful is good information. They emphasized that good research that will identify sound, practical digester construction and operation is needed. Good research would allow farmers the opportunity to see what is workable and adaptable to their own particular situation for energy production and utilization and for pollution and odor control.

After adequate technical, operating, and economic data are available, possible strategies for increasing the interest among farmers and for promoting investment in such facilities might take a variety of forms. We have listed several possible state-supported strategies.

- Establish a professional position or positions to coordinate the promotional and developmental activities of on-farm methane generation and act as technical advisor to qualified groups.
- Sponsor workshops to disseminate information to targeted groups.
- Develop state tax or other incentive programs through the use of exemptions from certain taxes or through various tax credits.
- Establish incentive programs for digester components manufacturers.

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