Energy and Economic ASSESSMENT of ANAEROBIC DIGESTERS for Rural Waste Management

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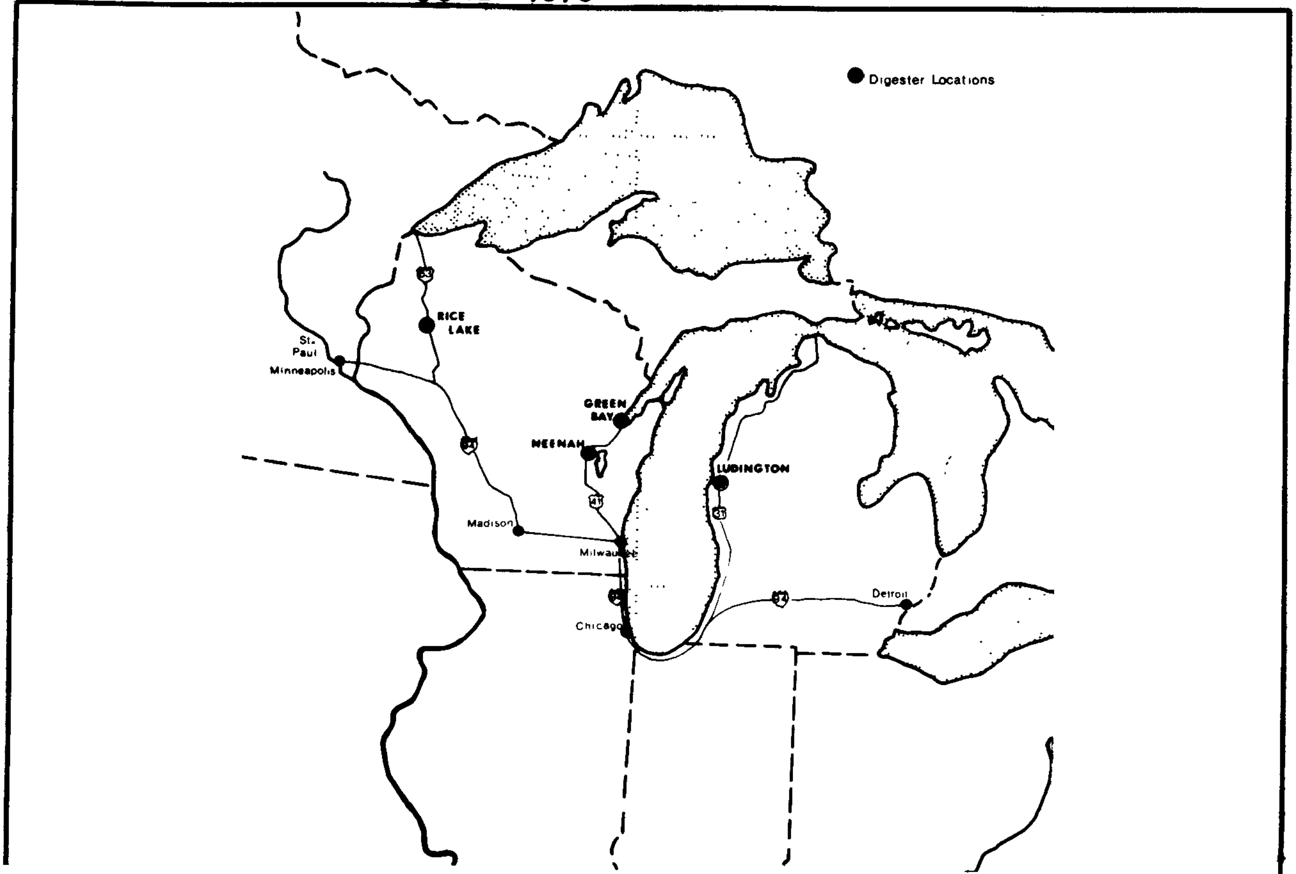

OASIS 2000
Rice Lake, Wisconsin

ENERGY AND ECONOMIC ASSESSMENT OF ANAEROBIC DIGESTERS AND BIOFUELS FOR RURAL WASTE MANAGEMENT

by

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ABSTRACT

A technological and socioeconomic assessment of anaerobic digester feasibility for small to mid-size livestock operations was undertaken. Three full scale digesters and one pilot scale facility were under various degrees of monitoring and evaluation to assess design and operational problems as they affect the adoption and establishment of farm scale anaerobic digesters.

Materials handling presented the greatest obstacle to satisfactory operation of the full scale systems. Conversion of the biogas to electricity via standard engine-generator sets is capital and maintenance intensive. Electrical conversion requires engine-generator sets which can add 30% to the cost of the system, and which have conversion efficiencies of only 10-25%. The system becomes more economical if the biogas can be used on site for direct thermal loads, suggesting that the economic feasibility of anaerobic digesters is site specific and should be closely integrated with the total farming operation. If excess engine heat can be recovered from electrical conversion equipment, and if provisions can be made on the farm to level electrical loads and conserve energy, then the economics are enhanced. Analysis was performed for farms with 100 animal units.

Laboratory studies using a 2:1 mixture of dairy manure to Municipal Solid Waste (MSW) showed that the biogas production per pound of volatile solids added is nearly the same as for straight manure. Addition of the organic portion of MSW to small farm digesters could make marginal systems economically attractive.

Preliminary refeed studies indicated that the digested manure may not have the same nutritional value as raw manure, and that the cost of dehydrating the effluent for refeed to the same animals could be cost prohibitive for the small to mid-size farming operation.

The feasibility of growing hydrogen producing algae on the effluent to enhance biogas production was rejected for the northern United States due to temperature extremes and to the difficulty in culturing selected species.

Socioeconomic research revealed the more significant factors underlying the adoption of agricultural innovations that will play important roles in determining the extent of digester establishment. The need for adequate service and maintenance organizations, specific standards and codes applicable to design and construction of these units, and the need for

support from insurance and financing institutions cannot be stressed enough if digesters are to be established on a wide scale. Combining wastes from several farms and/or communities could provide economies of scale provided management and social barriers were overcome. The sale of power back to the utilities would prove reasonable provided quality and reliability could be maintained.

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David Freedman built, operated, and collected two years of data on the Green Bay pilot scale digester, performed the laboratory analyses throughout the project, conducted and prepared the material on the combined MSW-Manure experiments, and, in conjunction with Luc DeBaere prepared the material on

dehydrating the digested effluent for refeed.

Luc DeBaere also prepared the comparative research on the refeed value of the effluent versus that of the raw manure.

David Ellsworth coordinated and wrote the Economic, Social and Institutional considerations, and Market Feasibility studies, and edited the final report.

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Cartography by: Susan Ernst

SECTION 1

INTRODUCTION

Recent concern over dwindling natural resources has enhanced the development of technologies that are responsive to energy shortages, resource conservation and environmental degradation. Growing interest in the anaerobic digestion of farm animal wastes as a potential source of fuel, animal refeed, and low cost fertilizer necessitated an assessment of farm scale digester systems.

Three full scale digesters and one pilot facility were evaluated on the basis of design and operational problems. A beginning assumption was that small digester systems feasibility would transcend the the concerns for engineering and chemical design alone. Methods of optimizing engineering and economic feasibility were developed with particular emphasis on technology transfer to the many small to medium sized farms in the Upper Midwest, where the study occurred.

Mechanisms which were considered to enhance the attractiveness of these systems included the use of digester effluent for animal refeed and aquaculture or algal farming. Because a combined Municipal Solid Waste (MSW) and animal manure system could make small or marginal digester systems economical, while at the same time help alleviate rural solid waste problems, the addition of MSW to animal manures for enhancing biogas production was experimented with on a laboratory scale. Socioeconomic research was also conducted to determine the public acceptance of these systems. Institutional, regulatory, and legal factors were examined to ascertain the impact of attitudes and decisions made in these arenas on widespread establishment of anaerobic digesters.

Characteristics of each site where the digesters were installed, particularly farm energy utilization, were also examined to ascertain the economic trade-offs between using the gas directly for thermal loads or converting to electricity.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

TECHNICAL COMPONENT

1) Materials handling is the major barrier to widespread utilization of anaerobic systems.

Four systems were under study during this contract. Two were built as commercial ventures from new materials. One was contracted for but partly built from used equipment, and one was a pilot plant built from new materials. Additionally, over thirty existing systems were either visited directly or were investigated via telephone conversations with owners, designers, or operators. All systems had, or were having, significant problems with routine conveyence of the animal wastes and other feed materials into the fermentation tank. These problems were either related to pumping or piping of the material. Few of the existing systems could sustain unattended operation for any length of time. Whether the systems were designed by professional engineers or lay people did not seem to matter. Thus, systems became labor intensive.

Recommendation--
Research is needed on efficient feed design to allow for routine, trouble free operations.

(2) Materials preparation for feeding was not carefully considered.

Too much energy in the past has focused on the chemical and biochemical composition of the feedstocks for fermentation processes and not enough attention given to the physical-mechanical characteristics. Some of the related problems encountered in the systems under study included: Heavy bedding of animals leads to excessive vegetable matter introduced into the fermenter. Unprotected or unpaved animal facilities lead to the inclusion of rocks, dirt, and debris clogging or preventing adequate feeding of the material. Lightweight materials create scumming problems in the fermenters. The use of Municipal Solid Waste is limited because of its variable nature and non-digestable components. Inert materials contained therein may plug fermenters and create problems in effluent disposal.

Recommendation--
Work needs to be done on effective means of separating the inert

materials from Municipal Wastes if they are to be used in small scale fermentation systems.

3) Gas production on current designs for small scale systems does not adequately address the daily and seasonal variations in energy use.

On farm energy consumption varies with the seasons. Daily farm electric peaks also coincide with power company peaks. Gas storage is a problem because biogas does not liquify readily. Carbon dioxide scrubbing systems, even if low cost, efficient designs were available would not alleviate the storage problem. Few natural gas pipelines are sufficiently close to allow for seasonal sales and buy backs. Conversion to electricity is not, for the most part, cost effective. Sale of the electricity back to the utility company would even be less economical due to the corresponding peak loads. Therefore, more attention needs to be given to designing systems which can follow seasonal loads.

Recommendation--
Waste storage-fermentation systems need to be designed to preserve the "fermenter fuel" for seasonal peaking. Also, low cost storage and scrubbing systems need investigation.

4) Conversion of biogas to electricity is capital and maintenance intensive with an engine-generator set.

Standard power units, in field situations, produce electricity with only a 10-15 percent conversion efficiency. Spark ignited or dual fuel diesels offer a 25 percent conversion efficiency. Unless the waste heat can be recovered for heating use, the cost of these units is prohibitive for small scale use. Reformer-fuel cell combinations to produce electricity from biogas, at 30-40 percent efficiency, offer a near term option which appears more attractive than the current engine-generator sets. These units can use the biogas directly, generate electricity at higher efficiency, produce usable heat, and produce carbon dioxide which can be used in greenhouses.

Recommendations--
More design work needs to be done on heat recovery systems from onsite power production units. Fuel cells for biogas systems need careful attention.

5) Neither this study or any other, up to this time, had addressed alternative uses for the biogas.

Biogas contains the essential components for production of either methanol or ammonia, as currently practiced in industry. The question of scale and ease of production affecting the applicability to farm scale systems is open to question. Exploratory talks with companies from which to obtain the necessary catalysts has been started under this contract.

Recommendation--
Research on uses of biogas for other than direct combustion or power production needs to be started.

SOCIOECONOMIC COMPONENT

1) Electrical production with small scale systems, from an economic perspective, is marginal and totally unoptimized.

Most farms are heavily electrified, thus, conventional wisdom dictates that biogas be used to produce electricity. On a cost/Btu basis this is the most ineffective means of using the gas. Thermal loads would be more cost effective for biogas usage. No studies exist on daily farm energy profiles or on the number of farms which could be converted from high electrical use to gas and what the cost of doing so would be. The two systems studied which utilized engine generators dumped 80 percent of the waste heat into the environment. Optimization for utilizing this heat will be required to enhance feasibility. Success of small scale digesters dictates that the biogas be used efficiently.

Recommendation--
Energy-power studies need to be undertaken to successfully integrate digester systems with normal farm operations with respect to energy utilization.

(2) Maintenance and service of digester systems has not been adequately addressed.

Contact with farmers during the course of this work indicated the need for reliability and service of these systems. All systems under study suffered from periodic breakdown and maintenance problems. Many of these were the result of faulty or experimental design. Other problems could be classified as routine maintenance which might occur under normal farm operation. Neither of the commercial systems had a service component in the contract agreement, nor had the company seriously considered such a component. Acceptability of digester systems is dependant on service organizations to maintain them. Without adequate service, safety and health problems could be compounded and eventually lead to abandonment of the systems.

Recommendation--
Research needs to be carried out on technical, legal, and safety considerations to assure reliable systems operation and maintenance. This might include setting engineering and construction standards and lead to licensing of the systems.

(3) Preliminary mapping of farms in Barron County, Wisconsin, indicates that there is a possibility of combining wastes from several farms and/or municipalities.

Combining wastes from several farms and/or municipalities could provide some economies of scale, provided management schemes were developed for payment, power, and fertilizer distribution. Also, transport, maintenance, and legal constraints of commercial power production must be overcome.

Recommendation--
Guidelines need to be developed for community power producing, waste handling systems to allow for small and intermediate scale systems.

(4) The sale of power to utilities may prove reasonable if quality and reliability can be maintained and the technical concerns of three and four can be met.

Small scale systems integrated with the power grid create management problems for the utilities. Electrical feedback into the power grid from many small generators creates potential dangers for linemen when a storm knocks the power out. Also, the power generators examined produce power below the quality maintained by utilities. This study began to investigate microprocessor technology for systems monitoring and control. Microprocessor technology can help to maintain levels of quality and provide the necessary service tool to aide in the creation of systems reliability.

Recommendation--
Extensive work needs to be done on microprocessor controllers and power conditioning systems to enhance alternative economic paths and, hence, viability of small scale systems.

(5) The introduction of municipal solid waste to anaerobic digesters enhances small systems feasibility and provides an alternative to rural waste problems.

This research showed, in a preliminary study, that the addition of 2:1 manure and municipal solid waste could equal, on a volatile solids basis, the gas production of straight manure. Other mixtures might provide a synergistic effect and have higher gas production rates. Also, several studies indicate that specialized microbial populations might affect gas production; systems could be conditioned to enhance this. Work on the 2:1 mixture seemed to indicate this possibility.

No serious work has been done on wasteshed modeling from either a transport, source separation, or quantity perspective in the case of diffuse population areas. Some solid waste studies have shown that county level systems in rural areas can often be more economical than regional systems. No work has been done on even more diffuse systems which may collect from a neighborhood with the farmer perhaps paying for the refuse.

Recommendations--

a) Socioeconomic studies on microscale disposal of municipal solid wastes via farm scale fermentation systems need to be carried out, including: transportation studies, attitudinal studies, and wasteshed mapping.

b) Laboratory and field studies on mixtures of MSW with different quantities of animal wastes, other organic matter such as field residues, and different types of animal wastes should be initiated.

c) Studies on the microbial populations should be carried out to ascertain if shifts in microbial populations do exist and can significantly enhance organic decomposition and gas production.

SECTION 3

OVERVIEW

Anaerobic fermentation processes have been used for many years in the treatment of municipal sewage. Several years ago, as municipalities replaced and enlarged their facilities, many of these anaerobic systems were abandoned in favor of aerobic treatment which was lower in capital cost. As the energy crisis developed, and lifetime costing clearly became a better measure of the investment an industry or municipality would have to make, anaerobic systems which produced energy as a byproduct became attractive again.

Prior to the awakening of the urban environment to the potentials of anaerobic fermentation, the rural sector became interested in the process for obtaining energy while treating and disposing of animal manures and other agricultural residues such as food processing wastes and cellulosic materials. These systems were used in rural Germany (1) during World War II and more recently in India (2,3), and China (4,5). With cheap energy in the U.S. and no severe pressure on the agricultural industry to meet pollution control standards, the anaerobic process was virtually ignored until about ten years ago.

Outside of a few farmers and some people seeking a self-sufficient lifestyle (6, 7), little formal research was done to develop reproducible systems. Most of the University research was in the departments of microbiology which were interested in the microprocess (8, 9) or in departments of civil or sanitary engineering. (10) Some work on agricultural wastes was undertaken by the Universities of Illinois, Wisconsin, and Cornell (1, 11, 12) and some full scale systems were being developed on one shot bases by entreprenuerial farmers.

Some of the earliest agricultural anaerobic systems to reach public attention were those of Auerbach, Rutan, Merrill, and Fry (6, 7, 13), which reached the public largely through alternative publications. Most of these systems were designed for a small number of animals in which 55 gallon drums, or the equivalent, were used for batch or continuous fermentation (Figure 1). This experience was translated into some very simple design manuals published by Merrill and Fry (13, 14), and Leckie (15) in the early and mid 70's. Two exceptions to the small size are notable. The first is the work of Fry in California, Figure 2, which resulted in a rather extensive, but simple design manual.

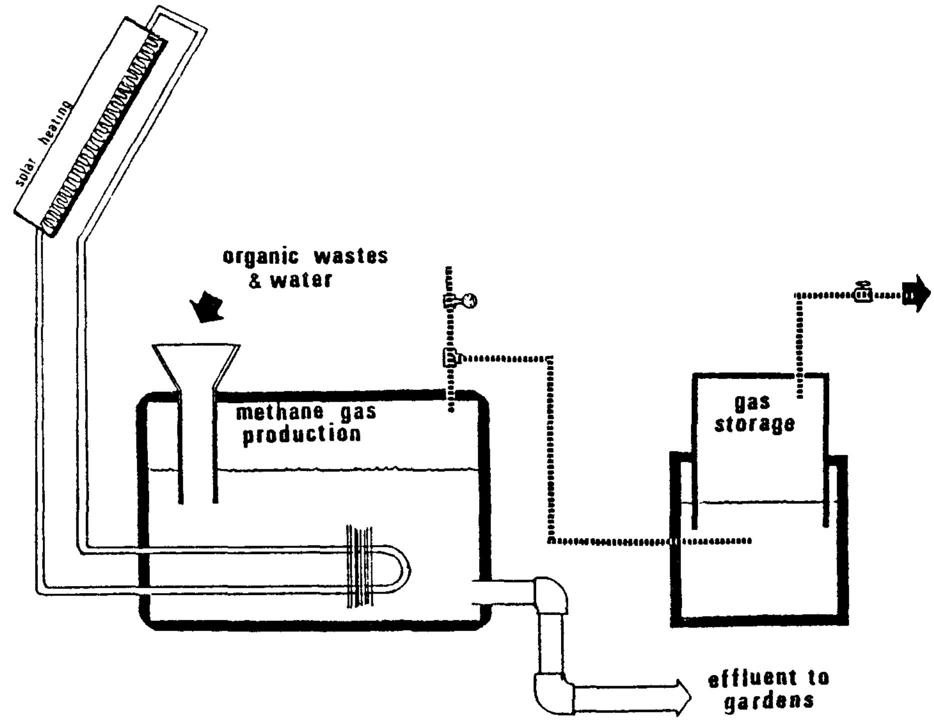


FIGURE 1 55 GALLON DRUM TYPE DIGESTER
(Auerbach, Merrill)

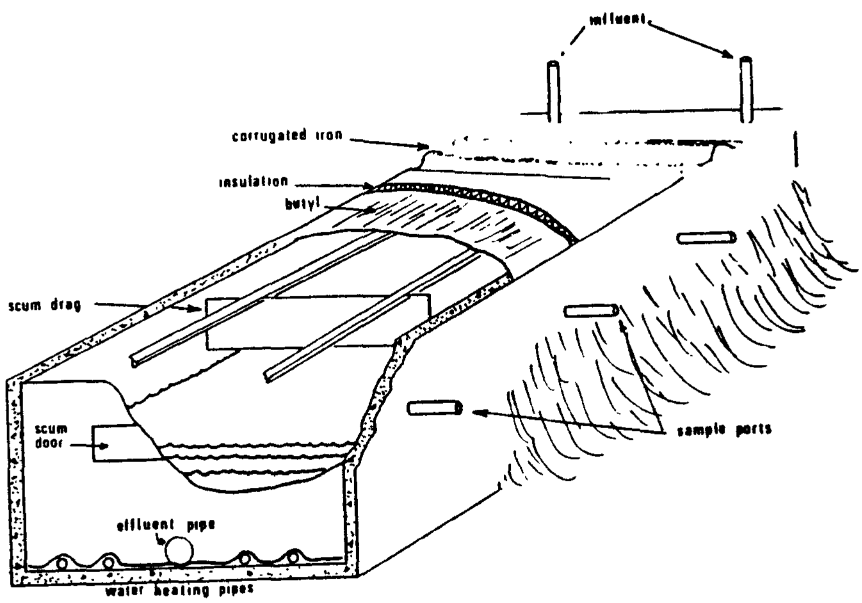


Figure 2. Horizontal displacement digester (Fry).

The second is a unit which was built by Niel Huber in Connecticut in the late forties. This system was developed for the purpose of selling the nitrogen rich effluent and capitalizing on the government subsidies for nitrogenous fertilizer. Since these subsidies were aimed at supporting the ammonia plants built during World War II, the Huber facility did not qualify and was abandoned as an unprofitable venture.

As the small scale research became better documented by a growing movement of individuals labeled "appropriate or alternate technologists", larger farm operations, major universities, companies and small entrepreneurs became interested in the feasibility of anaerobic digesters. Also, as interest developed, definite philosophies of design emerged, each aimed at improving the cost effectiveness of the process.

The majority of experimenters and researchers believed that operation in the mesophillic region, $15^{o}C$-$45^{o}C$, to be the most appropriate. It seemed the easiest to control and design. Examples of these early systems can be seen in units constructed by Ecotope, the University of Minnesota, and the University of Wisconsin-Green Bay (Figures 3-5).

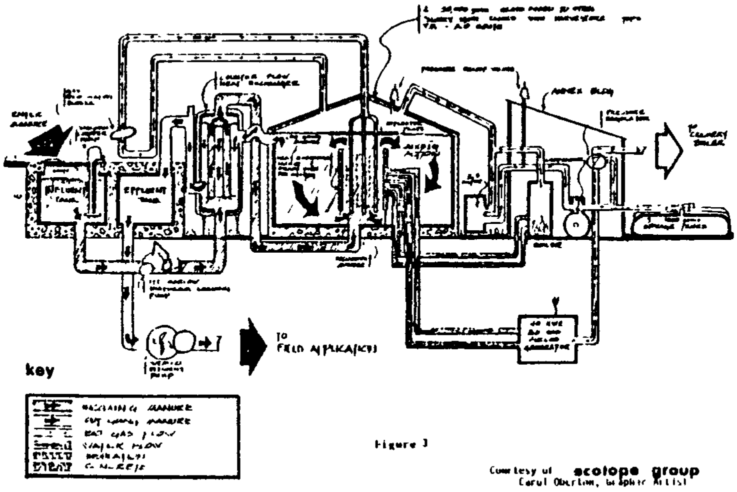
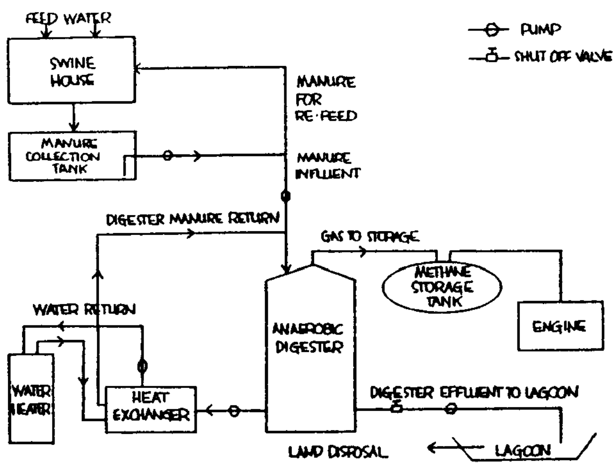


Figure 3. Schematic of Ecotope's 100,000 gallon dairy cow manure Biogas Demonstration Plant.

Figure 4. Schematic of University of Minnesota swine digester.



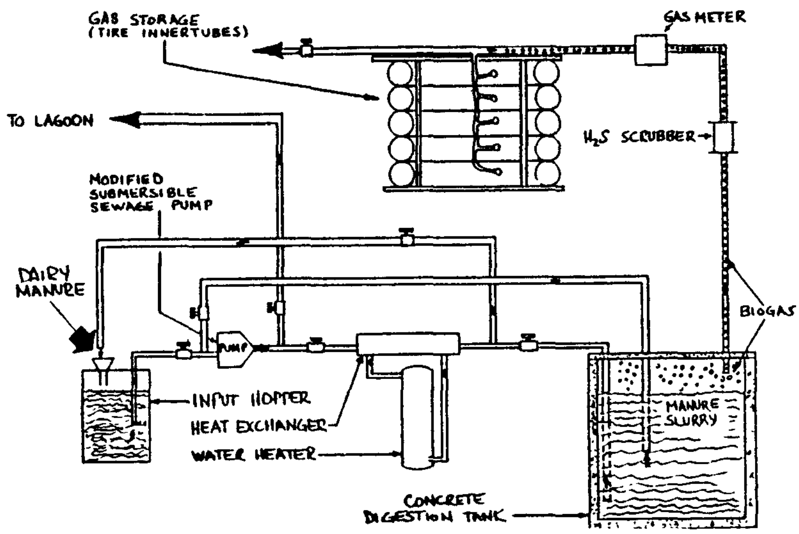


Figure 5. UW-Green Bay pilot scale digester.

Another school advocated thermophilic digestion (temp.). One of the major proponents of this theory was Hamilton Standard, Division of United Technologies (16). Perhaps the first company to develop a package unit for sale, the majority of their units are currently placed on sites being funded by U.S. government studies. Several Universities have also opted to focus primarily on the thermophilic process (17, 18).

The temperature question seems to have divided researchers into two schools. There are other engineering factors which cut across these lines. These include tank design, construction materials, and operational criteria such as plug-flow, no mix, partial mix, completely mixed systems, and the sophisticated two-phase operation developed and patented by the Institute of Gas Technology (Figure 6). This two-phase system, originally intended for municipal use, appears to offer real potential as a second generation farm system.

Tank materials represent one of the largest costs for a farm system. Thus, they must prove durable over a long period of time and/or be replaceable at nominal costs. The option for extreme durability is exemplified by the use of glass lined metal tanks, represented by the work of ECOTOPE in Washington State (19, 20). These tanks are marketed by A.O. Smith's Harvestore Division and were used by that company in an experimental system on a Wisconsin farm (21). (Figure 7) The system is no longer operational and the company has not indicated what its plans are in this area.

One of the lowest capital cost fermentation tanks is a plug flow design composed of a flexible membrane with a woven fabric reinforcement. This is similar to the lined and covered lagoons designed by Environetics (22).

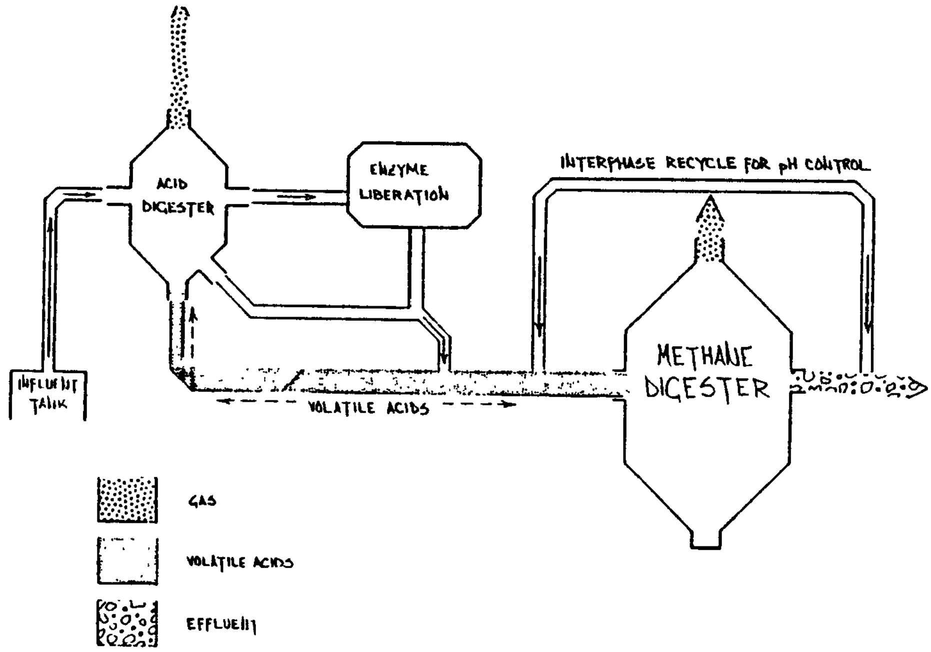
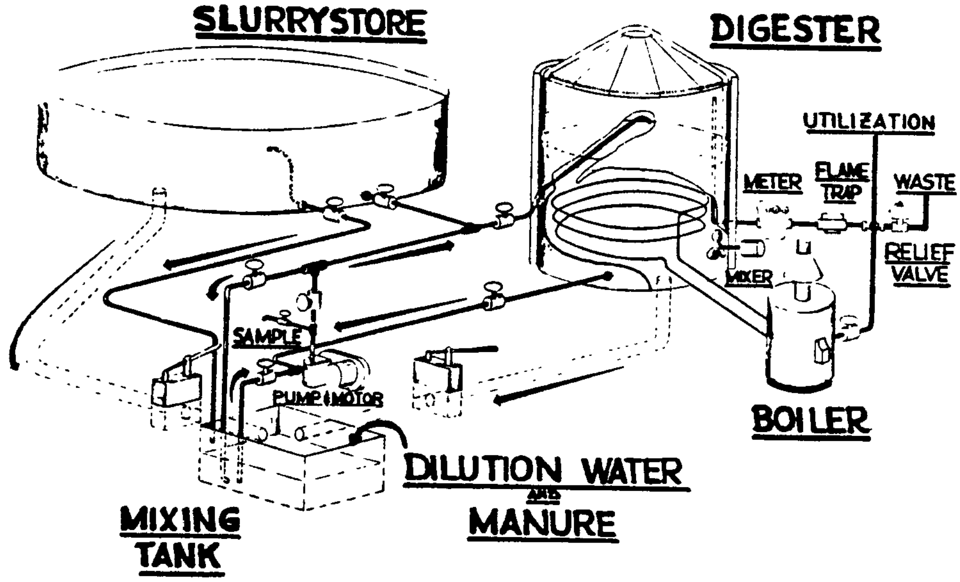


Figure 6. Two-phase anaerobic digestion, Institute of Gas Technology



Courtesy of A.O.Smith Corporation

Figure 7. Schematic of the experimental anaerobic digester installation

Figures 8 and 9 show two such configurations designed by Energy Harvest Company. Figure 10 is a schematic of a similar system, with solar heating proposed by Biogas of Colorado. A variation of this design is also under investigation by Cornell University under Department of Energy funding. These flexible membrane units all operate in the plug flow mode, meaning the material goes in one end and out the other, as in a pipe. Fermentation is controlled largely by temperature maintenance and flow rate (usually 15-30 days throughput). A number of these systems had gas jets installed along the length to mix the effluent, because standard theory indicated that mixing was imperative. Field experience with these units shows that the same quality of fermentation is achievable without mixing; thus, most of these mixers have never been used.

For the most part, anaerobic digesters in the U.S. and Europe have been vertical tank configurations with intermittent mixing. The original theory was that the microbial populations needed to be intimately contacted with the substrate; mixing would aid this process. Experience with packed bed reactors (1), expanded bed reactors (70), separated phase or

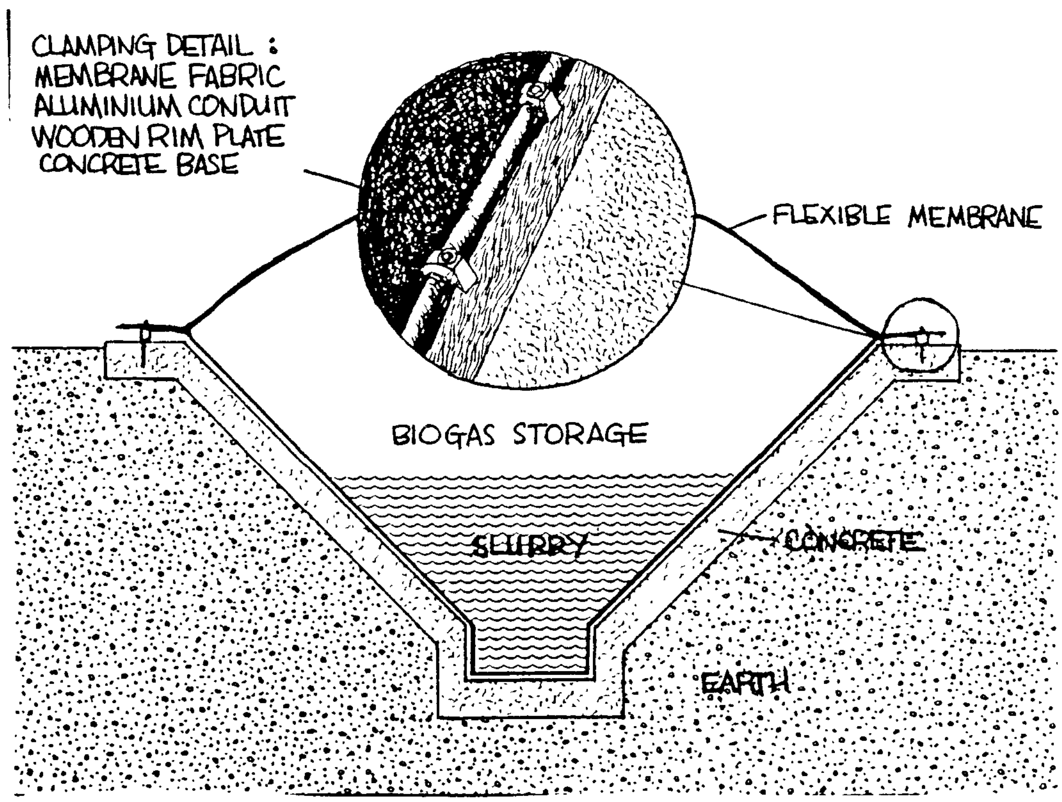


Figure 8. Earth supported flexible membrane digester, Energy Harvest Co.

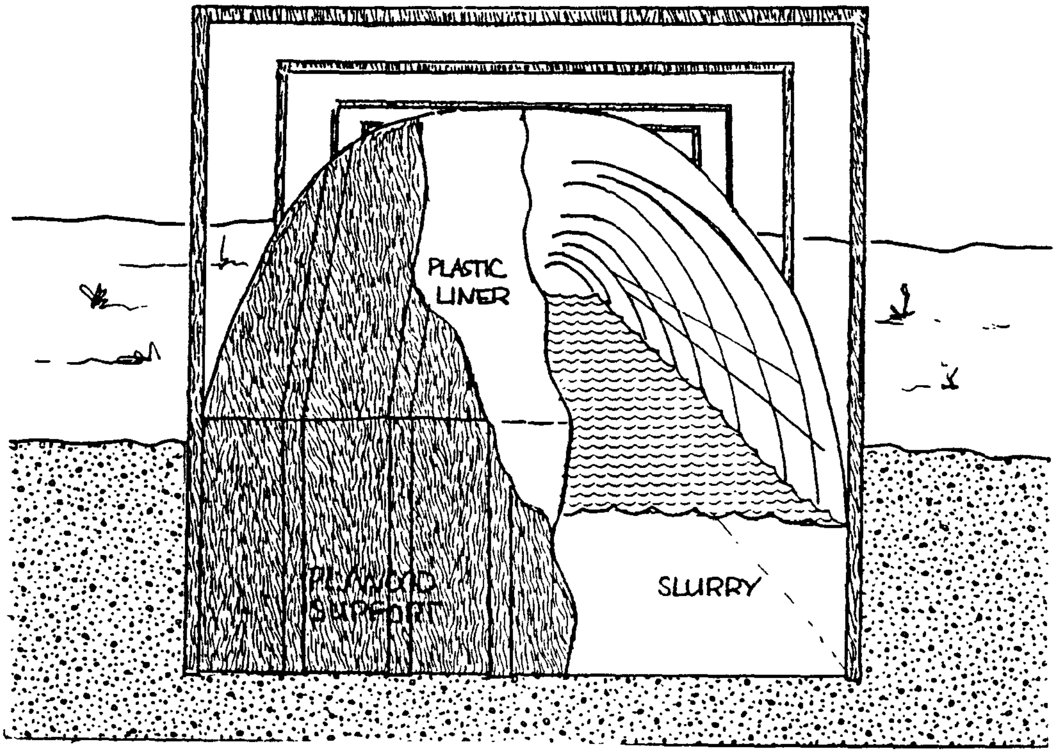


Figure 9. Redesigned fermentation tank-plywood and earth support, Energy Harvest.

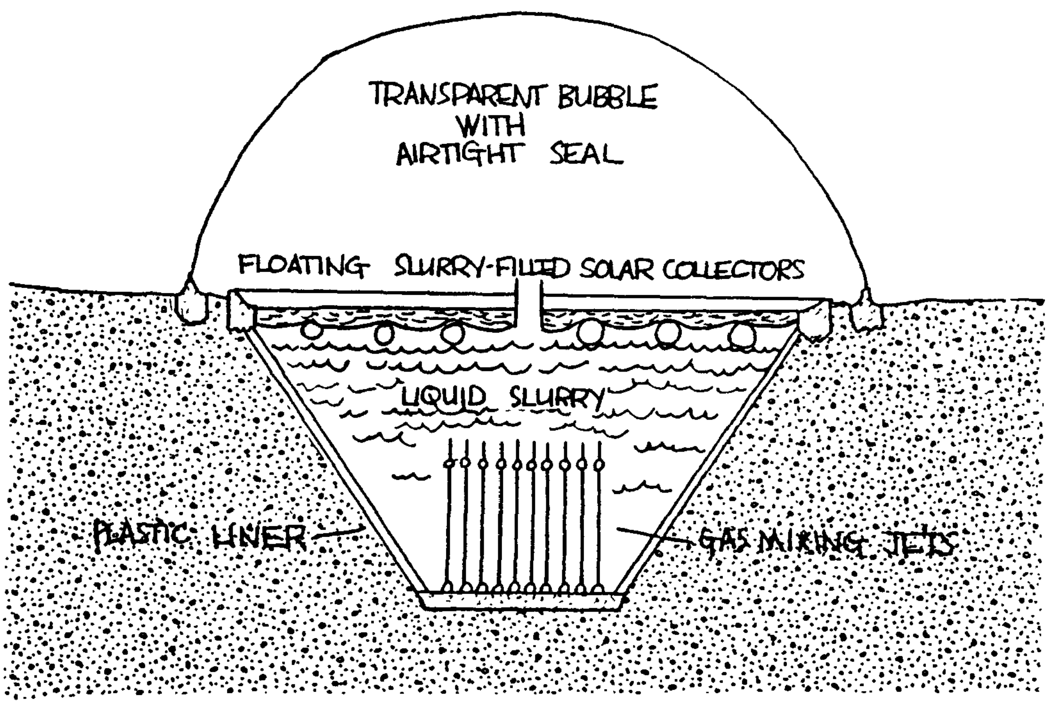


Figure 10. Patented solar heated digester, Biogas of Colorado

stage operation (23), high solids reactors (24), and even land filled systems (25) has shown that this assumption is not necessarily valid. This has caused serious reevaluation of engineering design and operation of anaerobic fermenters, expecially where the influent is essentially uniform. Cornell University is currently investigating the mixing question by systematically operating a digester in a variety of modes, from plug flow to complete mix.

The concern for cheap energy or energy independence from conventional utilities, rather than any inherent interest in pollution control, sparked the current interest in farm scale systems. As interest grew, so did investigation of the hard economics. This is the economics based on conventional cost/benefit analysis as opposed to crediting for externalities. It was argued that the systems would have to pay for themselves or a farmer could not afford to install a system just to cut off the local power and fuel companies.

In attempts to show positive economics other benefits have been factored in with economic values. These include enhanced fertilizer value of the effluent, increased value of the effluent as animal feeds (26, 27), and the use of these systems to control both water and air (odor) pollution. Also, economies of scale have been factored in, since the cost is not a linear function of the amount of waste available for fermentation.

A number of studies have attempted to ascertain the minimum size which was economically feasible. From the examination testing of several full scale systems, this study seems to indicate that the current state of the art puts the 100 cow or equivalent unit as a lower limit, if a very efficient system is designed for the production of gas but not electricity. Almost 100 percent of the gas must be used efficiently, and then only a five percent return on investment (ROI) is realized. This is a poor ROI from a business perspective where industry would like to see a 13-15 percent return. The case with electrical generation is even more precarious with higher capital investments, high maintenance costs, and low conversion efficiencies (at best 25 percent gas to electric). If the waste heat is not utilized and almost 100 percent of the electricity is consumed, the cost/kw for a biogas plant exceeds that supplied from the local utility even taking all credits and escallations into account.

Our research clearly shows that at the present time and in most cases, the interposition of a fermenter between an animal waste source and a well designed storage system must be justified on the gas production alone. Also, in most cases where the energy is to be used entirely on site, the economics will dictate the use of the gas produced for thermal loads as opposed to conversion for electrical energy. And, the economics require a very high conversion efficiency with little rejection or loss of the thermal energy produced. This analysis holds for the systems researched under this present study; which implies beef and dairy operations using animal wastes as a sole source of influent and which have only these same animals available for refeeding the effluent.

The above indicates that digester systems feasibility transcends the concerns for engineering and chemical design alone. It must also take into consideration the particular site in which it is to operate. Characteristics of the site may override some purely engineering optimization considerations.

There exist other mechanisms for enhancing the attractiveness of these systems. As mentioned above, such areas as use of the effluent for refeed is possible; in some areas, aquaculture and algal farming could be significant in proving economic feasibility (27, 60).

Another area which was investigated in this study was the addition of municipal solid waste (MSW) to animal manures. This could have a twofold advantage. First, this system could help alleviate rural and in some cases urban disposal problems. Also, combinations of MSW with animal manures could make small or marginal digester systems economical.

Success of these units is also predicted on public acceptance of the systems. Socio/economic parameters such as financing, safety, insurance, service, and farm operational changes must be factored in.

Interviews with farmers indicates that the availability of operating systems and established service organizations would be beneficial for widespread adoption of anaerobic digesters. Also, federal or similar support would help diffusion rates of these systems.

Standards and regulations dealing with construction, installations, and inspection of digesters would enhance the ability to finance and insure the projects. Certification would also be necessary before government assistance could be provided.

SECTION 4

SYSTEMS DESCRIPTION

During the course of this work, three full scale systems and one pilot system were under various degrees of study. This included the prototype full scale system of Agricultural Energy Corporation in Ludington, Michigan, the full scale system in Rice Lake, the pilot operation in Green Bay, and the system in Neenah, Wisconsin (Figure 11). This latter unit, designed for about 125 horses was constructed from old brewery tanks.

None of the full scale systems operated on a continuous, trouble free basis. The pilot operation ran continuously for about two years with only minor problems and occasional pump breakdown. The horse stable operation is currently not operational and its fate is in doubt partly because of faulty design but primarily due to the unanticipated expense which has to be incurred to construct a barn cleaning system consistant with proper stable management.

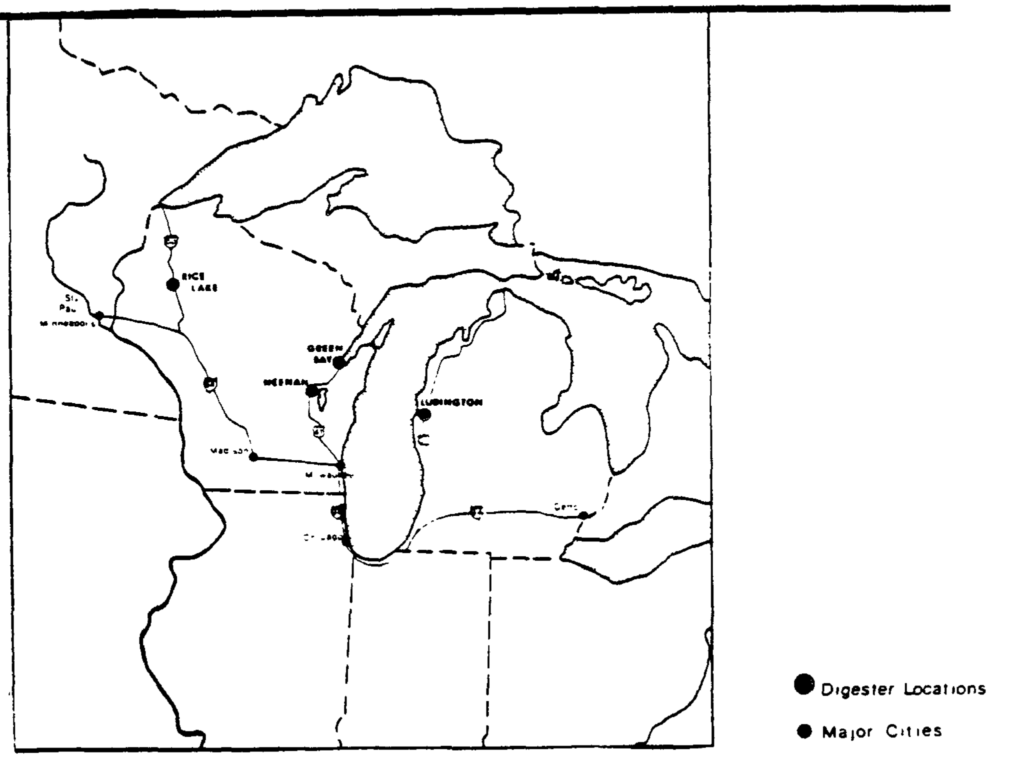


Figure 11. Anaerobic digesters under study. Wisconsin - Michigan

The Ludington system underwent a complete rebuild of the fermentation section. While it is now functioning adequately, it too, suffers from a materials handling problem on the front end. The feedlot is not winterized and is subject to freeze-over which makes manures unavailable for fermenter feedstocks.

The Rice Lake system underwent several major modifications in the control, power producing, and materials handling design which prevented extensive, continuous monitoring of operational parameters, though the data obtained paralleled closely the laboratory models. Materials handling problems here were due largely to the temporary nature of the feed system used for the turkey waste study.

The overall conclusions as a result of this study indicate that digester feasibility rests primarily in the development of reliable materials handling systems and that fermenter tank design and operation is of secondary concern. Fermenter operation becomes a problem when there are large quantities of bedding or other cellulosic material included with the manures or essentially non-digestible bedding such as rice hulls are included. Then one tends to see systems stoppage either through slugging or scum buildup.

All physio/chemical data reported were obtained using procedures described in Standard Methods (71) except as noted below. Gas analysis was carried out in a Carle #8000 G C using two columns and standardized against calibrated standards prepared by Scientific Gas Products. Phosphate analysis was carried out on a Technicon II auto-analyzer using standard procedures described in the operations manual.

SYSTEMS DESCRIPTIONS

Brockman Stables, Neenah, Wisconsin

The system, schematically depicted in Figure 12, is constructed from ten epoxy lined, used brewery tanks of approximately 37,850 litres (10,000 gallons) or 40 M^3 (1340 ft^3). The system is completely enclosed in a standard metal farm building which is insulated with styrofoam sheeting. The tanks, which are horizontal, are uninsulated and are heated by coils made from black iron piping and right angle elbows. The coils, six loops in each tank, are mounted so they follow the perimeter of the tank and are held by clamps welded to the side of the tank. Figure 13 shows a schematic of the tank heating system.

The tanks are configured in a series/parallel configuration. The concept here was to parallel tanks to get proper volume (to create a pseudo 75,000 litre, '20,000 gallon ' tank). Tank A1 is not depicted because it was removed from service early in the system operation and converted to gas storage. E1 serves as a settling tank and E2 as a mixing tank. The original plan called for an aquaculture operation in the lagoon and it was felt that some preliminary clarification would be needed. E2 would then be

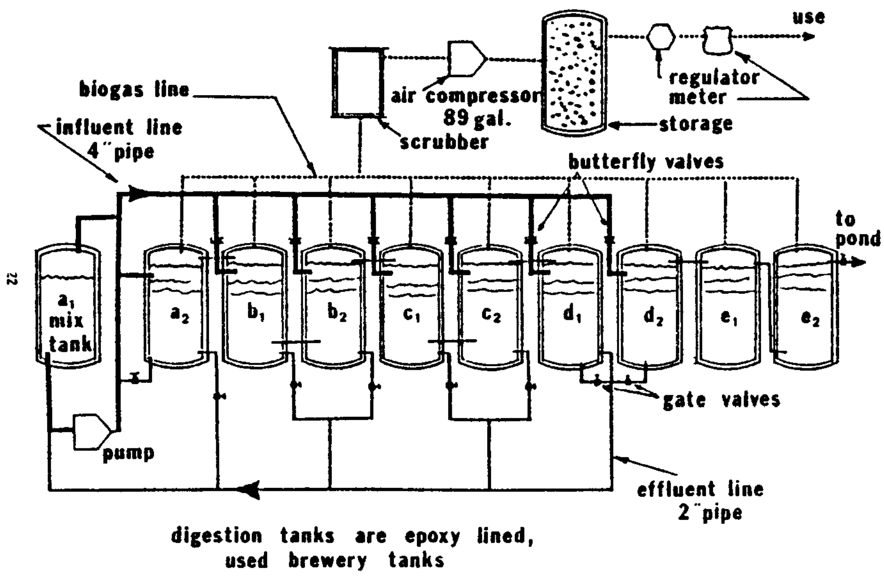


Figure 12. Brockman stables slurry and gas systems.

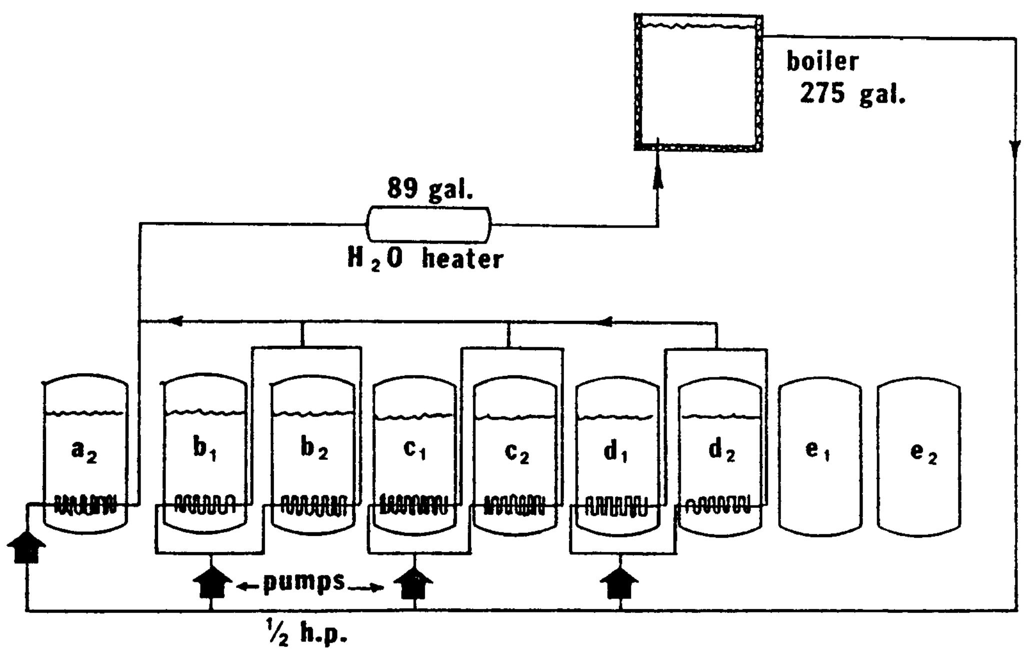


Figure 13. Brockman stables heating system.

used to add nutrient supplement for the aquaculture operation.

The "mixing" tank received the input from the barn. As the stable was about a quarter mile from the digester system, the original scheme had the manure collected by a spreader. The spreader unloaded to a hay chopper which conveyed the solids to the mixing tank. Early troubles with too much bedding forced the stable to hand sort each stall to eliminate the bedding and then hand load the mixing tank. This task became time consuming and cost prohibative and eventually led to systems shut down.

The system operated in a complete mix mode. Basically all tanks could be isolated from each other with hand operated valves. Manure was added to the mixing tank and water added to reach a total solids level of about ten percent. This mixture was then pumped to tank A_2 and valves opened to allow excess volume to be displaced from the system to the lagoon. Each tank pair could then be mixed in isolation by judicious choice of valves.

The system was supposedly designed for a 30 day retention time with a full complement of 125 horses based on a volume of .03 M^3 (1 ft^3) of manure and bedding/day and a dilution with .04 - .06 M^3 of H_2O. The system was sized and designed by individuals not trained in either science or engineering and standard design procedures were not followed. Because of the underloading of the system, retention times were often 120 days or greater.

Table 1 shows the basis for the systems sizing including assumptions. Table 2 shows a typical set of results throughout the system. It is clear that the materials are quite stabilized and if filtered to remove particulates and chlorinated to remove pathogens, the water would be potable. Gas analysis on the system yielded CH_4/CO2 ratio of approximately 45/55.

The gas system consisted of a pipe line which tapped all the tanks in a paralled arrangement. The pipes led to a two stage Ingersol Rand compressor (#LPG-5) with a 60 gal high compression tank, A_1 was later added as gas storage. The gas fed the hot water heater which maintained fermenter temperatures in the 95^oF region and could also be piped to the stable for heating; low feed rates kept the gas production at a level that this was never routinely accomplished. No dewatering or hydrogen sulfide removal was attempted.

The system cost in the neighborhood of $40,000 and operated essentially trouble free. All operations were manual except the gas compression and distribution system which was controlled by pressure transducers. The system was shut down largely because it became too labor intensive to collect the manure with a minimal amount of bedding. Thus, the system did not produce sufficient gas to warrant its continuance. Also, the original intent of the system was to process the manure to reduce the mounds of horse manure, which were self composting and hence both a fire and odor problem. Since the digester system could not handle all the waste, the composting was not eliminated and the dual operation became a source of frustration and additional expense.

TABLE 1. BROCKMAN STABLES--ASSUMPTIONS & SYSTEMS SIZING

Assumptions		Per Tank Calculations	
1.)	30 day retention time	ft^3 manure added:	17.52
2.)	Raw manure characteristics:	(gal)	131.05
	80% moisture (M)	(lbs)	700.80
	20% total solids (TS)	ft^3 H_2O added:	26.28
	80% volatile solids (VS) of TS	(gal)	196.57
	40% lbs/ft^3 raw manure	ft^3 total slurry:	43.80
3.)	1 ft^3 Manure/horse/day	(gal)	327.62
4.)	5 ft^3 biogas/lb. of VS input	lbs total solids	140.16
5.)	Biogas = 50% CH_4 50% CO_2	lbs volatile solids	112.13
6.)	100% recovery of waste	ft^3biogas	560.64
7.)	Tank volume = 10,000 gal = 1,334 ft^3	ft^3 CH_4	270.32
		btu value	$2.8x10^4$
		# of horses supported	18

Operationally, there were only minor design problems. First, inclusion of too much bedding led to scum buildup initially. This scum blanket collapsed a set of heating coils when the system was drained down. Rebracing the heating system and eliminating much bedding solved the problem. Secondly, the larger pipes used butterfly valves which restricted flow and led to plugging from bedding and particulates. Finally, the multiple tank system led to time consuming mixing schedules and added complexity to the plumbing system.

TABLE 2. BROCKMAN STABLES--SUMMARY OF RESULTS

PARAMETER	SAMPLE LOCATION	MIXING TANK	A-2	B Series	C Series	D Series	E Series
% M of Total Sample	% by weight	95.03	98.79	98,33	99.36	99.59	99.72
% TS of Total Sample		4.97	1.21	1.67	.64	.41	.28
% VS of TS		88.61	73.90	81.26	64.94	58.73	47.20
% FS of TS		11.39	26.10	18.74	35.06	41.27	52.80
%VS of Total Sample		4.40	.90	1.35	.41	.24	.13
% FS of Total Sample		.57	.32	.31	.22	.17	.15
VS in lbs/ft^3		.11	.02	.03	.01	.01	.003
VS in gm/1		1.81	.37	.56	.17	.10	.055
% VS destroyed		----	79.55	----	90.68	94.55	97.05
Total Alkalinity	mg/1	2040	1600	1570	1530	1490	1410
Volatile Acids	mg/1	1570	524	334	363	343	272
pH: Filtered	----	6.4	7.0	7.1	7.0	6.7	7.2
pH: Nonfiltered	----	6.5	7.1	7.2	7.3	7.1	7.3
Total Nitrogen	mg/1	556	304	365	251	210	176
Ammonia - N	mg/1	152	123	133	134	133	133
Total Organic Carbon		20,000					
Chemical Oxygen Demand	mg/1	36,000	5700	14,000	4100	3700	100

Gas Analysis: 49% CH_4, 40% CO_2, 11% O_2 + N_2

Key: M = Moisture
TS = Total Solids
VS = Volitile Solids
FS = Fixed Solids
CH_4 = Methane
CO_2 = Carbon Dioxide
O_2 = Oxygen
N_2 = Nitrogen
mg/1 = Milligrams/liter

Green Bay Pilot Plant

The Green Bay pilot plant was designed, constructed and operated by undergraduate students at the University of Wisconsin-Green Bay, with a National Science Foundation Student Originated Studies grant from the National Science Foundation (NSF) and some University monies. Total cost of the "3 cow" mesophillic (35°C) unit, including equipment, building, and lagoon, was approximately $20,000. The cost of the system includes labor and materials for the laboratory work to check design and labor for construction.

The system configurations for manure handling, gas utilization, and heating are shown in Figures 14 and 15. The design uses a single vertical concrete tank whose lid is flush with ground level. A small building over the tank provides thermal insulation and access to the tank and other basic components of the system. A single large pump periodically circulates the slurry from the tank through various pipes above the tank, and back into the tank, for the dual purpose of agitation and heating. Agitation is accomplished by circulation, while heating is achieved through an external heat exchanger. It is heated from a thirty gallon water heater and circulated to the heat exchanger by a small pump. Thermostats inside the digester are used to provide feedback to the heating and pumping system in order to maintain a 35°C (95°F) temperature within the tank.

Aside from agitation and heating, the main pump serves two other functions: 1) It pumps fresh input manure from a mixing hopper, through the heat exchanger into the tank; and 2) it pumps spent slurry out of the tank into the lagoon. Thus, the main pump takes part in circulation/agitation, heating, and input/output. Table 3 explains the different modes of pump operation.

The hot water system serves a two-fold function: 1) to supply heat to the heat exchangers, as previously described; and 2) to supply hot water to the mixing hopper for the purposes of diluting and heating the manure. Heating of the incoming manure is an especially critical operation, since the manure will have been transported from the barn to the digester without any protection from the severe climate conditions of winter.

The biogas passes through a hydrogen sulfide scrubber (iron filings inside of a five gallon drum) and a residential type gas meter, and into the hot water heater for consumption. Any excess gas which is produced flows outside of the building to a storage system, which consisted of a series of tire inner tubes. A natural gas system is also tied into the hot water heater to supply fuel for start-up and for back-up (primarily in winter, as the energy balance in Table 4 indicates).

The system is maintained at an operating pressure of ten inches of water by use of a pressure relief valve (a five gallon drum with ten inches of water inside) which is vented to the outside of the building. The maximum allowable pressure in the digester tank is 36 inches of water.

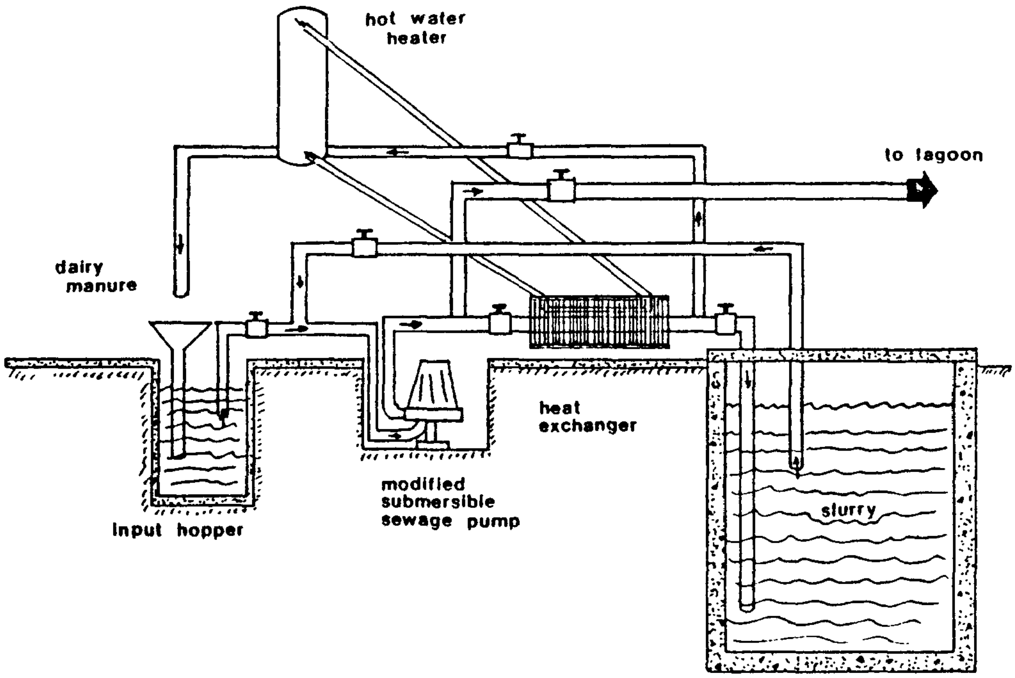


Figure 14. Manure handling and heating systems, Green Bay

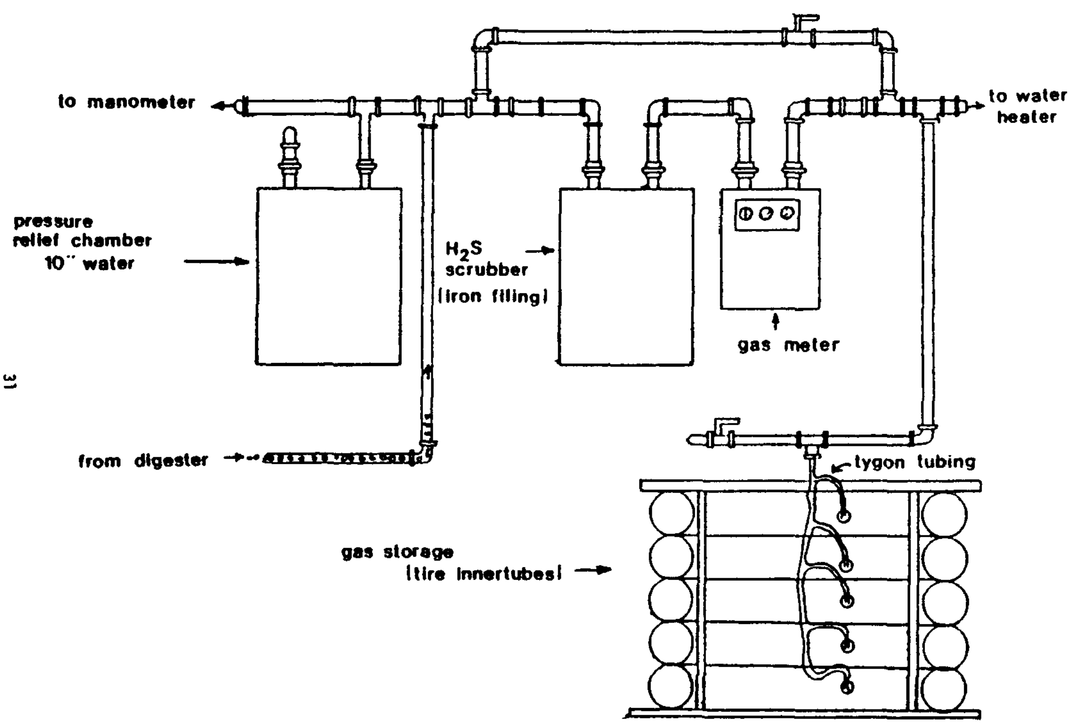


Figure 15. Gas Utilization System, UWGB

TABLE 3. MODES OF PUMP OPERATION--GREEN BAY SYSTEM

Valve Name	Abbreviation	Location
Lagoon Input	LI	Pump-Lagoon
Digester Input	DI	Heat Exchange - Digester
Hopper Input	HI	Heat Exchange - Hopper
Digester Output	DO	Digester - Pump
Hopper Output	HO	Hopper - Pump

Mode Name	Valve Positions LI	DI	HI	DO	HO	Effective Circuit	Purpose	How Often
Warm-up	X	X	0	X	0	Hopper-Hopper	Warm manure	Daily
Input	X	0	X	X	0	Hopper-Digester	Load digester	Daily
Night	X	0	X	0	X	Digester-Digester	Warm digester	All night
Inspect	X	X	0	0	X	Digester-Hopper	Unload digester	Daily
Dump	0	X	X	X	0	Hopper-Lagoon	Dump slurry	Daily
Pumpout	0	X	X	0	X	Digester-Lagoon	Empty digester	---

X = valves closed
0 = valves open

The Digester Tank is a precast, reinforced, ASTM Class III sewer pipe, with an inside diameter of six feet; and height of seven feet. The base is a steel reinforced plate cast on. A precast lid with holes for observation ports, slurry input, slurry output, gas outlet, and manhole, was gasked in place after installation. The tank was sized based on monies available and the ability to obtain materials within the time frame alloted for construction.

The system is actually too small to be self sustaining because of heating requirements. Had the system been well insulated, breakeven in energy might have been achieved. Tables 4 and 5 give power and energy requirements and gas produced based on both field testing and design calculations. The system actually performed better than calculations indicated. Table 6 summarizes loading rates and gas production during some typical feeding periods and also gives basic chemical performance data.

TABLE 4. ENERGY BALANCE - GREEN BAY DIGESTER

Month	Total Energy Input: Monthly Sum Btu x 10^6	Total Energy Input: Daily Mean Btu x 10^6	Total Energy Produced: Monthly Sum Btu x 10^6	Total Energy Produced: Daily Mean Btu x 10^6	Energy Balance: Monthly Sum Btu x 10^6	Energy Balance: Daily Mean Btu x 10^6
3/76	6.7	.29	.120	.0050	- 6.6	- .29
4/76	5.8	.20	.006	.0002	- 5.8	- .20
5/76	5.1	.17	.130	.0042	- 5.0	- .17
6/76	4.0	.13	.130	.0043	- 3.9	- .13
7/76	3.8	.12	.073	.0023	- 3.7	- .12
8/76	3.4	.11	.110	.0034	- 3.3	- .11
9/76	4.8	.16	.170	.0006	- 4.6	- .15
10/76	5.7	.18	.270	.0086	- 5.4	- .17
11/76	6.8	.23	.420	.0140	- 6.4	- .21
12/76	7.5	.24	.460	.0150	- 7.0	- .23
1/77	8.1	.26	.620	.0200	- 7.5	- .24
2/77	6.2	.22	.530	.0190	- 5.7	- .20
3/77	4.3	.13	.410	.0130	- 3.9	- .12
4/77	5.5	.18	.410	.0140	- 5.1	- .17
5/77	4.0	.13	.850	.0270	- 3.1	- .10
6/77	3.8	.13	1.400	.0480	- 2.4	- .08
7/77	2.9	.09	1.600	.0510	- 1.3	- .04

TABLE 5. PREDICTED ENERGY BALANCE (BTU/DAY)

INPUT	YEARLY MEAN	JANUARY	DESIGN LOW
Electricity	1.52×10^4	2.04×10^4	2.04×10^4
Heat	7.87×10^4	1.16×10^5	1.31×10^5
Total	9.39×10^4	1.36×10^5	1.51×10^5
OUTPUT			
Gas Generated	1.19×10^5	1.19×10^5	1.19×10^5
Surplus/Deficit	2.51×10^4	-1.70×10^4	-3.20×10^4

Rather than deal with the actual switching from biogas to propane backup, the system was operated entirely on propane and gas production noted. This was largely due to lack of time and funds to produce the dual fuel system and the need for test data reliability.

Only two major problems were encountered. First, the pump which moved the manures needed several modifications largely because budget constraint did not allow for optimum pump selection. Secondly, abnormally high heat losses were encountered because the tank was not insulated. Other problems were minor and in more of a maintenance category.

Experience gained on this system and other full scale systems indicated that this operation could have been run on a higher solids loading and thus achieved the equivalent of a 6 cow operation. This would have been a net energy producing system. The pump which was selected (Midland AFP submersible pump) was unable to handle the high loadings. Funding was not available to replace the pump, so the system was dismantled after experiments under this contract were terminated.

TABLE 6. LOADING RATES, GAS PRODUCTION, AND CHEMICAL PARAMETERS
GREEN BAY PILOT PLANT

		INFLUENT						EFFLUENT					
Load Rate lbs/ft^3	Gas Produced ft^3/day	% TS	% VS of TS	Volatile Acids mg/l	Alkal. mg/l	pH	COD	% TS	% VS of TS	Volatile Acids mg/l	Alkal. mg/l	pH	COD
.005	6.8	4.99	80.20	2707	5233	7.1	48,333	3.55	64.86	1200	5410	7.45	29,000
.010	11.3	4.76	84.00	2466	4898	7.2	67,400	2.22	68.27	980	5964	7.88	24,200
.021	29.8	7.31	87.60	2719	6008	7.2	96,667	4.20	80.57	1587	6911	7.75	51,000
.031	39.7	8.48	87.10	2925	7160	7.2	97,500	4.82	81.87	1840	7085	8.30	63,000
.039	37.8	9.65	88.30	3563	6663	7.2	103,333	5.01	83.09	1390	6980	8.05	64,300
.043	54.5	7.11	82.50	4380	6763	7.3	84,500	4.04	78.42	1210	5778	7.60	60,250
.078	96.0	7.42	75.60	5267	9337	7.2	100,667	5.17	78.60	1890	8000	7.80	65,000

Abbreviations: TS - Total Solids; VS - Volatile Solids; mg/l - milligrams/liter; COD - Chemical Oxygen Demand; Alkal. - Alkalinity

Ludington (Cluster) MI System

This is the first system constructed by Agricultural Energy of Ludington, Michigan (now Energy Harvest, Chicago, Illinois).

The Ludington unit was sized to utilize the waste from 350 head of feeder cattle. The lot is open and collects rain water and snow. It freezes in winter and dries hard in summer so that weather conditions affect it adversely.

The manure is collected in a 136 M^3 (4800 ft^3) concrete tank. An automatic system controlled with a timer clock fills and discharges a 300 litre (80 gallon) tank of 8 to 10 percent solids fed into the digester. The system had a pneumatic tank which metered materials from the mixing pit to the fermenter by first vacuuming up a volume and then using pressurized biogas to force the material into the fermenter. The operation is schematically depicted in Figure 16.

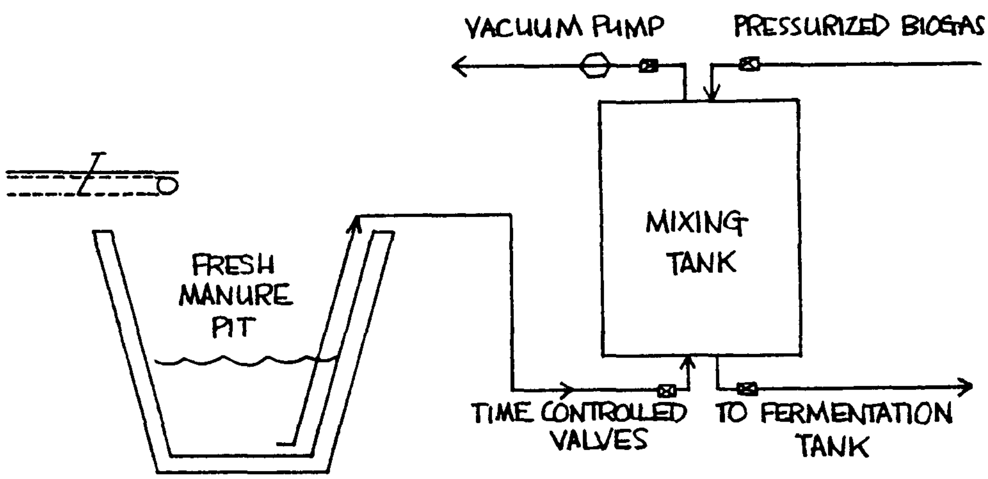


Figure 16. Schematic of fermentation tank feeding system, Ludington

The basic innovation of this system was the use of a flexible membrane for a fermentation tank and gas storage system. The original bag, manufactured from a fabric reinforced plastic and earth supported, suffered from faulty seams. This unit was subsequently replaced by a wooden frame, membrane lined unit which gave better structural control and insulation from the ground heat loss. (Figures 9 and 20)

The digester is approximately 191 cubic meters (6750 ft^3) liquid volume. Level is controlled by a level probe and a diaphragm pump. The bag expands when filled with gas and collects approximately 187 M^3 (6600 ft^3) of biogas. The biogas from this bubble is compressed in a small vane pump to 10 psi and is fed to an engine coupled with a 30 kw gas driven generator. The excess heat from the generator is used to keep the fermenter at temperature (35^oC).

Aside from the structural problems in the original bag fabrication, there were several major design problems. First, no provision was made to keep the feedlot from freezing in winter. This led to digester shut down in very cold months. Next, solenoid valves used in the automatic feed system were unreliable leading to uneven feeding. Problems with the vacuum pump also plagued the feeding operation.

The feedlot never had the full contingent of animals, thus the system has never operated under full design load for extended periods of time to test the efficiency of waste stabilization.

Rice Lake System

This unit was a spinoff from the Ludington design.

The Rice Lake unit is designed to use the manure from 110 head of dairy cows in confinement with floor scrapers. From the scraper pit the manure is pumped into the fermentation tank.

The original plan for the tank called for a half culvert to be placed over the original bag digester so that the entire system could be earth covered for insulation. Construction dictated that a complete culvert was necessary. The final design led to a culvert with end plates and no liner. Rather than use a one piece culvert, the 3.66 M (12 ft.) diameter by 14.6M (48 ft) long tube was constructed from 24 rings each .6 metres (2 ft.) wide. Each ring was made from three sections. The 72 pieces and the two end plates together with flexible gaskets comprised the fermenter tank, along with 8000 bolts which hold the system together. See Figure 21. The concept behind the sectional nature was to test the idea of modularity for flexibility in tank design, but the labor intensive construction of this design makes it cost prohibitive.

The tank is buried under three feet of earth and has an additional inch of styrofoam around it. Unfortunately, the water table in the area is high and no provisions were made to tile away any moisture build up which could yield a high heat loss and possible floatation problems if the system is drained at an inopportune time. The system is heated by coils running longitudinally along the bottom. These pipes use hot water from the engine/generator set. Currently there is no monitor on the flow rate and temperature of the water, so no accurate data as to tank heat loss can be obtained.

The control house (Figure 17) has undergone two evolutions as the system was redesigned. The figure shows the current configuration. The idea in compartmentalizing is to separate the electrical and engine controls from the section where gas enters the structure to reduce the possibility of explosion and fire. Also, the work area is isolated from the generator system to reduce the effects of noise on operators. A fan installed in the wall between the engine and gas section pulls fresh air through the work area, through the engine area and to the gas area to keep a positive pressure in the gas section. Gas detectors are located in the piping and engine areas. They were designed to sound an alarm at 25 percent LEL and shut the system down at 50 percent LEL. All motors are hydraulic to reduce the possibility of explosion. Experience in installation and maintenance seems to indicate that electrical systems are easier to install, operate, and maintain as well as being cleaner.

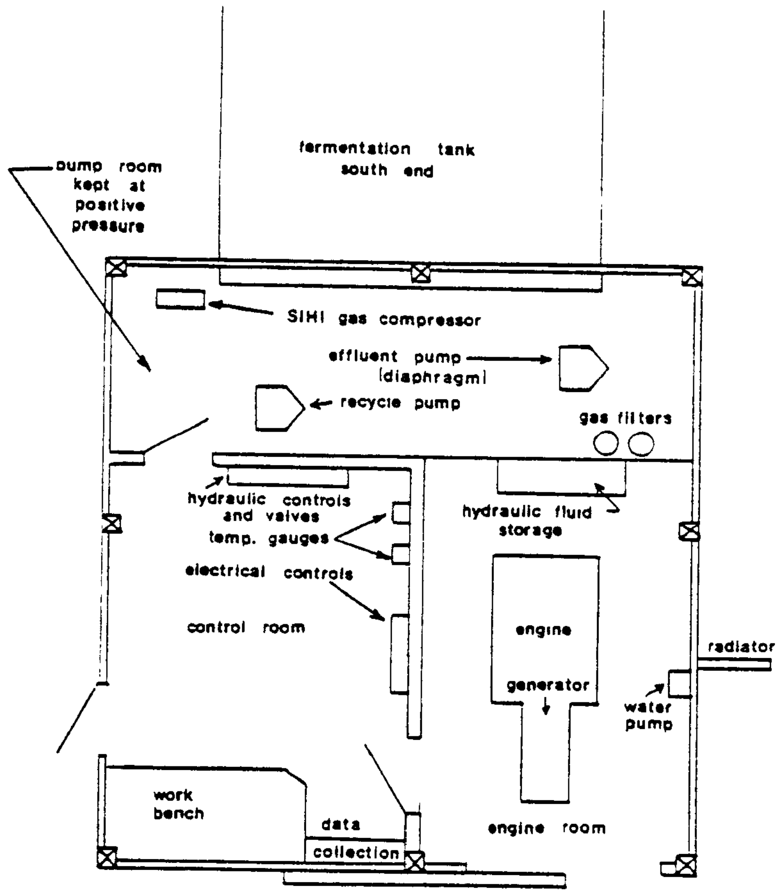


Figure 17. Rice Lake control house.

At the termination of this work, a small microprocessor for data acquisitions and control arrived and is being installed for monitoring and to ascertain problems in using microprocessors over hard wired programmers and timers.

The current engine generator is a 12 kw Waukesha engine coupled to a Kato generator set. Power is supplied to a portion of the house.

A schematic of the piping for the dairy operation is shown in Figure 23. The system was designed to operate on a 15 day hydraulic retention time (HRT) and possibly as short as 10 day HRT. To prevent a wash out of the microbial population on this short a retention time, a refeed pipe has been added. While the effluent pipe removes material from the bottom of the fermentation tank, another pipe, at the top of the liquid level, cycles spent materials back into the tank with the new influent. This acts as a seed material, preventing washout and enhancing the fermenter operation.

While the unit is set up to automatically feed on 24 hour basis, problems with materials handling has prevented the system from operating in this mode and the fermenter has been batch fed approximately three times a week with no adverse affects on systems operation.

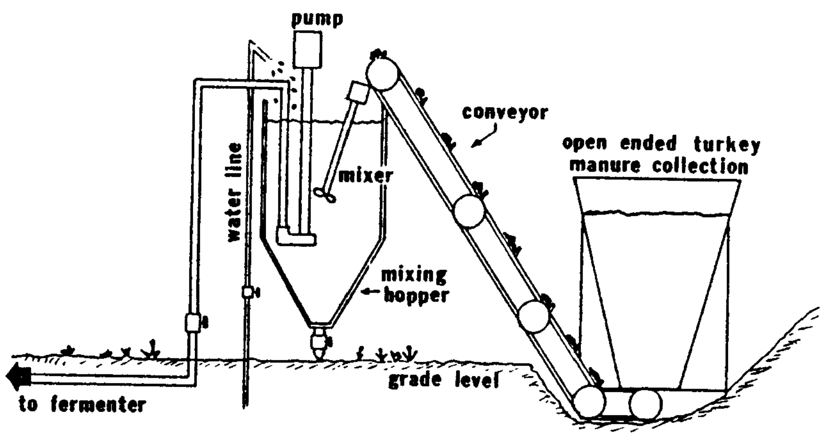


Figure 18. Temporary turkey manure collection, Rice Lake

Prior to operating as on dairy waste, the system was used as a pilot facility for evaluation of turkey waste from a local feeder operation. The schematic for the temporary operation is shown in Figure 18. Several problems appeared due to the temporary nature of the materials handling set up. Most of these were due to improper weatherization since the original intention of the experiment did not include winter operation.

Several problems arose in the materials handling systems operation which were due to the nature of the turkey waste. First, turkey waste is self composting like horse manure. This led to heating which had two effects, bridging in the storage hopper and loss of nutritive value leading to low gas production. Thus, turkey waste must be fresh for maximum benefit and ease of handling. Secondly, the material was removed from unpaved pens. This led to the inclusion of dirt and other debris which clogged lines. Finally, the turkeys were bedded with rice hulls which do not digest well and tend to create plugging problems. Analysis of the rice hulls is shown in Table 7.

TABLE 7. CHEMICAL ANAYLSIS*
OF RICE HULLS USED FOR TURKEY BEDDING

Crude Protein%	2.4
Fat%	.5
Fiber %	41.0
Ash %	18.3
NFE%	21.9
Water%	10.5
SiO_2%	1.60
Na_2O%	1.58
CaO%	1.01
MgO%	1.96
FeO%	.54
P_2O_5%	1.86
SO_3%	.92

*Analysis supplied by J.B. Hunt Company, Springdale, Arkansas

Table 8 is a typical analysis of the turkey waste in the system. The influent is equal portions of water, turkey waste solids, and recycled fluid.

Note from the recycle fluid and the effluent that there is stratification in the fermentation tank. The analysis of the solid turkey waste is also shown in Table 8.

TABLE 8. ANALYSIS OF TURKEY WASTE IN RICE LAKE SYSTEM

Parameter	unit	Diluted Influent analysis	s	Undiluted Influent analysis	s	Recycle Fluid analysis	s	Effluent analysis	s
% M of Total Sample	*by weight*	96.30	0.16	26.83	1.32	99.09	0.02	88.16	0.49
% TS of Total Sample		3.70	0.16	73.17	1.32	0.91	0.02	11.84	0.49
% VS of TS		69.65	0.80	55.03	0.66	54.82	1.32	57.77	1.60
% FS of TS		30.35	0.80	44.97	0.66	45.18	1.32	42.33	1.60
% VS of Total Sample		2.58	0.14	40.26	0.48	0.50	0.01	6.84	0.43
% FS of Total Sample		1.12	0.02	32.91	1.01	0.41	0.02	5.00	0.17
Total Alkalinity	mg/1	8650	41	-	-	7620	1	8010	45
Volatile Acids	mg/1	3530	60	-	-	1500	29	1820	0
PH: Non-Filtered	-	7.3	-	-	-	7.3	-	7.5	-
PH: Filtered	-	7.4	-	-	-	7.5	-	7.5	-
Total Kjeldahl Nitrogen	mg/1	3070	1	2.03%	0.13	2020	4	4140	4
Ammonia Nitrogen (as N)	mg/1	1690	6	-	-	1650	4	2060	1
Organic Nitrogen (as N)	mg/1	1380	5	-	-	370	4	2080	3
Total Organic Carbon	mg/1			-	-				
Chemical Oxygen Demand	mg/1	81,000	1032	-	-	39,000	1220	79,000	1548

M = Moisture
TS = Total Solids
VS = Volatile Solids
FS = Fixed Solids
s = Standard Deviation

SECTION 5

TECHNICAL COMPONENTS

One can define three basic components of an anaerobic digester: the influent tank which serves as a temporary storage of the material for fermentation, the fermentation tank which stabilizes the residues and produces the gas, and the lagoon for effluent storage. This particular study looked at the problems in the design of these major components, as well as materials handling, gas utilization, and power systems for full scale digesters.

INFLUENT TANK

The tank in the Ludington system was an underground concrete pit which received the animal wastes from an open feedlot as they were introduced via a scraper. (Figure 16) The Rice Lake system utilized a similar arrangement which was fed by a barn scraper which cleaned a free stall barn where the dairy herd was confined. (Figure 19) Several crucial design mistakes came to light in this study.

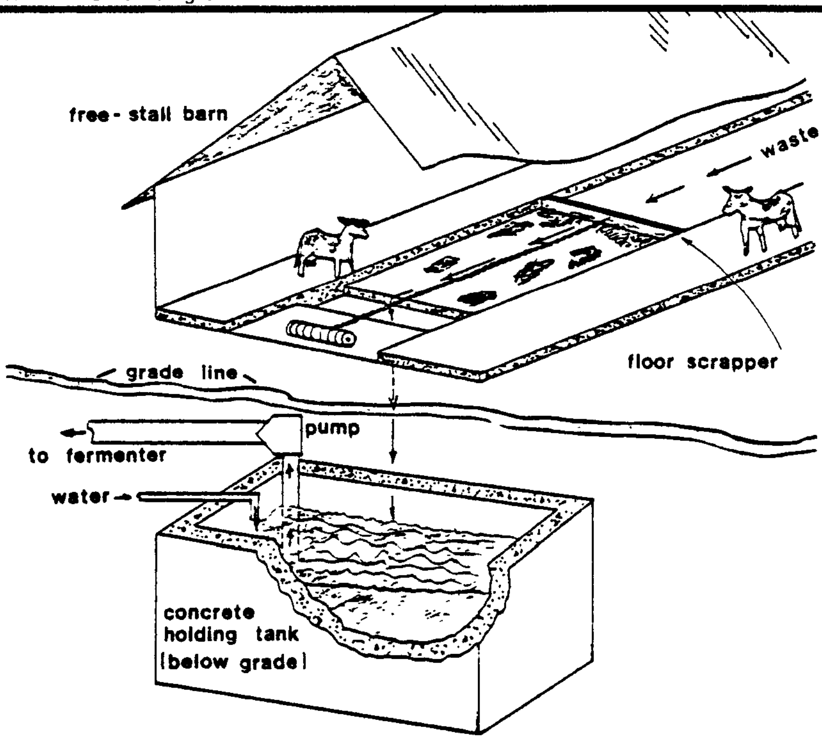


Figure 19. Rice Lake influent tank.

1) Both tanks lack insulation. Thus, the animal wastes soon reach ground ambient temperature or lower. This reduces biological activity and serves as a thermal schock to the fermenter when new material is introduced from the influent tank. In fact, the major need for heating lies specifically in bringing the animal wastes up to temperature.

The Rice Lake system was equipped with the capability for heating the influent tank with surplus heat from the engine/generator, but the system was never made operational. This is a large loss and causes a significant dent in the engineering economics of the system.

2) Sizing of the influent tank is important both in initial cost and in operation. The Rice Lake (RL) pit existed at the projects inception and was designed to store animal waste for several weeks before spreading on the fields. The large storage capacity was an advantage when the fermenter was down for maintenance, repairs, or reconstruction and clearly pointed to the need for reserve capacity and/or bypass from the influent tank to the lagoon. On the other hand, the large size created pumping problems because the manure tended to stratify. The solids settled to the bottom decreasing the pumping capacity from the influent storage to the fermentation tank.

Neither tank had a built-in bypass for direct pumping to the lagoon should operational conditions warrant. Based on the operational experience, this feature is desirable, especially if only a short term capacity is designed into the influent storage.

FERMENTATION TANK

Both Ludington and Rice Lake operations are horizontal, pseudo-plug flow systems, in that the tank design did not prevent thermal mixing. Also, there was no way to assure that the Hydraulic Retention Time (HRT) and the Solids Retention Time (SRT) coincided. The Rice Lake system operated on a very short (10-15 days) HRT and, thus, refed part of the effluent with the influent to keep the bacterial population up (see systems operations).

The plug flow, or horizontal, mode of operation seems best from a structural perspective and low installation costs. It appears that trouble free operation with low mixing costs are possible with horizontal systems. Neither of these systems, nor the ones under study at Cornell are mixed in normal operation yet have comparable gas yields to completely mixed systems. Thus, a costly installation and maintenance item, mixers, are eliminated.

The dimensions of the tank follow conventional wisdom for plug flow units (length = 5x width). Experience at Cornell seems to indicate, though, that tank shape is of little importance to efficient systems operation of anaerobic fermenters.

All tanks were insulated with sheet styrofoam to below the frost line; the Rice Lake system was covered with styrofoam and three feet of earth. No special provisions were made to provide drainage to keep moisture from the tanks. Small changes in soil moisture can create large changes in heat loss, so it appears that good drainage around the structure is imperative to minimize heat losses. (28) One researcher has gone so far as to advocate not burying tanks because of heat loss. (61) However, no data has been developed to support the contention that a tank free of the earth is cheaper to build, operate, or maintain.

Both the Rice Lake and Ludington systems had internal heat exchangers running the length of the fermenter. They also had gas pipes placed so that mixing, if desired, could be accomplished by introducing biogas under pressure. (Figures 20 and 21)

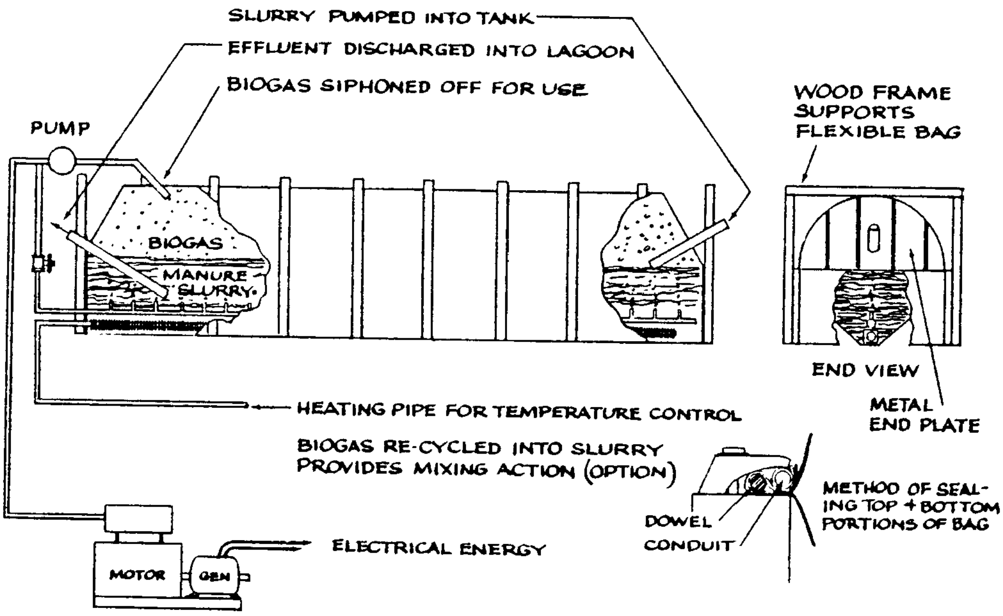


Figure 20. Ludington fermentation tank.

The Ludington system appeared in two versions during the study (Shown earlier in Figures 8 and 9). Both employed a fabric reinforced tank liner manufactured by Staff Industries. The upper and lower segments of the tank liner were field assembled. The first flexible membrane system was earth supported while the second model also had a plywood frame for support. The Ludington system floated styrofoam sheets on the effluent to protect against heat loss. Gaps in the sheets permitted gas to escape the solution and to fill the cover which served as storage.

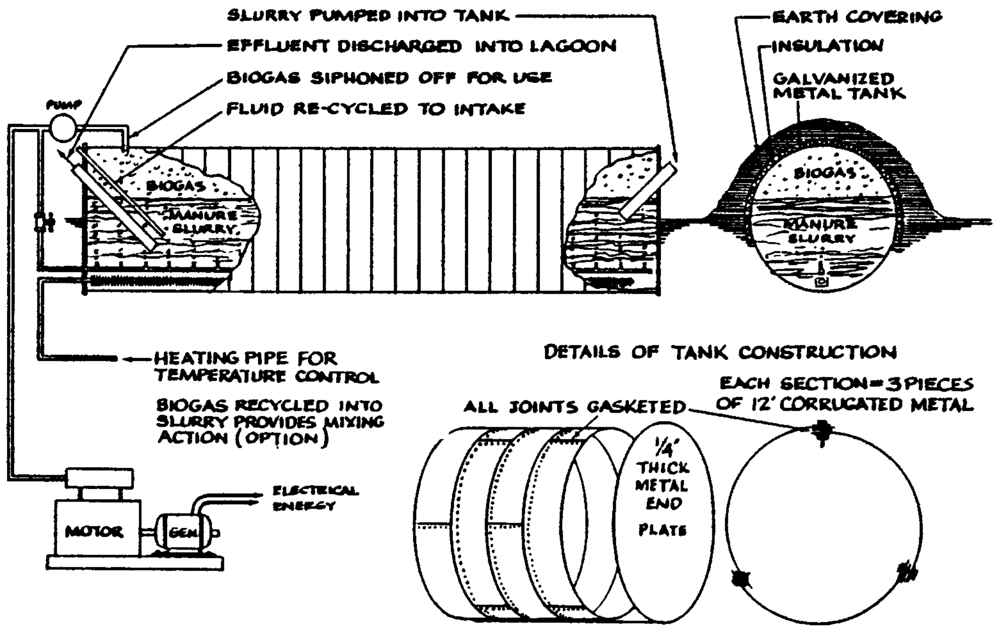


Figure 21. Rice Lake fermentation tank.

The Rice Lake system was formed from segments of galvanized metal field bolted together (Figure 21). The labor involved, however, precludes this method of construction. The company, Agricultural Energy, feels confident that a metal tank will survive the mechanical and chemical abuse from the fermentation process. Their assumptions seem contrary to the published literature (29) but are partially supported by the experiences of Biogas of Colorado (30) who ran a portable unit for one summer. In the latter system no corrosion was found in the anaerobic fermentation tank though there was some deterioration in the metal influent tank which was exposed to the air. Experience in India (3) seems to indicate that corrosion could be a problem over the long run and that interior protective coatings should be applied at regular intervals. The Rice Lake tank has not been opened for visual inspection since start-up, thus, no data is yet available on actual field condition.

For low costs, the preferance is for the flexible membrane tankage because it is easily installed, maintained, and also provides gas storage. Another alternative is wooden tanks which have been used for fermentation vessels in the past. They stand up well to anaerobic environments and are used where harsh chemical environments would destroy steel. Both traditional stave structures or plywood could be used. (31) Metal tanks of mild steel require more maintenance and are expensive, as is concrete. Galvanized tanks such as the Rice Lake operation are worth watching. No data on longevity or durability is yet available.

LAGOON SYSTEM

Both the Rice Lake and Ludington systems have standard farm lagoons for effluent storage. Our studies, those at the University of Minnesota (36), and data provided by Environetics (22, 23) leads us to conclude that anaerobic lagoons should be completely covered to prevent nitrogen loss from the effluent. This cover would pay for itself in fertilizer savings. Lining the entire lagoon with a membrane (creating a larger "fermenter") would allow easier pumping of the liquid when the lagoon is emptied and also prevent loss of solids and liquids which would be caught in a soil lined system.

MATERIALS HANDLING SYSTEMS

Both systems were designed with the idea that the daily influent would be fed at a uniform rate throughout the day (24 hours). The intent was to prevent shock loading of the fermenter with large slugs of cold, unfermented material. Both systems suffer from intermittent clogging, failure of the automatic or manual operation done on daily or twice daily operation. While the principles behind the feeding systems are sound, they are unnecessary if one judges by the operation of other systems. Shock loading would be prevented if the influent were kept warm or preheated.

The Ludington system operates on a vacuum principle. (Figure 16) A small vacuum pump evacuates the tank. A valve opens permitting manure to fill the tank. Biogas then blows the manure into the fermenter. The system is controlled by a timer adjustment to meet the needs of the daily loadings.

Because there is no pump in the system there is no opportunity to chop the influent to break up large particles which may cause plugging. A number of inline mascerators have been tried with little success. The largest problem appears to be animal hairs which wrap around mascerator or pump impellers bringing the operation to a halt.

The Rice Lake system is unique in that it is the first system to use hydraulics to control valves and motors. Hydraulics were chosen: 1) to test the concept of using hydraulics; 2) hydraulic motors are smaller and more compact; 3) the hydraulic pump needed to run motors adapts readily to engine generator set; 4) use of hydraulics reduces the potential for an explosion. The hydraulics are run from a pump which is driven by the engine/generator. Hydraulics then run off idle power similar to an air-conditioning compressor on an automobile. The biggest problem here is there are no manual over rides on the valves and no way to activate the pumps should the generator system be down. Because of the late installation of a satisfactory engine from which to operate the hydraulic pump, do data is available under this contract, but it has been operating satisfactorily.

Figure 18 schematically indicates how the Rice Lake unit was operated as a test bed for turkey wastes. From a materials handling perspective, the turkey waste proved to be the most burdensome because the fresh waste tended to heat up, cake, and then bridge in the temporary hopper. Since the material was cleared from unpaved houses, dirt, rocks, and similar debris were also picked up. This caused problems in movement and pumping, because the debris materials would not pass through pumps and pipes. Additional problems occurred because the addition of water caused the rice hulls to settle out and create plugs in low piping points. The system was not winterized because of the temporary nature of the turkey test. Thus, freezing problems developed during the winter of 1976 and 1977, which was unusually cold.

The basic idea was to work with an influent of 8 percent to 12 percent total solids. This was accomplished by first loading a portion of raw effluent, adding a measure of spent effluent as seed and then adding water. In the turkey operation, these materials were mixed to assure uniformity and ease of pumping. This was pumped into the fermenter after an equal volume of spent materials had been removed.

Figures 22 and 23 show how the dairy handling was originally designed and how it operates now. The original dairy system was to have operated similar to the Ludington operation (a portion of spent effluent was to be pumped into a tank aloog with a charge of influent and water. The mixture was then to have been introduced to the fermenter via pressurized gas). Prior to the startup of the dairy operation, however, the system was re-designed eliminating the tank and operating as follows. After pumping effluent from the bottom of the fermenter to the lagoon, a portion of effluent from the top of the tank is diverted into the influent line joining manure pumped from the influent pit. The operation is controlled by a timer which regulates valves and controls quantity of input. Previously, quantity had been controlled by level sensors in the tanks. These were high voltage, low current sensors similar to those used in farm lines.

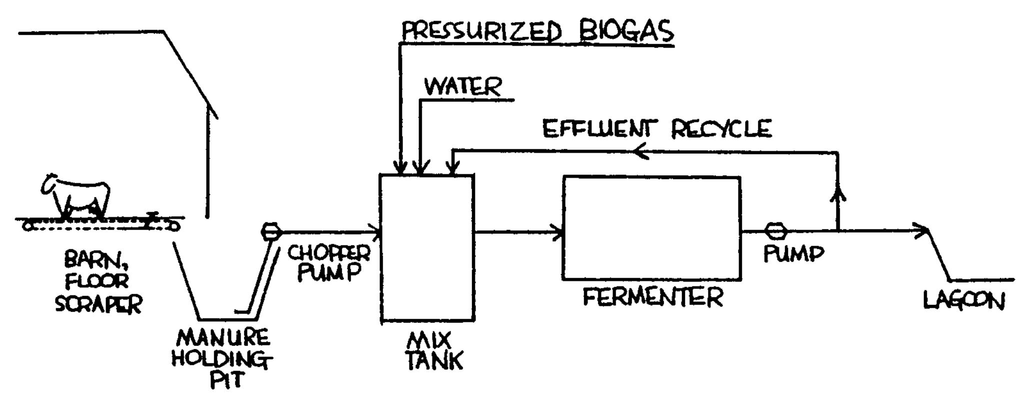


Figure 22. Schematic of original manure handling system, Rice Lake

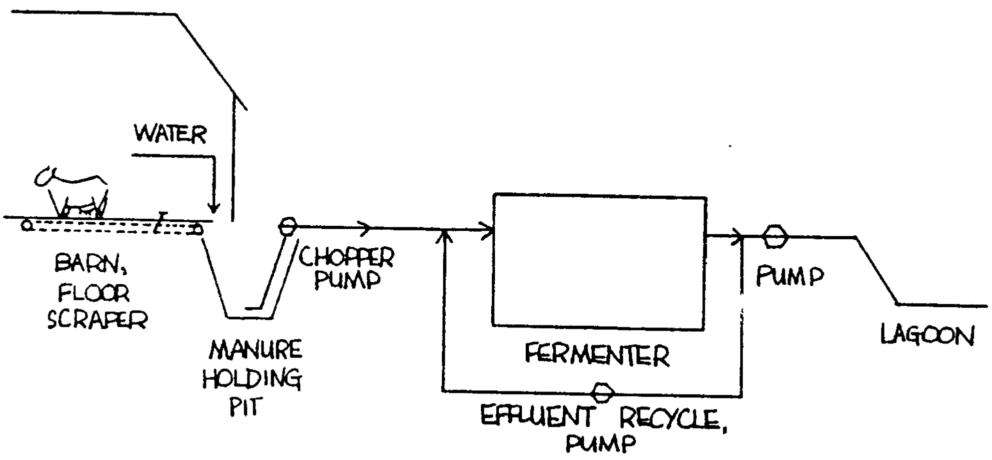


Figure 23. Schematic of redesigned manure handling system, Rice Lake

About the time revisions to the Rice Lake system were made to the materials system, Cornell indicated that a fermenter could operate at high solids concentration of manures (undiluted). This was the original intent of the revised Rice Lake system but the installed pump could not handle the head from the influent tank. This required that the operation be modified so that the operator could add water to the influent tank prior to pumping. The pump was then used in a mix or recirculating mode prior to pumping the mixture to the fermenter. At the present time, this is forcing the operation to be in semi-automatic mode.

Several factors became clear in observing both the Rice Lake and Ludington operations. First, piping and pumps need to be oversized to take into account the peculiar properties of the manures. Second, piping runs with angular turns create obstruction problems, especially if bedding is present. Thus, careful attention must be given to layout and inclusion of sufficient cleanout ports to allow total access to all parts of the line. Third, manual operation, at least for small operations, appears to be the most efficient way to go. Finally, the pumping system should have a means of being operated separately from an on sight generator set (more will be discussed about this in the gas utilization, technology and economics sections.)

GAS UTILIZATION SYSTEM

Both the Rice Lake and Ludington systems run an engine/generator set from the biogas. Additionally, the gas can be burned directly on the Rice Lake farm, though this is not being done currently.

Since the Rice Lake system has a rigid fermenter, gas storage was needed. This was accomplished by floating a flexible membrane on the lagoon (Figure 24).

Several problems cropped up with this gas storage system. First, the flexible membrane froze in the lagoon in winter and spring thaw caused the ice to give unevenly allowing the bubble to tilt and release the gas. Also, the high moisture of the gas may have caused icing problems in the gas line, though this has not been verified. It should be noted that trace amount of water can form hydrates with methane. These hydrates have a freezing point well above the freezing point of water. This phenomena is well recognized in the natural gas industry; pumping methane over long distances without dehydrating it could cause freeze-up problems.

In both systems, concern was expressed for the quality of the gas (approximately 600 Btu/cu feet) because of storage and efficiency issues. Experience at the Ludington facility verified that lime water (limestone in cold water) is a poor scrubbing medium, even under pressure. No significant increase in quality was observed.

On the Rice Lake system the gas passes through a water trap and a hydrogen sulfide trap (copper wool in the form of pot scrubbers from the local supermarket) before passing through a standard gas meter. The gas for the engine manufacturers. When the system operated on turkey waste, the presence of hydrogen sulfide was indicated by the formation of copper sulfide on the piping; though it was not noticeable by odor.

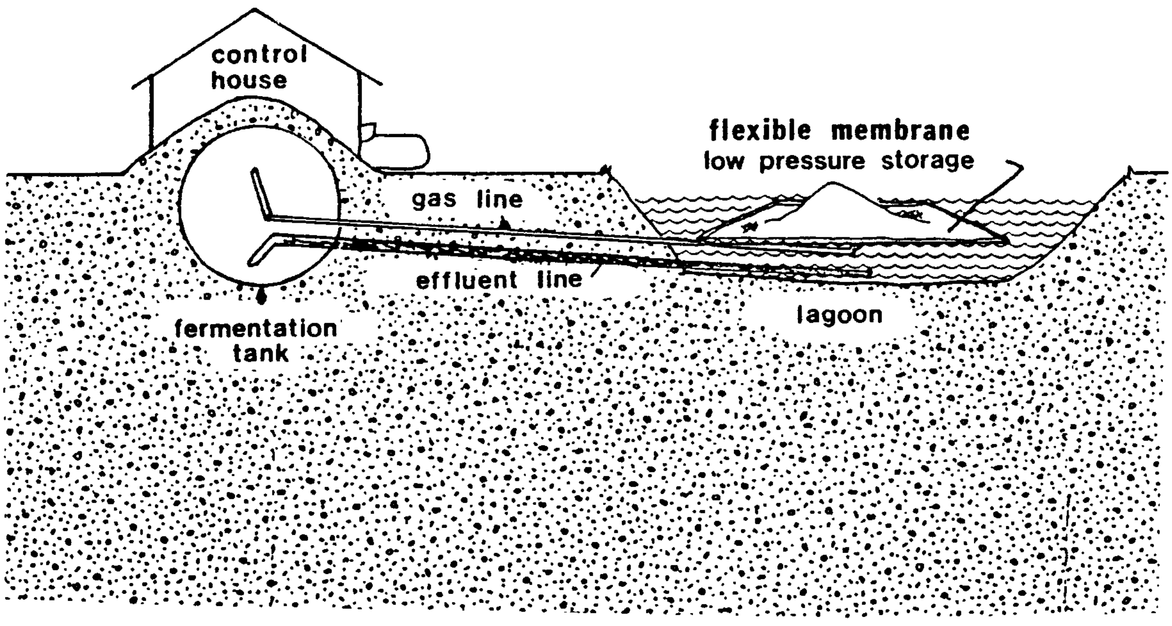


Figure 24. Gas and effluent storage system.

The Rice Lake system included a unique method for gas compression. (Figures 25 and 26) The core of the system was a Sihi ring seal compressor. The theory was that CO_2 could be dissolved in the water which served as a seal compressor. After compression, both the water and gas were then sent to a storage tank where the biogas separated and the water overflowed a check valve into the lagoon. While the system worked well for low pressure storage for the generator set and for other uses, the gas enrichment via carbon dioxide removal proved to be insignificant. In fact, air trapped in the well water was released into the gas mixture--a potential explosion problem. (Table 9)

The presence of a 10 percent concentration of carbon dioxide in the gas is of concern only from the economic point because it is not usable in the gas mixture and it requires storage volume. The quantity of CO_2 is too small and the systems too simple to warrant a sophisticated amine scrubbing system used in industrial applications. However, some chemical alternatives do exist, and could significantly enhance the quality of the gas, as well as economics of the system. This is discussed in the Biochemical section.

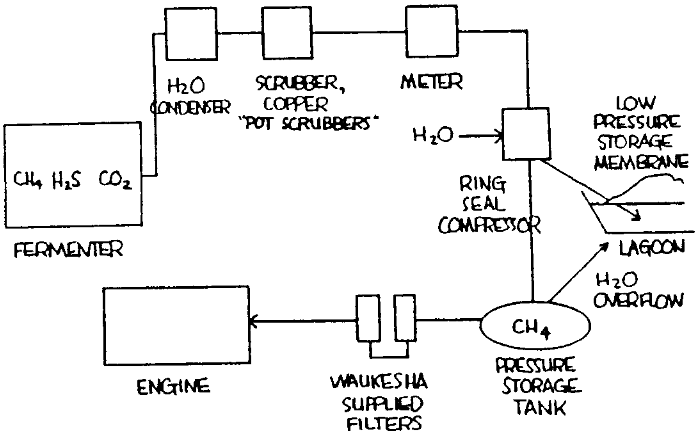


Figure 25. Gas scrubbing and compression system.

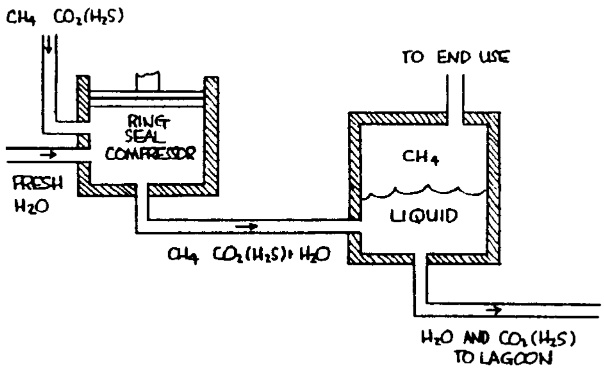


Figure 26. Schematic of SIHI ring seal gas compressor, Rice Lake

TABLE 9. AVERAGE GAS SAMPLE ANALYSES
RICE LAKE SYSTEM

	Low Pressure System	High Pressure System
% CH_4	58.23	58.27
% CO_2	36.96	29.51
% $O_2 + N_2$	4.82	12.22

ENGINE GENERATOR SYSTEM

The Rice Lake and Ludington systems utilize the entire gas production of the fermenters to generate electricity via an engine generator unit. From both an engineering and economic perspective, this is the most inefficient means of utilizing the biogas. Direct combustion is the most efficient. The economics are particularly bad when the engine generator unit runs 24 hours a day, even under full load. This is almost a necessity in cold weather since the cooling water is needed to provide heat to the fermenter. When the systems are on automatic, the engine provides power to the material handling system. Use of a large generator unit for providing waste heat and, intermittently, pumping power is not an efficient use of resources.

Figure 27 shows the schematic of the Rice Lake power system. The original design included a four-cylinder Ford industrial engine. Special pistons were designed to increase the compression ratio to the level suggested by a Cornell study for optimum performance. These pistons were never installed. Instead, a Ford spark ignited diesel was substituted. This ran satisfactorily, however, no actual power curves were generated since the digester never produced gas for an extended period of time, due to research and redesign. This engine/generator set was replaced by a Waukesha engine/ generator unit specifically designed to run on biogas and/or propane. Propane was used as a backup in case the fermenter was not working or producing sufficient biogas.

The engine/generator unit did not supply enough electricity to meet the farm/home requirements, thus, part of the house load, within the 12 kw capacity, was transferred to the unit. The generator output was kept separate from the utility lines so there was no need to provide a synching mechanism to phase the two power systems. Clocks on the biogas generator circuit indicated that good frequency control was hard to maintain with the Ford engines. This was improved by a close tolerance governor on the Waukesha unit, though still not completely satisfactory for delicate control mechanisms such as turntables for stereo units. Separate frequency conditioning units may prove essential where good control is needed, or where motors (such as compressors) could be subject to burnout from poor regulation in frequency or power.

Both the Rice Lake and Ludington operations have heat exchange systems

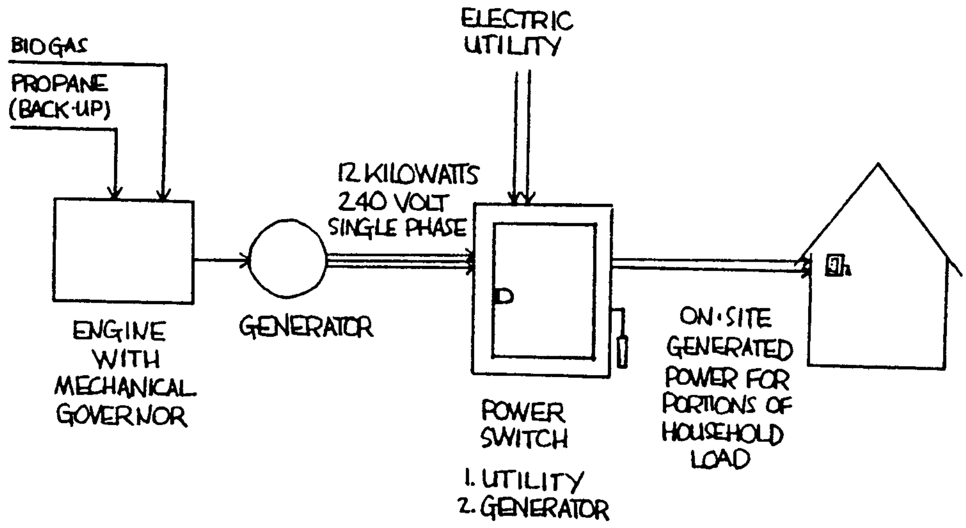


Figure 27. Schematic of Rice Lake power system.

between the engine and the fermenter. (Figures 28 and 29) The design includes two pumps and a thermostatic control. When the fermenter is warm enough, the thermostatic control directs excess heat to a radiator/fan unit. Design consideration must be given to pipe sizing so that the engine water pump does not exceed its design capacity due to the additional heat created in the heat exchanger network.

Several operational characteristics became clear during the course of this study. First, continual running of the generator unit produced minimal energy at maximum cost, since waste heat was used only for fermenter temperatures maintenance on both the Rice Lake and Ludington units. Greater utilization of waste heat would improve energy costs somewhat. (See the Economics section)

Next, most industrial engines have a finite time between overhauls. For example, a standard automotive engine can get about 3,000 hours between major overhauls; an industrial engine manufacturer may recommend about 60,000 hours between major overhauls. This implies that under continuous operation, one major overhaul would be necessary every six years. Routine maintenanence and normal breakdowns must also be anticipated. Routine engine maintenance and overhaul costs on the Rice Lake system are estimated to be $.012/kwh based on full load utilization. Thus, this study indicates that an anaerobic digester should be integrated into the farm operation so that most of the gas is used for its thermal value directly, and a minimum amount of gas is utilized for power generation.

CONTROL SYSTEMS

The control for both the Rice Lake and Ludington systems were designed to be automatic. They consisted of electromechanical components such as sensors, timers, and relays. The timers were set to start the systems cycling "x" times/hour. During that cycle, level sensors were used to determine the status of various tanks and regulate valves which controlled water, effluent or influent. The timers and level sensors also activated the proper pumps. The controls operated with minor problems, but there were no alarms to indicate when malfunctions, such as plugging up or bridging in the hoppers, occurred in the materials handling system. An alarm system would have been too costly with electro/mechanical controls. During initial startup of the Rice Lake system, one person was there full time for a period of one year to monitor and work bugs out of the system.

A controller/monitor which works on the basis of a small microprocessor has been under d sign and construction for the last six months under this study.

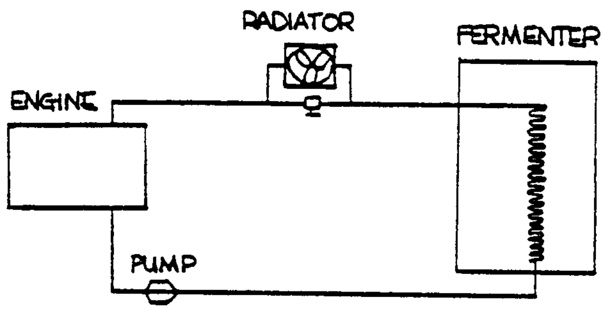


Figure 28. Schematic of original heat exchange system.

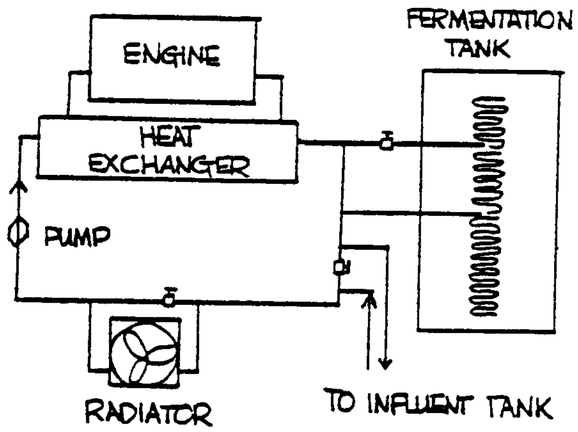


Figure 29. Schematic of rebuilt heat exchange system.

It is to be used to collect data and relay it on demand to a computer located in Minneapolis. The unit, being designed by Automatic Hardware, also will have some control functions via "on/off" relays. The cost of the processor is low enough, that a number of desirable features can be incorporated. They include safety, control and alarm monitoring functions, choice of manual, semi-automatic, and automatic operation, and continual remote monitoring of functions. This unit will be effective when the materials handling problems of digesters have been reduced to a minimum. At the present time, the unit serves as a data collection device for the digester operation.

SECTION 6

BIOCHEMICAL CONCERNS AND ADVANCED RESEARCH

INFLUENT CHARACTERISTICS

Four systems were studied. Rice Lake, Ludington, Brockman Stables in Neenah, Wisconsin and the pilot facility at Green Bay. They have been run on dairy, beef, or horse manures, and the Rice Lake system has operated in an experimental mode on turkey wastes with a bedding of rice hulls. Table 10 lists the systems, and influent analysis on representative samples.

In addition to strict biochemical analyses, several concepts were developed to possibly enhance the economic feasibility of anaerobic systems. Preliminary studies on algal growth on the effluent, uses of the effluent for animal refeed, and the addition of municipal solid waste to the influent were among the research topics considered to enhance feasibility.

The manure of various animals have different storage characteristics. Collected turkey wastes will ensile themselves and heat up. In the turkey waste system examined, the urine was lost because the houses were not cleaned daily. This problem was exacerbated by long storage in the hopper prior to use. Radical changes in gas production could be observed depending on the age of the waste. The longer the time between storage and use, the poorer the gas production. No correlation was made because of the varying composition from the different turkey houses. Ensiling would not be a problem for the unfermented dairy or beef waste. One way to store these materials is in a covered lagoon, which in the case of the digester can double as gas storage. Swine manure behaves in a manner similar to beef, while chicken and equine wastes react like turkey wastes.

Rice hulls in the bedding of the turkey wastes proved to be a problem from a materials handling perspective. The addition of water caused the rice hulls to settle out, creating plugs in low piping points. As indicated by the analysis, (Table 7), the rice hulls do not ferment well due to the high amount of inert materials. Therefore, a shift in the type of bedding or elimination of bedding material prior to fermentation is desirable. Should a digester system be installed in conjunction with the turkey operation, changes would be needed in the choice of bedding materials and husbandry of wastes.

When the Rice Lake digester was shifted to operate on dairy input came from a freestall dairy barn. The influent was essentially bedding free. The daily production was metered to the fermenter uniformly over 24 hours under the original design. The Ludington system's input was similar to that of the Rice

Lake operation but came from an open feedlot and a mixing pit exposed to the environment. Two unique feed problems occured in addition to winter freeze up. First, there was a considerable amount of animal hair which plugged pipes and tied up mascerators, which were installed to alleviate the problem. The second problem was foaming in the mixing pit. This was eliminated by a silicone surfactant (propriatary) which did not noticeably affect systems operation.

The Green Bay pilot system was hand fed. Straw and bedding were omitted intentionally to study animal waste characteristics free from beddings.

None of the influent tanks were heated; thus the temperature of the influent was reduced to ambient and/or soil temperature. No experiments were made on changes in biological activity of the influent due to this cool down period. Nor has there been a sufficient history of systems operation to attribute any change in biological systems efficiency to this cooling effect. However, additional energy is required to bring the material up to temperature when it is introduced into the fermenter.

FERMENTER OPERATION

All three systems (Rice Lake, Ludington, and Green Bay) have essentially been run as underloaded digesters. The Green Bay digester has the only history of consistant operation during this work because of mechanical problems with the full scale systems. The loading rates and chemical parameters of the pilot unit are shown in Figure 30. Table 6 under systems description gives the data from which this graph is plotted.

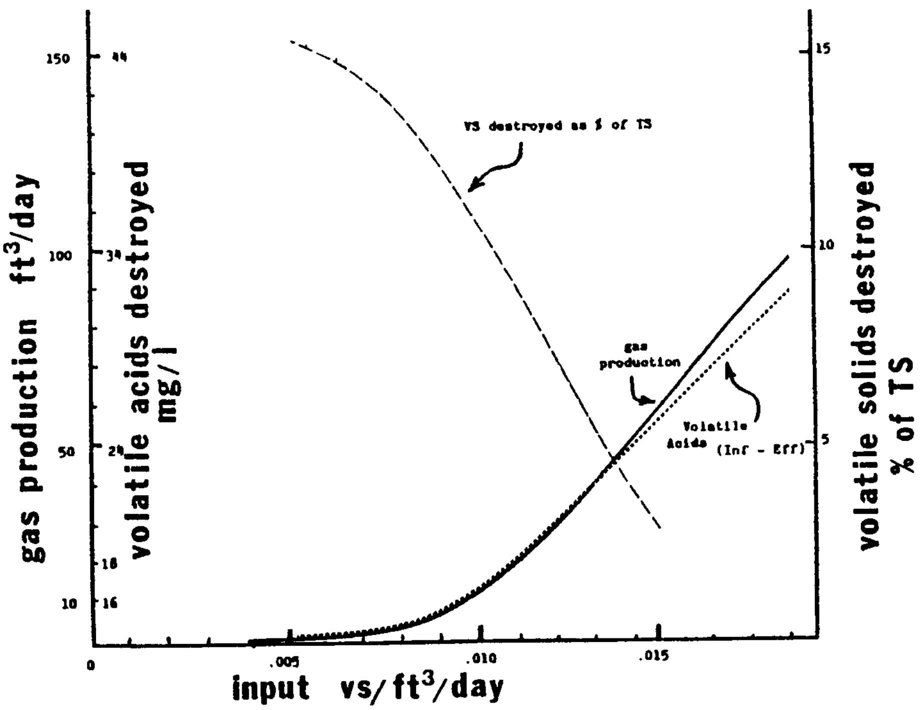


Figure 30. Loading rates and chemical operating parameters of Green Bay system.

It is apparent from the graph that as loading rates were increased the volatile acid content increased but so did the destruction of volatile acids. As gas production and loading rates increase, so does the destruction of volatile solids and volatile acids. The rate limiting loading rate, however, was not determined. No data, is, as yet, available on long term operation of a digester running on high load rates to ascertain the long term effect on microbial populations and acidity inside the tank.

Experience with swine wastes by others (33,34,35) and our experience with turkey, indicates that fermenters can operate at high pH or under other conditions considered undesirable provided that the feed rate and materials are kept within reasonable ranges on a daily basis. This experience is contrary to recommendations and observations for sewage digesters. However, municipal and industrial systems suffer the disadvantage of uneven loading rates coupled with variable feed composition and lower solids composition. With low solids concentration, slight changes in composition are liable to show up more quickly.

With farm systems there is a possibility of drugs or other farm chemicals entering the fermenter and upsetting the biochemical system. Cornell has observed this with certain barn sprays. However, the systems observed in this study have not reacted to normal farm practices. There were no attempts to poison the systems during this study with common drugs or other materials; therefore, no limits of tolerance have been discovered which could be used as cautionary guidelines.

Of particular concern in digesters is the possibility of scum build-up which can lead to crusting and a halt in gas production. This has not been a problem with any of the systems which we have observed. One untested possibility is that the insulation floats on the Ludington system keep the light materials, which form scum mats, submerged in the liquor. Thus, the light materials do not dry out and form a solid layer. Some credence to this theory is the fact that in high solids digesters the materials are prevented from separation and thus scum build-up. Another factor could be the short retention time. This tends to wash partially digested materials out before build-up. A third contributing factor could be that these systems are under loaded. The dynamics of scum prevention are not well defined; pragmatic operational parameters seem to be the best guide at present.

MUNICIPAL SOLID WASTE/MANURE MIXTURES

These above factors become more important in light of the results of a laboratory study which was conducted with a municipal solid waste: manure mixture (2:1). The feasibility of using manures mixed with municipal solid waste (MSW) appears to be attractive for small and large scale systems. As mentioned earlier, small scale systems can be marginal economically. The addition of the organic fraction of MSW to a fermenter can effectively increase the size of the system to where it could be profitable for the farmer. The effluent could still be used for fertilizer or other ends.

Appendix A points out the details of the laboratory studies on mixed manure and MSW. These systems were operated in the same fashion that a large system would be. Sufficient numbers of identical systems were operated to obtain statistical significance. The results indicate that the mix of 2:1, MSW:Manure gives the same gas production as all manure over the time frame under which the experiments were conducted. It remains to be seen what different ratios will produce.

With MSW, one reintroduces the materials handling problem and the possibility of introducing toxic materials. MSW also includes plastics which can float to the surface and create scumming problems. Toward the end of the experiment, gas production began to pick up. Time did not permit continuance to verify the increased production but the question is raised as to whether the population of microbial species was adapting to the new mixture. Other investigators have indicated a difference in gas production from the same waste source depending on the seed materials used in starting the fermentation. One farmer in Missouri, in cooperation with the University there, is running a fermenter totally on hay. There is an attempt there to seek natural microbial populations which enhance digestion of the organic matter. Thus, this area needs to be explored more fully to ascertain whether there are selective strains of microbial species which favor certain substrates. This might eventually lead to the development of selected species for different substrate materials.

The transition to MSW/manure mixed feedstocks was not tried on the full scale systems due to lack of time. The Rice Lake operation did shift from turkey to diary wastes by the gradual addition of dairy wastes. However, no data was available on the shift from turkey to dairy because the system was down for piping and engineering modifications. Turkey manure remained in the digester at operational temperatures for two weeks before switchover occured, thus, digestion may have been completed. Also, rice hulls remaining from the turkey wastes caused severe plugging problems and necessitated a partial pump out of the digester.

EFFLUENT CHARACTERISTICS

Effluent from the fermenter has a variety of uses: fertilizer, animal refeed, algal growth and several other options. The use of the effluent for algal growth has been studied by Golueke and others (37, 38, 60) and is currently under investigation by Biogas of Colorado (27). Because of temperature needs and large areas for solar absorption, this option is not feasible for the Northern region of the United States where this study took place. Thus, the two most feasible uses for digester effluent are fertilizer and animal feedstuffs.

Use as fertilizer requires careful protection of the effluent to prevent nitrogen loss. Spot samples from Green Bay, and studies by Moore at the University of Minnesota (36) indicate rapid loss of this nitrogen via volatilization from the effluent. This implies that a covered lagoon is a cost-effective method to store the effluent and that knifing the material into the ground is most efficient in preserving the fertilizer value.

The possibility of developing an aquaculture system with digester effluent was considered and would have been carried out on the horse farm had operation been maintained by the owner-operators. Negotiations with a commercial fish farmer were underway when the system went down. The practice of growing fish in sewage has been carried out for municipal wastes in countries outside the United States and has been experimentally investigated in the United States. Fish can grow in deeper ponds which allows for their use with fermenter systems in colder climates.

Refeed

Using the fermenter effluent for animal refeed is a real possibility and is under investigation in a number of places. USDA at Clay Center, Nebraska (26) has a digester system designed by Hamilton Standard to check the feasibility of using fermented effluent as a cattle feed. Biogas of Colorado (27) has feeding trials using both fermented manures and algae grown on effluent (the climate in the "Four Corners" area is suitable for this alternative).

Appendix B and C give the details of the preliminary "refeed" analysis carried out under this contract. The first concern was the recoverability of the material in a form suited for feedstocks.

A major problem in refeed is that digested effluent is dilute and should probably be dewatered. This study looked specifically at the feasibility of economically dewatering the effluent to obtain a feedable cake. Chemical flocculents were rejected because of costs and the problems of obtaining FDA or local food code approvals. Obtaining all necessary approval seemed to involve a prohibatively long and costly procedure.

Centrifugation was rejected for small operations (the focus of this study) because of high capital cost and maintenance problems. Hamilton Standard has tested this process and it is under current investigation with USDA and DOE funding (26, 16). The preliminary analysis indicate that the procedures need more research.

Filtering via a filter press was also rejected because of high capital costs. This left the option of a variety of low intermediate cost screens and filters. It is possible to obtain a reasonable filter cake, but a large fraction of very small matter is passed through the filters. It is these particles which consist of high protein matter locked in cell walls.

Our studies indicate that there are no cost effective, FDA approved precipitating materials for use with small scale farm systems. The only viable alternative for reasonable, large scale capture is a centrifuge. This conclusion was also reached by Biogas of Colorado and Hamilton Standard. Capital and maintenance costs make these units cost prohibative for small scale operations, though a lower feasibility limit was not ascertained.

Dewatering may be eliminated by utilizing high solids systems or mixing the effluent in with haylage or other roughage and then feeding or ensiling it for further fermentation. In arid regions or areas of high insolation, solar stills with water recapture is the most appropriate method. For the region under study, aquaculture seems to be the method of choice. For small operations the effluent can be fed directly to other animals, such as swine, through the drinking water, as is done with undigested manures (41, 42). For refeed to the same animals, there is a need for a moisture absorbing nutrient supplement, due to the quality of the effluent. Addition of such a supplement will create volumes too great for total refeed to the same animals, thus, not all the effluent will be used for refeed.

Another question with regards to refeed is open. That is the nutritative value of the effluent. Three factors have to be taken into consideration, the digestibility, palatibility and long term cumulative effects on the animals and those who might consume the animal or their products such as milk and eggs. The first two could be linked even if one does not anthropomorphize. The digestibility of the effluent as opposed to the raw undigestible manures also needs consideration in any economic evaluation.

At the present time, two extensive feeding trials are being carried out. Biogas of Colorado is testing mesophilically digested effluent along with algae grown on the waste water from the filtering process (27) The USDA is testing the effluent from thermophillic systems. Research under this contract was only preliminary because this was not a major emphasis of the study. Results show that there appears to be a quantifiable increase in the organic nitrogen portion of the effluent over that of the unfermented manures. Biochemical breakdown of this material, simulating the ingestion by a ruminant indicates that this material may be in a form somewhat less available than that of the original manures. The use of this material by other animals, however, is a genuine possibility. The results are only indicators of possible differences and no firm conclusions can yet be drawn.

All indicators in this study point to the use of less capital and labor intensive systems for processing the effluent. Thus, for small scale systems it seems that the best alternative for uses of the effluent are as fertilizer or as feedstocks for aquaculture and/or algal culture. The algae would be used either as feedstock for animals or returned to the fermenter for enhanced gas production.

GAS PRODUCTION

Both the quantity and quality of the gas produced is a function of the digester operational parameters, but until special strains of microbial populations are developed or innovative operational techniques are found, the methane/carbon dioxide ratio will remain about 60 percent/40 percent.

There is some indication in the literature (43) that hydrogen is a rate limiting factor. The direct addition of hydrogen to enhance the gas production might be considered questionable unless a quantity of methane were produced which exceeded in energy value that of the hydrogen which was used. Less directly hydrogen could be made available by cultivation of hydrogen-producing algal microbial species. These organisms would also add cell mass for refeed to the fermenter or animals.

A preliminary study (Appendix D) was instituted to see whether such species could be readily cultivated from existing algal species. Algal growth on the effluent for use as either animal feed or biomass for the fermenter was initially rejected for this part of the country because of the large acreage and shallow ponding required. This would have required too much heat energy to maintain in the winter months.

The possibility of finding specific algae which could produce hydrogen during biomass growth could possibly have made this work worthwhile. The hydrogen is combined with carbon dioxide by microbial action to form methane in the fermenter. This and the additional biomass could possibly enhance gas production from digesters significantly. Results from this work, which are preliminary, seem to bear out the experiences of Golueke and others (38, 39, and 60); the control of algal populations is difficult under all but ideal conditions because of the inabliity to isolate pure strains and maintain them. Additionally, the quantity of hydrogen produced per unit of biomass or unit area is small.

But, the production of hydrogen from biological species has been under investigation by a number of researchers (48) who are looking at modifying existing species or finding different systems which can be induced to provide high yields of hydrogen. Krampitz at Case-Western is currently trying to create mutant species which can effectively produce hydrogen, (44) and Mitusi, in Florida, is looking at tropical species which may be adaptable to the United States for a variety of purposes. (45, 46, 47) In this spirit, it may be possible to enhance the fermentation via some form of pretreatment of the manures or other residues, such as plant biomass or MSW, to enhance both solids digestion and/or gas production. The Environmental Protection Agency and other groups have been sponsoring research on cellulosic degredation via acid, basic and enzymatic hydrolysis. The Forest Products Laboratory (USDA), Madison, Wisconsin,has been looking at various wood rot fungi with the same interest (destruction and/or preservation of cellulosic materials). (67, 68) Mitusi seems to be the only researcher taking a systematic look at potential tropical species adaptable to the United States for energy production via biological processes. (47)

The problem of gas quality and quantity is not severe if the biogas is to be combusted directly and economics and efficiency are not a significant consideration. Under most operations these constraints are severe. Thus, to optimize the system it becomes necessary to decrease the carbon dioxide, eliminate it entirely, spearate it for another use or transform it into a useful product. As pointed out previously, it will not be economically feasible in the foreseeable future to significantly decrease the production or separate the CO_2 for small systems. The possiblity of transformation in an economical fashion is real and the technology is adaptable from industrial knowledge; some which is readily available and some which is yet propriatary.

This is standard industrial practice for the production of either methanal or ammonia. Both of these are readily used on a farm and could be an alternative use of the gas. The question of technology and economics of scale are currently being investigated. This is an area for future research.

TABLE 10. INFLUENT ANALYSIS ON REPRESENTATIVE SAMPLES*

Parameter	Unit	Rice Lake[1]	UWGB[2]	Ludington[3]	Brockman[4]
% M of Total Sample	% by weight	97.09	94.69	95.03	95.28
% TS of Total Sample		2.91	5.31	4.97	4.72
% VS of TS		69.52	83.27	81.49	89.59
% FS of TS		30.48	16.73	18.51	10.41
% VS of Total Sample		2.02	4.42	4.04	4.23
% FS of Total Sample		.89	.89	.93	.49
Total Alkalinity	mg/l	6360	5750	2940	1890
Volatile Acids	mg/l	2330	3880	4340	1690
pH: Non-Filtered	--	7.7	7.0	5.5	6.6
pH: Filtered	--	7.7	7.0	5.7	6.7
Total Kjeldahl Nitrogen	mg/l	2260	1780	1830	670
Ammonia Nitrogen	mg/l	1317	428	457	130
Organic Nitrogen	mg/l	943	1352	1373	540
Chemical Oxygen Demand	mg/l	46,000	84,600	67,000	28,000

M = Moisture
TS = Total Solids
VS = Volatile Solids
FS = Fixed Solids
mg/l = Milligram/liter
(16,000 mg/l = 1 lb./ft^3)

1) Sample was diluted, aged TURKEY manure
2) Sample was diluted DAIRY manure.
3) Sample was diluted CATTLE manure.
4) Sample was diluted HORSE manure.

* All of these systems were run as underloaded digesters because of the materials handling problems associated with high load rates.

SECTION 7

ECONOMICS

The economic feasibility of anaerobic digesters is predicated on a number of significant parameters. These can be categorized into two areas of concern: Design engineering and market economics. The amount and type of waste available, type of farming operation the system is designed for, capitol cost, end use of the biogas, operating expenses, insulation of influent and fermentation tanks, engineering efficiency of the system, and the cost of fuels the biogas replaces are just some of the factors.

If the gas can be burned directly on site, the recovery period and annual returns are more favorable than if electrical conversion is necessary. Direct combustion will lower initial investment costs and decrease operating expenses. Coupling an engine generator of sufficient quality to provide several years of reliable service can increase investment costs as much as 32 percent and annual operating costs up to 39 percent. Conversion efficiency of biogas to electricity by a gas engine is quite poor (10-15 percent for standard manufactured sets and up to 25 percent for mixed fuel-diesal/biogas units), leading to low annual returns and a great deal of waste heat. Careful siting of the engine generator would enhance the economics by using the waste heat from the engine to heat outbuildings or, perhaps, a greenhouse. The use of integrated systems with electrical generation similar to the district heating concept, is an avenue that must be explored further. This investigation indicates that the economics of producing electricity from biogas on a small scale is unfavorable unless the waste heat is recovered.

The upper midwest, particularly Wisconsin and Minnesota, contain a significant number of small dairy farms. Many of these operations are economically marginal. As energy costs continue to rise and pollution regulations become increasingly strict, a large percentage of these operations may be forced out of business. It is for that reason that anaerobic digesters are being evaluated for use on small dairy farms.

The Rice Lake digester is located on a dairy farm in Northwest Wisconsin. The system was considered a prototype to determine the feasibility for application on the many farms of this size in the region. The existing Rice Lake digester is sized for 125 milking head, but the farm operated closer to the 100 cow level. This has been the lower limit to which the economics of dairy farm digester design have been field tested. Cornell has done theoretical studies showing that, in some cases, dairy farms with as few as 75 head can show anaerobic digestion to be an economical investment. (1) They are just now beginning operation of a 65 cow digester.

While dairy farm operations are basically similar, variance in acreage, age of equipment, and current management practices does not allow for a simple economic analysis which can be immediately transferred from one operation to the next, much less to other types of farms such as swine and poultry. The issue is further complicated by potential uses of the biogas coupled with uncertainty in energy prices.

An economic analysis was performed on a design similar to the existing Rice Lake digester. To show returns based on energy production alone, the digester was assumed to be an additional investment to the best possible manure handling system in terms of nutrient conservation, the covered anaerobic lagoon. Costs of the covered lagoon are found in Table 11. The costs of the digester are based on installed system components found in Table 12. To determine the relative significance of design parameters, the Rice Lake system was used as a baseline operation. Specific parameters were then altered to show the impact on economic feasibility. Engineering improvements that were considered to enhance the feasibility include:

1) Increasing generation efficiency of the engine generator to 25 percent.
2) Insulate the influent tank and fermentation tank.
3) Utilize waste heat from the engine to heat outbuildings.
4) Combust the biogas directly on site.

TABLE 11. BASELINE COSTS FOR A COVERED ANAEROBIC LAGOON

100 Cow Dairy

Barn Scraper, Earthen Manure Storage Pit	$ 2,000
Lagoon	2,000
Lagoon liner & cover	5,000
Pumps (2)	7,000
Piping	500
Large tank manure spreader	7,000
TOTAL	$23,000

TABLE 12. COMPONENTS AND INSTALLED COSTS OF EXISTING RICE LAKE DIGESTER

Tank	$ 6,250
Pumps	1,500
Controls	1,500
Hydraulics	2,500
Piping	1,000
Building	3,600
Engine-Generator	12,000
High Pressure Storage	2,000
Electrical Tie-In	1,500
Well	600
Miscellaneous (15%)	3,250
Engineering (15%)	5,350
Total	$41,050

By calculating the present cost per kilowatt of digester produced electricity and plotting these costs against the present cost and rate of fuel price increases, the feasibility of anaerobic digesters can be determined. In most cases, the return on fuel savings would not begin until the investment costs are paid off, the system fully depreciated, and operating expenses are the only annual costs involved in the cash flow. Therefore, the shortest possible loan and depreciation periods will prove to be the most economical.

For comparative purposes the annual costs and returns from the Rice Lake digester are shown in Tables 13 and 14.

A heat value of 580 Btu per cubic foot of biogas was assumed. If 85 percent of the manure produced is fed to the digester, approximately 720 x 10^6 of biogas will be produced annually. Conversion efficiency of the gas to electricity is low, 10 to 14 percent. Ecotope Group of Seattle has a similar engine generator operating off biogas. Their average conversion efficiency has been 11 percent. (19) Converting the gas produced by the Rice Lake system to electricity, at 11 percent will yield 23,200 kilowatts per year, or 22 percent of the operating capacity of the Rice Lake generator and approximately 25 percent of the total electrical consumption on the farm.

An optimistic analysis was carried out by assuming that 100 percent of the electricity and biogas produced would be consumed in useful work. The graphs, then, show costs of the "best case" dairy farm system should the engineering and marketing problems be worked out. In reality, a large portion of the electricity generated goes unused, as witnessed by the farm load profile shown in Figure E1 (Appendix). Between the hours of 10 p.m. and 5:30 a.m., there is virtually no electrical load, yet the generator is

TABLE 13. ANNUAL COSTS OF RICE LAKE DIGESTER

		5 yr. loan	10 yr. loan	20 yr. loan
Capital[a]		$41,050.00	$41,050.00	41,050.00
Annual Capital Costs[b]		10,691.00	6,538.00	4,658.00
Annual Operating Costs[c]		2,869.00	2,869.00	2,869.00
Equipment maintenance[d] and repair	$ 1,174			
Labor[e]	624			
Taxes & Insurance[f]	1,071			
Total Annual Cost		13,560.00	9,407.00	7,527.00
Total Annual Costs Averaged over 20 years		5,801.00	6,397.00	7,786.00
Annual Cost Per Cow normalized over 20 yr. life		58.01	63.97	77.86

[a]Actual installed cost of the equipment, site preparation, and building; cost of land excluded.

[b]Annual capital costs are based on a yearly amortization rate of 9.5% for 5, 10, and 20 year periods. All capital is borrowed.

[c]Annual operating costs are assumed constant for the first 10 years, after which they rise at the rate of 3% per year.

[d]Equipment maintenance and repairs includes the cost of maintaining the engine/generator system, which comes to $200 per year in parts and labor, based on maintenance procedures recommended by Waukesha. Also included is the cost of an engine overhaul every 6 years at $2500. Maintenance and repair of other system components was taken at 2% of the remaining $23,700 equipment costs.

[e]Labor. The present owner of the digester puts in approximately 20 hours per week operating and maintaining the system. If the system is working as designed the number of hours labor per week should be 10 or less. Four hours per week at $3 per hour was used to obtain the labor cost figure.

[f]Taxes and insurance were estimated at 3% of the original equipment value of $35,700.

operating 24 hours a day. Load leveling would enhance the economics of site generated electricity. Figure 31 shows the cost per kilowatt hour of digester produced electricity from the Rice Lake digester versus electricity purchased from the utility company for a range of current prices.

Because the farm is a business, tax deductions can be taken for interest paid and depreciation of equipment. Costs per generated kilowatt include tax deductions from interest and straight line depreciation for the 30 percent taxable income bracket. Annual operating costs for the first 10 years are assumed constant, after which they rise at a rate of 3 percent per year.

At this present value of \$.027/kwh to large northwest Wisconsin electrical users such as the Rice Lake farm, (49) the returns from the electricity generated will be \$626 the first year. Over a 20 year period, with electricity prices rising @11 percent per year, the returns would total \$40,191. Table 15 shows the 20 year lifetime costs and returns for the different loan and write off periods. The cost per kilowatt hour, normalized over the 20 year period, is compared to the same costs of electricity if purchased from the utility company.

TABLE 14. ANNUAL BIOGAS PRODUCTION, RICE LAKE*

	LBS. x 10^6	KG x 10^6
Manure	3.10	1.41
Total Solids	.39	.18
Volatile Solids	.32	.14
Biogas Production		
100% capacity	1.46 cf	.041 m^3
85% capacity	1.09 cf	.031 m^3
Btu content of gas produced 719.2 x 10^6 @ 85% capacity		

*Based on 100 animal units, avg. live weight 100 pounds. (1)
85 lbs. of manure/cow/day
10.6 lbs. total solids/cow (TS)
8.7 lbs. volatile solids (VS_A)
4.56 cf biogas/lb. of VS_A
580 Btu/cf of biogas

TABLE 15. COST/KWH OF RICE LAKE DIGESTER NORMALIZED OVER 20 YEAR LIFE

Loan & Write off period	Cost over 20 years	20 year returns	Average 20 year cost/kwh*
5	$116,020	$40,191	.219
10	127,940	40,191	.230
20	155,720	40,191	.275
(no digester, electricity purchased @ .027)	(40,191)	-----	(.087)
(@ .05)	(74,475)	-----	(.160)

*Deductions accounted for.

From these figures and from the graph, it is apparent that biogas conversion to electricity as currently designed on the Rice Lake farm, will not become economical for another nine to 17 years, depending on the current cost of electricity and on the period chosen for write off. In all cases, the sooner the system is paid for, the sooner the returns will begin. Should engineering design be optimized, the economics will be affected as indicated in the following analysis.

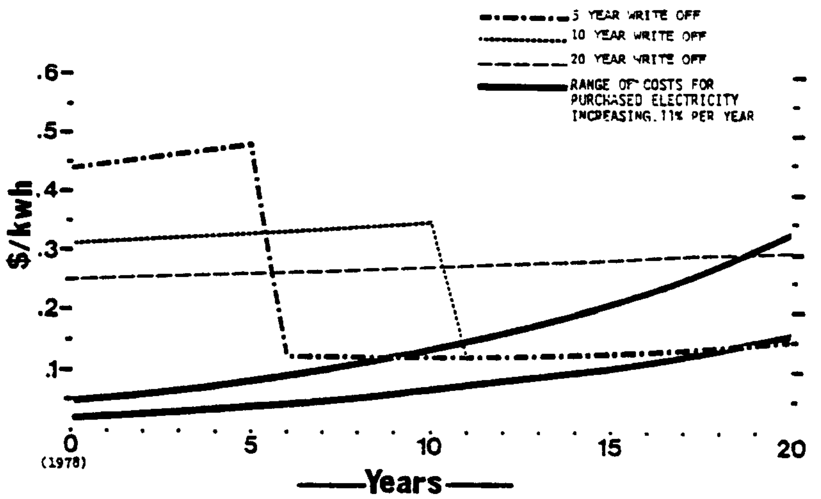


Figure 31. Cost of electricity from $40,000 digester vs. cost of electricity from utility company.

Using Excess Heat to Heat Outbuildings

The amount of excess heat available from the engine cooling system is significant. When operating at part load (50 percent) the heat output from the cooling jacket is 69,000 Btu/hour. (50) The fermentation tank requires 23 percent of 50,700 Btu/hour, or $5.32 of propane, equivalent ($4.48 of fuel oil) heat per day is being vented to the outside air. If this could be captured for use in outbuildings, the impact on economic recovery would be noticable. Assuming 60 percent recovery of this waste heat for 200 days of heating, the annual savings, based on equivalent propane usage, would be $638 per year, and $538 of fuel oil savings. This is virtually equivalent to the first year of electrical savings, cutting the recovery period in half. Cost of heat recovery equipment was assumed to be $5,000 or $800 annually. If the heat is coupled with a productive unit, such as a greenhouse, the returns, in the form of increased farm productivity, would be even more significant.

Increased Generation Efficiency

Optimization of the system would include, not only heat recovery, but increased generation efficiency as well. An engine generator that is 25 percent efficient would be capable of producing 52,725 kwh/year, or two and one quarter times the amount generated at current Rice Lake efficiency of 11 percent. This could be accomplished, theoretically, by using a diesel engine run on a 90:10 mixture of biogas and diesel. (51) Initial capital costs for a diesel run generator would be approximately 25 percent above the costs of a gas engine generator. The system investment would be increased $3,000, while the operating costs would increase $376 annually, due to cost of the diesel fuel required. (Table E3) Returns, on electricity alone, would be $1,425 the first year. When coupled with heat recovery, returns total $2,063. Figure 32 shows the cost per kilowatt of diesel-biogas generated electricity and heat recovery over the 20-year life versus costs of electricity purchased from the utility company. It becomes apparent that paybacks could begin as early as six years with 25 percent generation efficiency and a five year write-off period. Table 16 shows the 20-year costs and returns for different write-off periods.

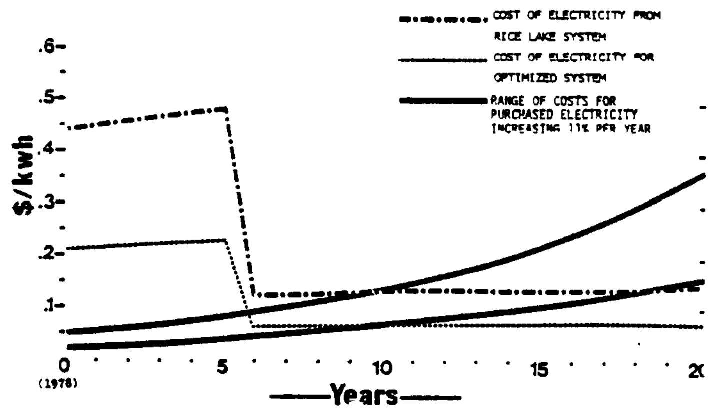


Figure 32. Range of costs for electricity from digester systems (100 cow dairy.

TABLE 16. COST/KWH OF OPTIMIZED DIGESTER ELECTRICAL SYSTEM

Loan Period	20 Year Costs	20 Year Returns	Average cost/kwh* for 20 yr. Period	Cost/kwh with 80% use factor
5	$134,637	$110,041	.077	.096
10	148,927	110,041	.081	.102
20	183,487	110,041	.098	.123
Equivalent Electricity				
@ .027	110,041	-------	.072	.072
@ .05	170,542	-------	.112	.112

*Deductions accounted for

These figures show that for small scale dairy farms with electrical operation, the economics of anaerobic digesters are marginal. Careful optimization for use of waste heat, maximum generation efficiency, and use of electricity, is required to achieve reasonable savings over a 20 year period. If optimized, and electricity costs are above $.037/kw, then such a system would pay for itself in a twenty year period if care can be taken to use all the electricity produced. The alternative to electrical generation is to burn biogas directly on site.

Combust Biogas Directly

Direct combustion of the biogas on site would replace the use of liquid propane or fuel oil as current fuel sources. Significant savings could be accrued if there was a use for this amount of gas. Total capital required would be much lower because the engine generator, the electrical tie-in, and engineering fees associated with the electricity would not be required. Costs range from as low as $16,000 to $25,000. The capital costs used in this analysis are shown in Table E4.

Operating costs would also be significantly lower. Twenty-two percent of the biogas produced would be requred to heat the fermentation tank. Net biogas production from a digester the size of the Rice Lake system would be 6,138 gallons of propane equivalent, or 4,493 gallons of fuel oil equivalent. At present value of $.40/gallon of propane, the first year returns would be $2,455. If fuel oil is displaced, the reutrns would total $2,067 the first year. Table 17 and Figure 33 show the costs and returns of direct biogas combustion on site averaged over a 20-year life compared with equivalent usage of propane or fuel oil.

With direct combustion , the system would pay for itself in less than 20 years. The ability of the farm to utilize all of the gas produced will determine whether this analysis holds true. Also, the initial cost of converting the farm operation to use biogas must be explored for those operations having high electrical and low fuel usage.

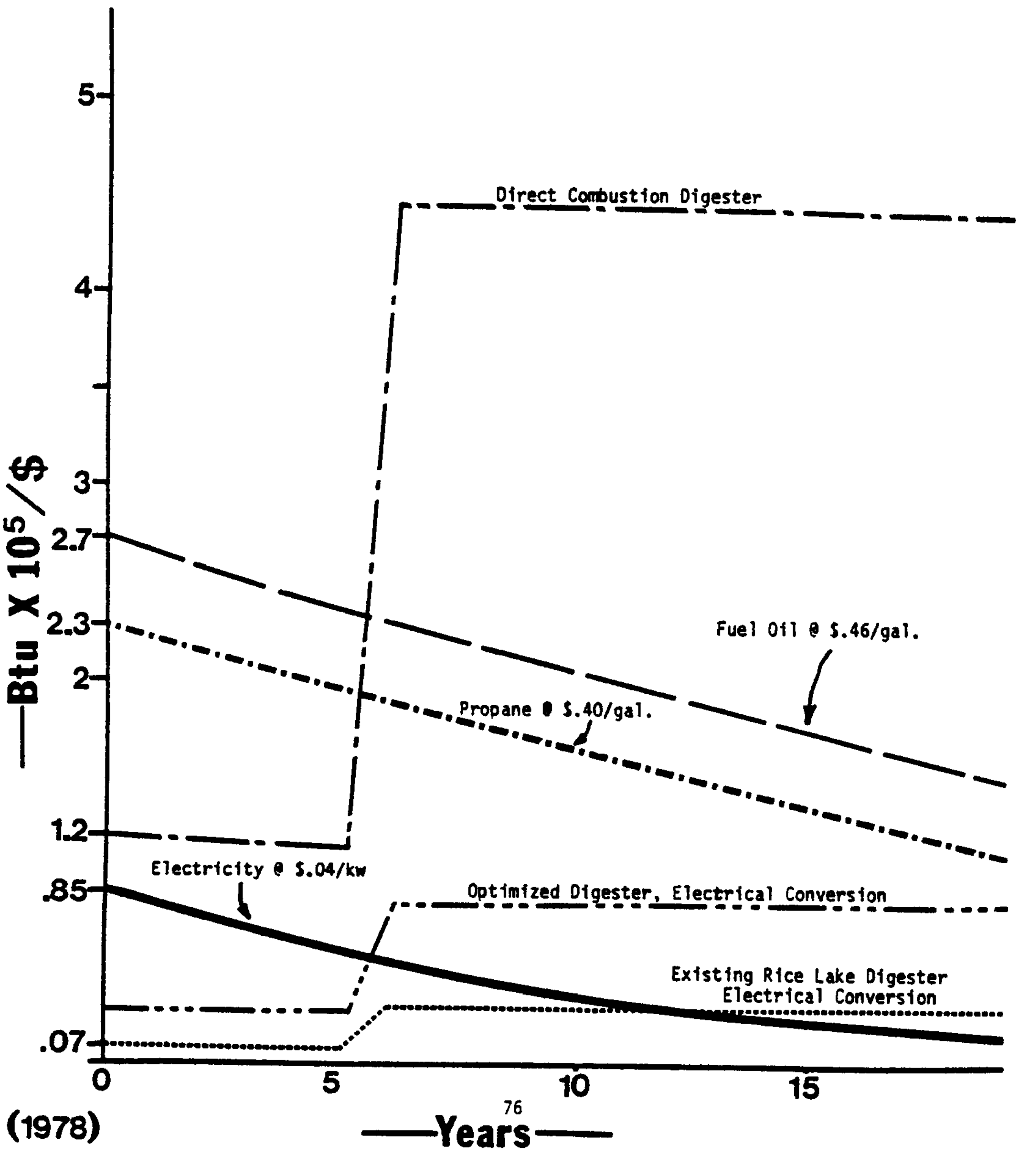


Figure 33. Btu/$ of different energy and digester types.

The amount of energy required to heat the influent to fermentation tank temperature of 95 degrees is significant. This is compounded during cold winter months if the influent tank is exposed to air or ground ambient temperatures. There have been times during the past two winters when the Rice Lake influent tank actually froze. If the influent can be kept at 55 degrees during the winter months, versus 35° F, a savings of 170,000 Btu, or $.74 worth of propane equivalent can be saved per day. This would amount to approximately $89 per year in energy savings, which would be accrued in increased biogas available for on-farm use. Close to seven percent of the average daily biogas production could be saved by insulating the influent tank. This added investment would pay for itself in less than two years.

TABLE 17. COSTS AND RETURNS OF DIRECT BIOGAS COMBUSTION ON SITE

Loan Period	20 Year Costs	20 Year Propane	Returns Fuel Oil	20 Year Average Cost/Gallon Fuel Oil	20 Year Average* Cost Gallon Propane
5	$51,591	73,105	64,013	.502	.368
10	56,931	73,105	64,013	.529	.387
20	69,371	73,105	64,013	.630	.461
No Digester	-----	-----	-----	.712	.595

*Deductions Accounted For.

CONCLUSIONS

Two factors should be noted. This analysis is predicated upon a small number of animals. Increases in systems size rapidly change this economics. Next, the economics are on energy alone since no proven credits can be taken for animal refeed or fertilizer over that of undigested animal wastes. Certain externalities, such as odor control, or those which require a farmer to install pollution abatement practices would nullify the economic analysis. Future research in this area, and extenuating circumstances, change the economics radically.

1) Direct combustion of biogas on the farm offers significant savings and shorter payback periods over power production via an engine generator system.

TABLE 18. COMPARISON OF DIGESTER SYSTEMS

System	*Cost Over 20 years	**20 year Returns	***Return on Investment
Current Rice Lake System	$116,020	$ 59,580	-6.9$
Optimized Rice Lake System with diesel generator and heat recovery	134,637	174,139	4.0%
Direct Combustion of Biogas on site:			
(replacing propane	51,568	72,759	5.8%
(replacing fuel oil)	51,568	61,545	2.7%

*Using 5 year payment plan and 5 year write-off.
**Based on electricity @.04/kwh, increasing 11%/year; Propane @.40/gallon, increasing 4%/year; fuel oil @.46/gallon, increasing 4%/year.
***ROI = (20 year value of energy produced - 20 year cost of producing it) / 20

2) The cost of producing electricity is high and conversion efficiencies low for the existing engine generators. More efficient engines must be used to improve economic recovery or alternatives such as load following fuel cells need to be explored.

3) With electrical conversion careful siting of the digester and power plant will allow waste heat recovery. Energy and actual dollar savings could virtually double if the heat is recovered.

4) A diesel powered, duel fuel)oil and biogas mix) generator is twice as efficient as present gas engines. This option, coupled with waste recovery from the colling system, appears to be the most economical form of converting biogas to electricity using current commercially available systems.

5) It is essential that the fermentation and influent tanks be insulated in colder climates. Insulation of both tanks is low cost investment which can increase net biogas production up to 20 percent.

6) The sooner the digester can be paid for, the more economical it becomes.

Economic models have a certain inflexibility which tends to lock us into a narrow vision of lifestyles and development patterns. The development patterns of farm energy use have dictated increasing electrical demand. For this reason, most digesters being installed today are converting biogas to electricity. The economics show that direct combustion, or careful planning to recover waste heat and optimize conversion efficiencies have the most promise for small farm use. The implications of this model can be several depending on how it is viewed:

a) Digesters for small farm use may never be adopted on a widescale because they are not economical.

b) Small to medium sized digesters will not solve energy use problems by themselves. They must be effectively integrated into the total farm operation through energy conservation, load leveling, and matching low quality thermal loads for direct combustion and high quality machinery loads for electrical use.

c) Diversification of small farm operations through refeed of animal wastes, coupling a greenhouse with the digester to utilize the waste heat and create year round farming opportunities, and posible aqua-culture or algalculture on the effluent will be necessary to accomodate and enhance both digester feasibility and total farm stability.

d) The anaerobic digester can become central to a farm integrated utility system providing both power and heat to farming operations and also opening new avenues for farm production.

SECTION 8

OTHER CONSIDERATIONS

QUANTITY OF WASTE

The amount of organic material available for anaerobic digestion will have a significant impact on total biogas production and, hence, on the economics of the system. Cost/benefit ratios of digesters as energy producing systems have been shown, in 1975 dollars, to break even at around 250 animal units. (20, 57) More recent studies (30) show that below 400 animal units the system economics deteriorate rapidly. One company, Hamilton Standard, has set 8,000 head as the minimum size feedlot for which anaerobic digestion is economically feasible. (52)

While increasing biogas production is largely a function of input material, a higher percentage of solids and increased retention times could also enhance the amount of biogas produced per pound of manure added. By increasing loading rates, Hamilton Standard is targetting system feasibility at one to two thousand head. (52) The thermophilic digester temperatures examined by Hamilton Standard could play an important role in determining the necessity of large scale systems for economic feasibility.

The addition of other organic material, such as crop residues or municipal solid waste (MSW), would increase the quantity of biogas produced. Laboratory experiments during the course of this study showed that the addition of MSW to dairy manure would increase biogas production, based on the amount of digestible material, but would not increase the gas production per pound of volatile solids added (VSA). For manures with higher nitrogen contents, the gas production per VSA may be greater due to the better carbon to nitrogen ratios. Further research must be accomplished in this area, but it appears that the combination of MSW with animal manures could make small systems economical if circumstances were right.

While MSW is a resource found in rather large quantities, the costs of obtaining it may be prohibitive for small farms. These are costs associated with separation, classification, hammer milling, and transportation of the material. Currently MSW in rural areas is landfilled, and it is not available in a form suited for use in farm anaerobic digesters. If MSW processing facilities develop in these rural areas, its use for farm scale digesters must compete with the other uses of it as an alternative fuel. For this reason, an economic analysis was not performed on the use of MSW in conjunction with animal wastes for 100 cow dairies. While the use of MSW to enhance biogas production from farm animal wastes appears reasonable, the feasibility seems limited to large scale operations in conjunction with solid waste processing facilities, or, to those farms located in close proximity to such a facility.

TAX INCENTIVES

Incentives provided by governments in the form of tax credits or cost sharing could give anaerobic digesters the necessary economic boost needed to make the system competitive. Tax credits for solar energy conversion devices, synthetic natural gas producing equipment, or water pollution control equipment would qualify anaerobic digesters, providing the system was defined as such.

Present income tax laws would exclude farm scale digesters from pollution control deductions because 1) digesters are not classified as a non-point pollution control measure, and 2) most farms have too few animals to qualify as a point source feedlot operation. (53, 54)

The State of Wisconsin has proposed a bill that would give investment tax credits to purchasers of alternative energy producing devices (55), and in the 1978 National Energy Plan both the House and Senate versions contain provisions for 10 percent tax credits on synthetic gas producing equipment. The Senate version also contains provisions for bioconversion equipment.

For the systems examined in this economic analysis, a 10 percent tax credit would enhance the economics as follows: For the existing Rice Lake digester, with no optimization, a 10 percent credit would make the system competitive with electricity at $.26/kwh. For the optimized system, with 25 percent conversion and heat recovery, first year costs of the credit would make the system competitive with electricity costs at $.09/kwh. For a digester located on a farm using 100 percent of the first year gas directly, a 10 percent tax credit would make the system competitive with propane at $.45/gallon and fuel oil at $.61 gallon for the first year of operation. These figures were generated for the five year annual cost models.

A one year tax credit, however, would not have any effect on the competitiveness of the systems in the following years because of the high annual costs involved. If the credit was available for a period of three to five years, giving a total credit of 30 to 50 percent, then the systems could be considered competitive with other forms of energy.

SOCIOECONOMIC

Social or cultural acceptability is often a major factor influencing the success or failure of an innovation. Because this is so subjective and ill defined, there is an obvious temptation to favor the more rational criteria of engineering efficiency or economic viability. The feasibility for widespread adoption of anaerobic digesters, however, transcends strict economic analyses.

This becomes apparent if one examines the relationships between innovative technologies and the people to whom the innovation is addressed. Successful innovations, be they industrial or agricultural, are characterized by the development of a new technology, or new form of organization, to meet the need or demand for a new product or service. The innovation presumably corresponds to a pre-existing demand, which will allow it to diffuse throughout the economic and social system. Success is not the general rule, however, and a strategy for development of innovative technologies in energy from agriculture must account for this.

Two approaches can be seen. The first is to help increase the total number of innovations in the field, thereby increasing the liklihood that one or several will succeed. The second approach is to try and reduce the incidence of failure through systematic identification of the factors which contribute to the success of innovations. (56)

Research concerned with the adoption of agricultural innovations revealed some of the more significant factors underlying the success of innovations in the agricultural sector. (63 through 66) (Appendix F) The more significant of these, shown in Figure 34, include: (in addition to economics) The social and environmental implications of the technology, institutional factors such as the ability to insure and finance the project, assurance of systems reliability and service of the technology, and regulatory and legal decisions influencing farm practices. All of these factors are weighed against the technology in light of the significance it may have for the overall farming operation. In essence, the perceptions of the people to whom the technology is addressed and those of the innovator must be compatible.

The innovator is usually an outsider, highly educated, and familiar with what is going on in the rest of the world. In this case, the innovator is the person or company responsible for the design and construction of the anaerobic digester. If an innovation is adopted and the promoter then leaves town, it runs the risk of being neutralized or even rejected by the community. A perfect example of this is the Rice Lake digester. It was built by an outside company who made no provisions for local service people to maintain the system in good operating order. The design is a prototype and requires constant attention; time that is simply not available to most farmers. Because the system has been inoperable most of the time, it is not viewed by the local population as a successful venture.

Support of these factors affecting adoption can be found in a 1974 survey of Brown County, Wisconsin farmers concerning the attitudes of farmers toward manure handling practices (57). Over ten percent of those surveyed were actively interested in trying anaerobic digesters if they could see an operational system and could be assured there would be adequate service and trouble free operation. Interviews with farmers in Barron County, Wisconsin substantiated this. When asked to weigh barriers preventing their use of anaerobic digesters, virtually all of them gave as the most important reasons (besides initial cost too high): "I would have to know of operational systems on farms like mine", and "I would need to be assured of good reliable service." (58) Thus, a primary factor contributing to the success of

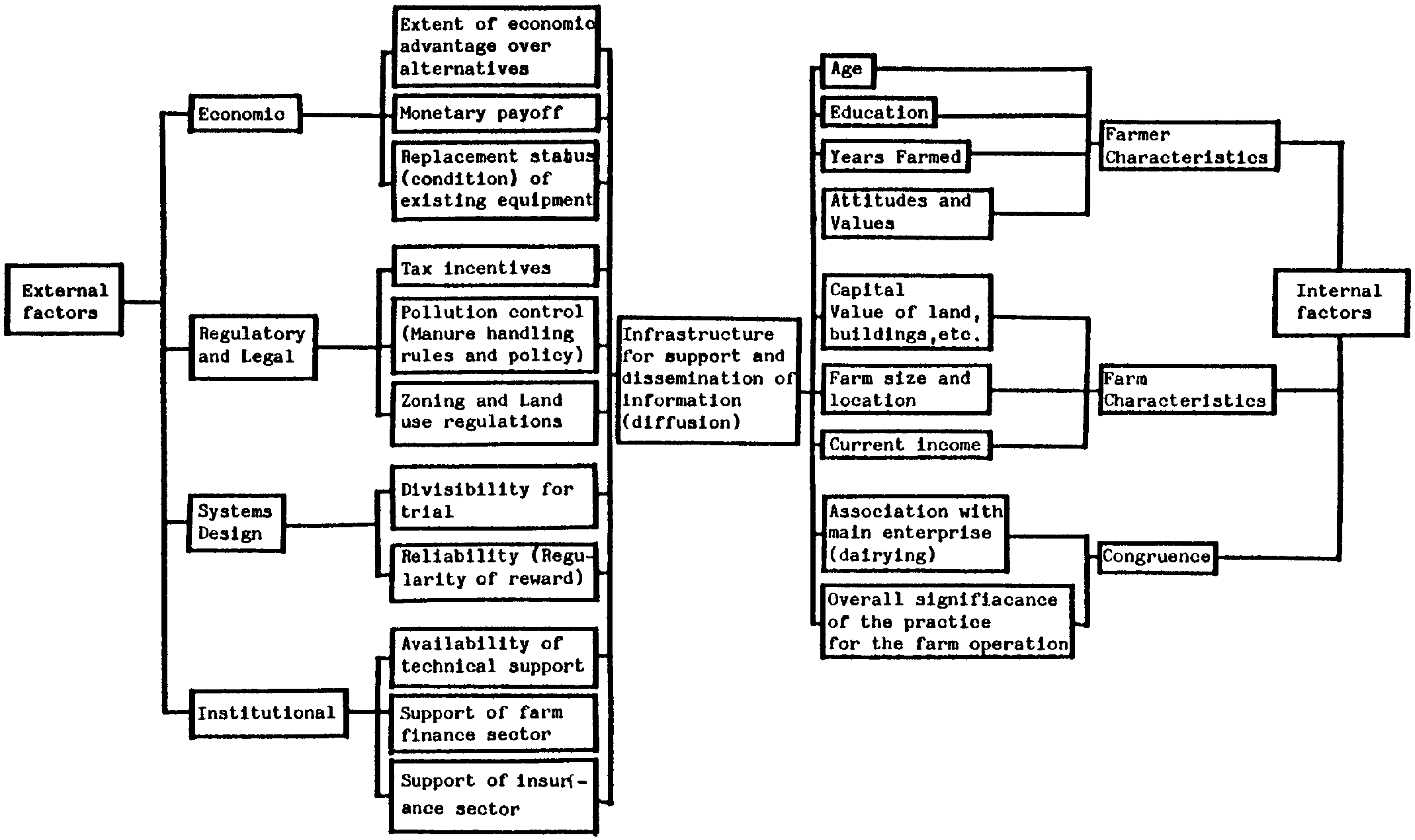


Figure 34. Significant factors underlying the adoption of agricultural innovations.

anaerobic digesters will be the availability of service for the systems.

REGULATORY AND LEGAL CONSIDERATIONS

The development of a strong service organization seems dependent on sound engineering, in materials and operational guidelines, as well as safety aspects of the system. Some day use of biogas may be commercialized in much the same manner that natural gas or LP gas is now. But until the equipment and operational practices are developed, special attention needs to be given to the development of standards, codes, and regulations concerning the safety of anaerobic digesters.

At present, there are a plethora of codes, regulations, and guidelines which have applicability to the construction of anaerobic digesters, though none are specific. The Occupational Safety and Health Administration (OSHA) has adopted the National Electric Code, which makes reference to locations in which flammable gases or vapors are present in sufficient quantities to constitute an explosion. The National Gas Code, and guidelines established by the American Society for Testing Materials are other regulations and guidelines which must be considered by designers. Most of what is found in these types of documents does not apply to biogas. Extracts from the various agency guidelines should be combined to form a standard by which farm scale digesters can be assured of providing safe, trouble free operation.

Two types of standards, or regulation seem necessary. The first would deal with construction and installation standards. This would assure the purchaser of a commercial system that the design was sound from an engineering standpoint. The second would be a licensing type of regulation which would assure that the systems are maintained and could be deactivated in a safe manner, protecting the public from a potentially hazardous situation.

INSTITUTIONAL CONSIDERATIONS

While the establishment of regulations and standards would assure the purchaser(s) he was getting quality equipment and reliable design, they would also increase the liklihood that insurance, and financing institutions would support anaerobic digesters as a viable technology.

Most insurance companies base their premiums on past experience. With new technologies, insurers do not know ahead of time what their losses and loss adjustment expenses will be. Anaerobic digesters have no history or demonstration of safety, thus insurance and products liability are difficult to obtain. The American Mutual Insurance Alliance (59) suggested that to break the initial barrier a demonstration of systems' safety to an innovative member of the insurance community would be beneficial.

One hundred years ago, boiler insurance was difficult to get. Seventy-five years ago, however, a group of engineers got totether to set up ASME standards for boilers. Now boiler insurance is not difficult to obtain.

The fact that anaerobic digesters are located in rural areas, away from population concentrations, is an advantage in case of explosion. Basically, the product must be designed, manufactured, and installed with quality control to become readily insurable. Vulnerable areas of manufacturing include: design errors, improper material selection, assembly errors, inadequate testing, improper instruction on product use, inadequate warning of latent dangers, insufficient or inadequate safety features, failure to anticipate forseeable misuse of the product, and failure to take corrective action when problems are discovered. (59) All of these could be accounted for with proper standards for design and construction of anaerobic digesters.

Because anaerobic digestion is a relatively unproven technology, lending institutions are also leary of supporting such a project. Discussions with lenders revealed that long term money will be easier to obtain until the system proves itself economically. As indicated by the economic analysis in this report, long term money can put a severe dent in the recovery of capital system invested in digesters. While initial cost is not a significant factor, the system is viewed in terms of payback on the digester and savings of time. An innovation that will save time will allow the farmer to become a better manager of his farm operation.

Considerations which the lending institutions examine before committing money for innovative projects fall under "farm and farmer characteristics" of Figure 34. These include:

1) Will the digester make or save money?
2) Can the farmer afford the luxury of gambling on a somewhat unproven technology? (In other words, what is the net worth and capital income of the man?)
3) What is the experience and ability of the man who will become the one to make the system work?
4) Is the innovation congruent with the existing operation, and will it improve the efficiency of the farm operation?
5) What is the salvage value in case of failure?

ENVIRONMENTAL

In attempts to show positive economics for small scale anaerobic systems, other benefits have been factored in with economic values. These include enhanced fertilizer value of the effluent, increased value of the effluent as animal feed, and the use of these systems to control water and air (odor) pollution. Our studies have not shown the fertilizer and refeed values of the effluent to be enhanced by anaerobic digestion. Thus, the control of water and odor pollution must be evaluated.

Odor Control

One argument for anaerobic digestion is that the process stabilizes wastes and reduces odor. This practice has been particularly encouraged in rural residential areas where odor is of concern. Presently, manure holding ponds which go under the name of anaerobic lagoons, have such high BOD loadings that anaerobic stabilization does not occur. When the systems are agitated for removal of the materials odor becomes a nuisance.

If a completely covered anaerobic lagoon can be built, however, the advantage of odor reduction via anaerobic digestion is eliminated. The covered lagoon can be agitated, the effluent removed and knifed into the soil in such a fashion that odor can be minimal. (22)

If a covered lagoon cannot be built, part of the digester can be credited to odor pollution control. Also, some additional credit may be obtained because the stabilized manure from the digestion tank would not require so large a retention pond as unstabilized manure.

Water Quality

A study of the water quality in Northwest Wisconsin and elaboration of nonpoint source planning problems was undertaken to determine the liklihood of environmental regulation stimulating the adoption of anaerobic digesters.

In summary: Northwest Wisconsin does not have the serious pollution problems prevalent in other portions of the state. Since there are few large-scale industrial polluters, nonpoint agricultural pollution becomes the major concern. High nutrient levels in the Red Cedar River and sediment problems in the Chippewa, below Eau Claire, are considered problem areas. (Figure 35) Though no studies have identified the exact cause of these problems, non point agricultural sources are suspected to be the major contributor.

Figure 36 identifies the problem areas the County Soil and Water Conservation District (SWCD) has found attributable to waste management practices in Barron County. The magnitude of these problems are not defined. Polluted lakes and streams noted are combined sediment and fertility problems, with agricultural runoff or cattle grazing in the stream considered the sources. Barnyard and feedlot runoff indicated problems traced to their source, many being dairy operations. Nutrient losses indicate high nutrient levels in the waterways which are suspected to be agriculturally related.

The most significant affect land disposal of manure has on water quality stems from proper timing and rate of application, the degree to which manure is incorporated into the soil when spread, soil structure, and the slope of the land on which it is spread. A well designed waste storage facility and management plan can incorporate all of the above management practices. Anaerobically fermented waste contains less solids than non-fermented waste. This, perhaps, makes it more desireable for land application,

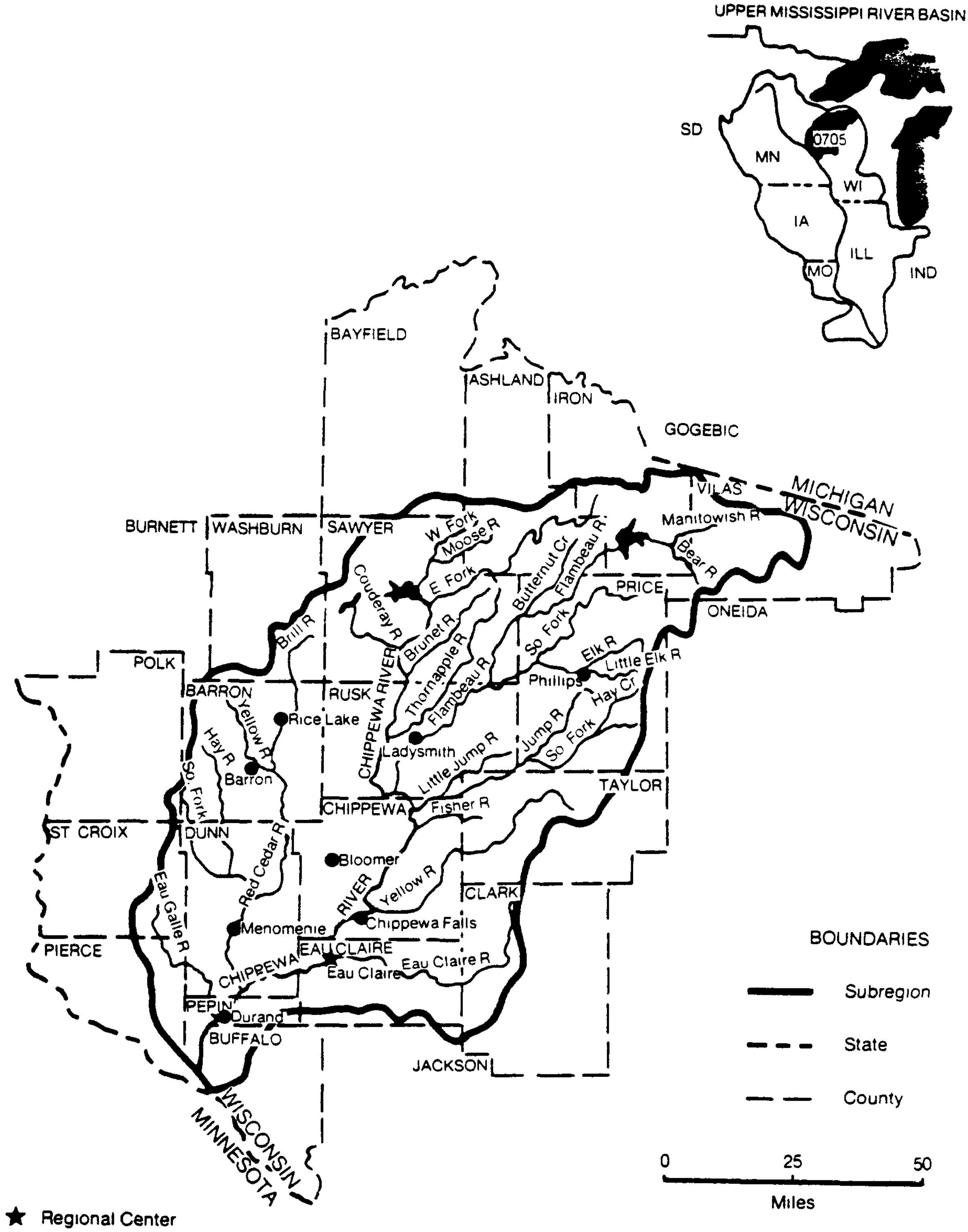


Figure 35. Chippewa River Basin, Upper Mississippi Region - Location map. (from Upper Mississippi River Basin Commission)

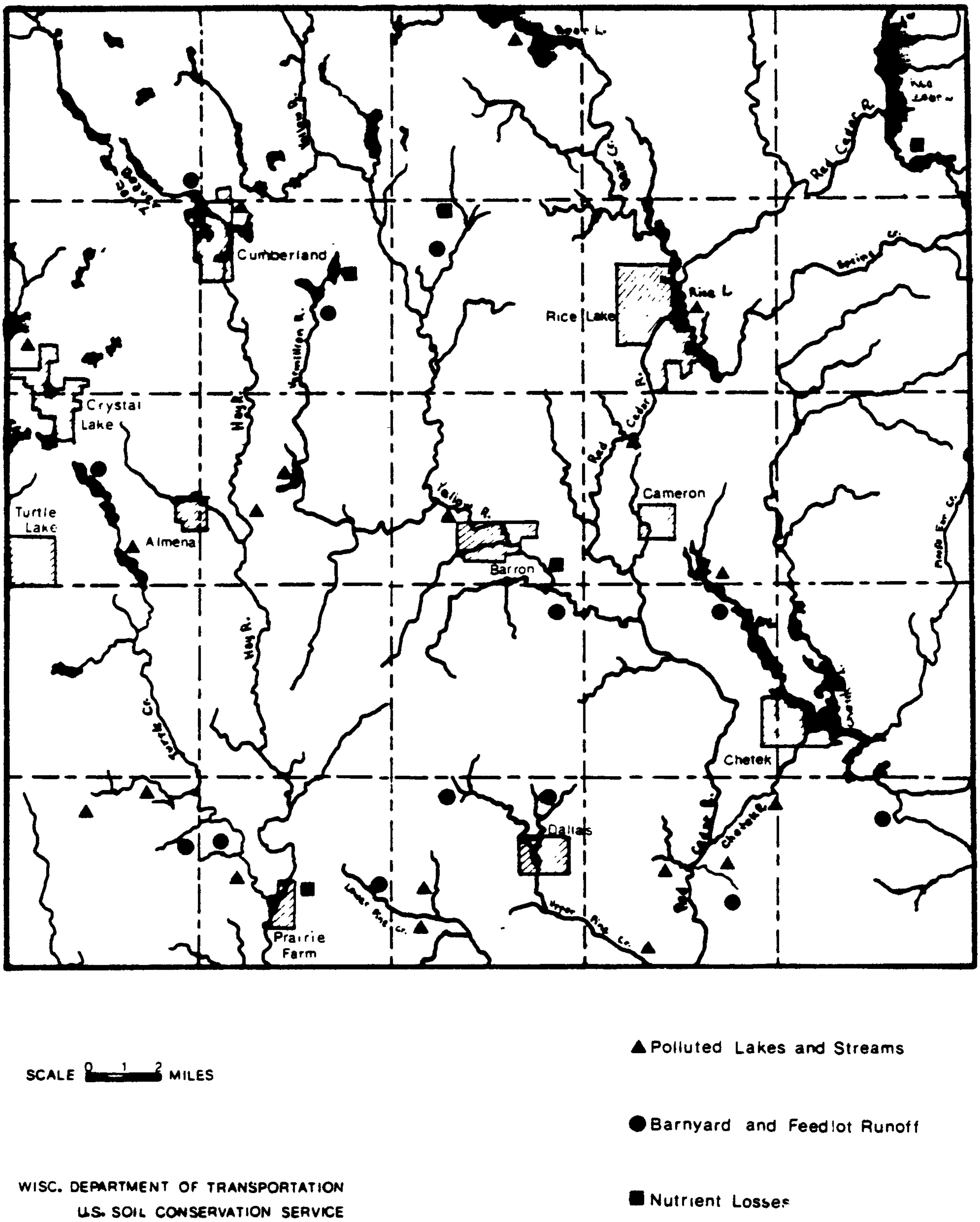


Figure 36. Barron County water quality problem areas.

if not disked in promptly, because it will soak into the soil more readily. Whether or not digested slurry could significantly reduce water pollution beyond liquid waste management systems remains to be determined. However, it appears that the reduction would be minimal.

The interactions between manure management, soil, and water quality are not completely understood nor quantified. Thus, it becomes difficult to prove the necessity of waste management practices and the impact anaerobic digesters would have on water quality, and, also, it becomes difficult to enforce nonpoint water quality regulations. The 208 nonpoint source planning program, being developed by the state DNR and Soil Conservation Service (SCS), advocates the use of Best Management Practices (BMP's) of manure to help alleviate deteriorating lake and stream water quality. These include:

- A waste storage pond with a minimum of 120 day retention time.

- Waste should not be spread on frozen soil, but spread and and incorporated into the soil prior to the tillage for planting.

- Waste may be spread on fields in the fall and incorporated to prevent runoff.

- The amount of waste applied to the soil must not exceed the requirements of the crop and the soil nutrient holding capacity.

Actual regulation of these practices will be difficult if not impossible. First, data assessing the ability of the BMP's to reduce water pollution is not available. Second, the nature of the problem requires individualized regulation for each farm. Manpower would be required that is not presently available. Permit programs would need to be set up, with field representatives and clerical staff required. Money put in to the regulatory beaurocracy would be better spent on direct alleviation of the problem, through technical assistance and cost sharing. Third, the cost of annual waste storage facilities may be prohibitive for the majority of small farmers. Should forced regulation occur, many of these marginal enterprises could be forced out of business.

Farmers, themselves, recognize the water quality problem and some of them actually expect regulatory action. Those that have installed waste management systems have done so with assistance from the county SCS, either in the form of design assistance, cost sharing, or both. This funded, volunteerism approach is a gradual means of improving water quality that focuses on local initiative for problem solving. The strong selling points of waste management systems, however, are the benefits such as reduced need for fertilizer, lower annual fuel costs, and convenience. Improved water quality is the desired goal, but to be widely accepted, waste management systems must be perceived as a significant contribution to the overall farm operation.

Cost sharing is available for liquid waste management systems but not for anaerobic digesters, because digesters are not being viewed by nonpoint planners as method of alleviating the water pollution problems. Regulations and recommended practices affecting agricultural inputs to nonpoint pollution may contribute to the adoption of anaerobic digesters by increasing the number of liquid waste management systems. When digesters can be shown to be an economical investment, based on energy production alone, as an addition to the waste management systems, then those farmers who have installed the waste management systems will be the likely ones to adopt anaerobic digesters. This conclusion is based on the present course of planning for the 208 nonpoint program and the attitudes of those involved in the program.

Utility Interest

Unlike other forms of renewable energy (solar, wind), methane gas converted to electricity is not subject to variations in climate. The electrical generation from a digester power plant is quite predictable and can actually be controlled for seasonal peaking through manure storage systems.

Public utilities have expressed an interest in alternative energy sources, if they can be done on a large scale. For smaller operations, the electric utilities are accommodating alternate energy producing units by purchasing power that is fed back into the line. Wind generators have been the only ones in the North Central Region to date that have requested this service. (72)

Safety is of prime concern to the power companies. When a storm knocks the power out, there needs to be some assurance that the linemen will not be zapped by numerous small generators feeding current into the line. If a self-synchronous inverter with a DC generator is to be used, or if an AC generator is involved, relaying must be incorporated which will recognize a a situation where the generator is energizing a portion of the utility system which is no longer connected to the main utility system and will interrupt the back-feed.

Preliminary consultations with the power company in the region has revealed that they are quite interested in alternate energy sources, and that they fully intend to cooperate and provide technical support for such connections. They have already expressed that the synchronous inverter system would be designed, installed, owned, and maintained by the utility to assure reliability and safety.

Also, if the farm could level their peak loads, or change the peaks so they are not corresponding with the power company peaks, pricing mechanisms could be worked out so it would be more beneficial for the farmer to send current into the line at power company peaks. Should enough of these systems be dispersed, there is a chance that the utilities would look to digesters as load levelers to help meet their peaks.

SECTION 9

MARKET FEASIBILITY

Anaerobic digesters, as indicated by the "Technical Components" section, consist of a number of technical subsystems which require various degrees of engineering, construction/installation services, and manufactured components. Most of the equipment, such as pumps, energy conversion units, boilers, piping, compressors, and hydraulics are readily available through existing farm suppliers. Other components such as the fermentation tank can be designed for modular construction, requiring minimum factory/warehouse space. Most of the tank fabrication can occur in the field. Electrical control panels can be easily fabricated in a small warehouse facility. There are a number of small shops which specialize in subcontracting the fabrication of these panels. Manure storage systems, the lagoon and influent tank, are already found on many farms as part of liquid waste management systems. If they are not already on site, the Soil Conservation Service will provide design and, in some cases, cost sharing assistance.

The manure handling equipment has caused the most significant problem of any digester component in the systems studied. The problem seems to stem from lack of understanding and poor engineering rather than any inherent lack of adequate equipment. There is manure handling equipment on the market which, if properly sized, can move virtually any quantity or type of manure solids concentration. Close work with manure equipment manufacturers by the designer of the system would help to alleviate these problems.

There are a number of ways for a digester to be designed and installed. Engineering is important. In an earlier section the need for standards related to design and construction of these systems was outlined. Standards and proper licensing of firms involved in digester design and construction businesses would enhance marketability of the product. Currently, there are approximately eight firms involved in the digester business. Most of these provide both the engineering and construction services. Engineering, however, could be specific and construction performed by local contractors.

Subsystems work could also be subcontracted to local manufacturers. This could help alleviate many of the service problems that are currently encountered by the firms in business now. It is crucial to both market feasibility and to keep manufacturing costs to a minimum that the out of town engineering firm work closely with the farmer in contracting a reputable service organization to keep the system in operating condition. This could be done through a local contracting representative who is commissioned to build the system.

The potential farm market for anaerobic digesters includes all dairy farms, poultry operations, beef cattle farms, large hog operations, and meat packing plants with the equivalent of 125 animal units or greater. This was seen as the lower limit to which digesters are, as yet, economical. However, with improved conversion efficiencies, cost reductions, escalating energy costs, and the availability of additional input material, such as municipal solid waste or crop residues, this lower limit could become lower. Coop systems involving several farmers would also increase the number of systems that can be economically installed.

The Rice Lake digester is located in Barron County, part of the Northwest Wisconsin Crop Reporting District. (Figure 37) Of the 8,300 livestock operations in the district, the greatest concentration of farms is found in Barron, Chippewa, Polk, and Rusk Counties. Table 19 shows the numbers and distribution of the different livestock operations. (69)

TABLE 19. NUMBERS OF FARMS IN THE FOLLOWING WISCONSIN COUNTIES (NORTHWEST DISTRICT)

	BARRON	CHIPPEWA	POLK	RUSK
Total	1,959	1,793	1,716	864
Dairy	1,358	1,192	1,019	610
Beef	288	289	343	172
Hog	80	218	100	23

Barron County also contains a high concentration of turkeys, the majority of which are in the ownership of one company.

The Statistical Reporting Service reports eight Barron County farms with over 100 head of milking cows. Our data, gathered from Township Assessors, generated closer to 50 farms with over 100 head. These include all cows, however, not just milkers.

Initially, the use of these systems will also be restricted to the more innovative farmers. Of the dairy farmers in Barron County there are 21 that can be considered innovative in terms of manure handling practices. These 21 were the first to install liquid waste handling systems as prescribed by the SCS. Interviews with the 21 farmers by outside sources, also helped to characterize them as innovators. (62) As a group, these farmers were better educated, had larger farm operations, earned more, and had more community involvement than the average Barron County farmer.

Preliminary indications show anaerobic digesters being adopted for a variety of reasons. Most evident is the rising cost of energy purchased for normal farm operation. Economics show the addition of a digester for energy production alone, on this size farm, will require other changes in farm operating procedures to enhance feasibility. Once an operating digester can be seen by local farmers, and the implications of diversifying operations becomes clear, more of these innovators will be considered likely adopters.

Provided that a local service organization can be contracted to maintain and perhaps build the digester the following two years could see one digester per year installed in the county. Success of these installations could increase this rate to five per year after five years. At a cost of approximately $40,000 per unit, the five year period would represent a total Barron County sales volume of $560,000. With the adoption of standards for construction and installation, governmental tax incentives, and assistance from farm agencies, such as extension, soil conservation services and the USDA, digester adoption rates will be increased.

TABLE 2

YR.	# OF DIGESTER INSTALLATIONS	SALES VOLUME
1	1	$ 40,000
2	1	40,000
3	3	120,000
4	4	160,000
5	5	200,000
TOTAL	14	$ 560,000

Extrapolations of this data to the remainder of the Northwest District would show Chippewa County with about 18 digester installations after five years and Polk County with close to ten. Total Northwest Wisconsin sales volume for the five year period could total $1.5 million for dairy farms with over 75 head. On a statewide basis, dairy farms could potentially represent some $15 million in sales over the next five years.

One means of increasing feasibility and adoption of digesters for use by greater numbers of farmers would be through the cooperative agreement of several farmers or a township to invest in liquid waste management systems. A centralized digester to provide power and gas could be sited so runs by a large tank truck could be made to the farms on a regular basis. The tank trucks would pick up one to two weeks of stored manure, truck it to the digester, where gas and electricity would be produced, and return equivalent amounts of slurry back to the holding ponds on the farmer's land. This type of arrangement would be beneficial both for improving water quality and alleviation of energy shortages. Electric utilities could help in construction and design of the power plant as it would be to their benefit to use as a load leveling tool. If sited near an existing natural gas pipeline, the gas company could purchase the gas from the coop for use in nearby towns where gas lines are prevalent. Arrangements could be made with participating farmers to return the percentage of spent slurry and percentage of gas or electricity provided by their animals' waste contribution. By working closely with utility companies, the farms could arrange to adjust their farming operations to coincide with off-peak electrical loads.

The engineering of such a system would be rather straight forward. Digester designs are common civil engineering practice. Manure collection would be coordinated similar to garbage collection routes and creamery milk routing. The obstacles would be primarily management, legal problems, and overcoming social barriers.

It seems that if a joint effort was made between the rural electric coops, the soil conservation services, the participating farmers, with cost sharing from other governmental agencies, such a plan would not only prove feasible, but highly beneficial. Increased community self-reliance and uses of local resources to meet energy demands, along with soil and water conservation would have long term benefits for the community and nation as a whole.

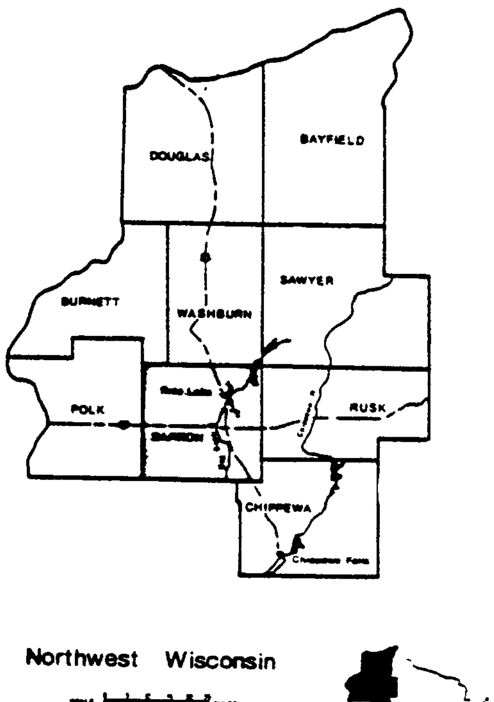


Figure 37. Northwest Wisconsin Crop Reporting District.

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Appendix A

ANAEROBIC DIGESTION OF DAIRY COW MANURE PLUS THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTE: A PILOT FEASIBILITY STUDY

ABBREVIATIONS & TERMINOLOGY

ANOVA	-- analysis of variance
C.O.D.	-- chemical oxygen demand
feedstock 1	-- dairy cow manure only
feedstock 2	-- dairy cow manure + MSW
g	-- gram
HRT	-- hydraulic retention time
l	-- liter
lb	-- pound
m	-- meter
MSW	-- municipal solid waste
N	-- elemental nitrogen
SRT	-- solids retention time
TS	-- total solids
TS_A	-- Total solids added
TS_W	-- total sample weight
VS	-- volatile solids
VS_A	-- volatile solids added
VS_D	-- volatile solids destroyed

SUMMARY OF FINDINGS

Completely mixed and continuously fed laboratory scale anaerobic digesters (operating on a 16 day SRT) were used to determine the feasibility of producing methane gas from a mixture of dairy cow manure (67% of the total solids) plus the organic fraction of municipal solid waste (33% of the total solids). Biogas production from this mixture was found to be 4.35 ft^3/lb VS_A, or 17.7 ft^3/lbVS_D. Biogas production from the same set of digesters, run on dairy cow manure alone, was found to be 4.56 ft^3/lb VS_A, or 18.2 ft^3/lb VS_D. Although the difference in biogas production is slight an analysis of variance showed it to be statistically significant (p 0.0001).

Biogas composition from the dairy cow manure plus MSW mixture was found to have a CH_4/CO_2 ratio of 1.23 ($\sim$ 55% CH_4); for the dairy cow manure only phase the CH_4/CO_2 ratio was found to be slightly higher at 1.34 ($\sim$57% CH_4).

Chemical analyses of the influent and effluent during the dairy cow manure plus MSW phase showed a reduction in total solids of 20.1%, a reduction in volatile solids of 24.6%, a reduction in chemical oxygen demand of 16.7%, and an increase in total Kjeldahl nitrogen (9.1%) and ammonia nitrogen (19.3%).

Overall, the anaerobic digestion of a 2:1 mixture of dairy cow manure plus MSW is nearly equivalent to the anaerobic digestion of dairy cow manure alone. This finding is explainable by the fact that both dairy cow manure and MSW have a low percentage of readily digestible organic matter; i.e., both are composed of a high percentage of non-solubilized cellulose.

INTRODUCTION

Previous studies by Jewell (1,2) have shown that the use of anaerobic digesters is not an economically feasible investment for dairy farms with fewer than 125 cows. In Wisconsin, nearly 90% of the dairy farms have fewer than 50 cows (3). Thus, the applicability of anaerobic digesters would appear to be quite limited in the near future, at least until changes in a number of factors (such as the price of natural gas, technological improvements in digester design, and the number of larger size dairy farms) alter the feasibility picture.

Another approach to the question of feasibility is on the basis of the amount of organic material available to the farmer for digestion. On most dairy farms the primary source will be dairy cow manure. The break even point of 125 head of dairy cows represents 1325 pounds of manure total solids production per day (1100 pounds of volatile solids per day) available for digestion. Suppose that some fraction of this 1325 pounds of total solids could be replaced with another type of organic material, which, when combined with the manure, digests equally as well. Then the break even point, in terms of number of cows, is lowered, depending on the quantity of that "other" source of organic material in the digester feed.

One potential source of organic material is through the intentional growing of field crops for digestion, perhaps a mini version of the Energy Plantation scheme proposed by Intertechnology Corporation (4-9) amd others (10, 11). Another potential source is the organic fraction of municipal solid waste (MSW). The use of MSW in farm scale digesters would not only improve the feasibility of digesters for dairy farms with fewer than 125 cows, but it would also attenuate the ever growing problems of MSW disposal.

Objective of this Study

The objective of this study was to compare the anaerobic biodegradability of a 2:1 mixture containing dairy cow manure plus the organic fraction of municipal solid waste with the anaerobic degradability of dairy cow manure alone.

MATERIALS AND METHODS

Apparatus

Thirteen laboratory scale anaerobic digesters were used to carry out this experiment. Each digester was completely mixed, vertically placed, and continuously fed (on a slug basis, i.e. one load/discharge per day). The reactors consisted of one liter glass jars (8.0 cm in diameter, 17.0 cm in height), sealed at the top with a #14 rubber stopper. Three glass tubes passed through the stopper; one for extracting effluent and adding influent, a second for biogas sampling, and a third for allowing the biogas to be discharged (See Figure A1)

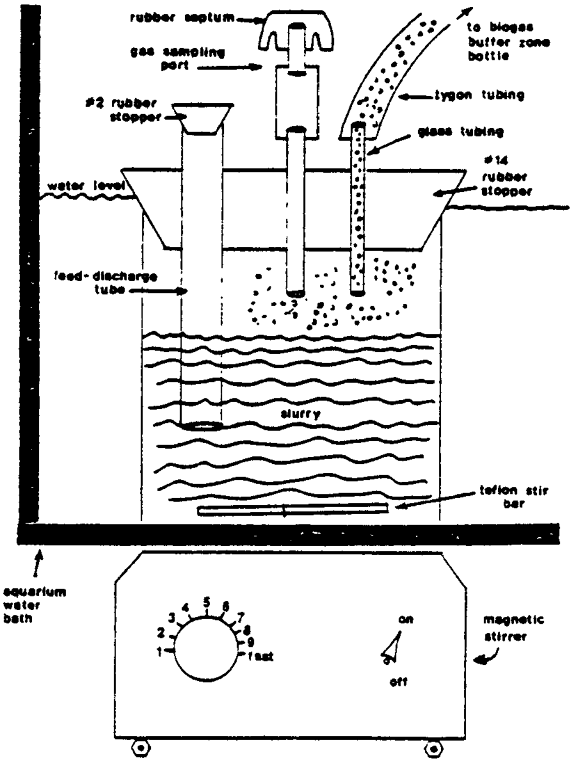

Figure A1: Reactor

In order to maintain the digesters in the mesophilic temperature range, they were kept inside a water bath (rectangular aquarium) with a heater/ thermostat, set at 35°C + 2°C. Air was continuously bubbled through the water bath to ensure an even distribution of the heat.

Mixing of the digesters was accomplished with magnetic stirrers. A 5.2 cm long teflon stir bar was placed on the bottom of each reactor; the entire aquarium rested on top of the 13 stirrers. Off-center drift of the stirring bar is often a problem when a material as viscous as animal manure is mixed. To help prevent this, the water bath was fitted with a "grid" structure which held the reactors directly on-center in relation to the stirrers (see Figure A2). Also, the small size of the reactors made stirring that much easier.

An electric timer switch with a one-hour cycle was used to turn the stirring units on for one minute every hour.

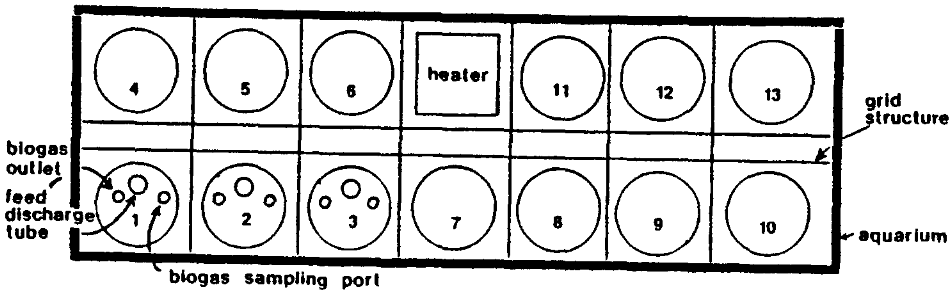

Figure A2: Top view of water bath

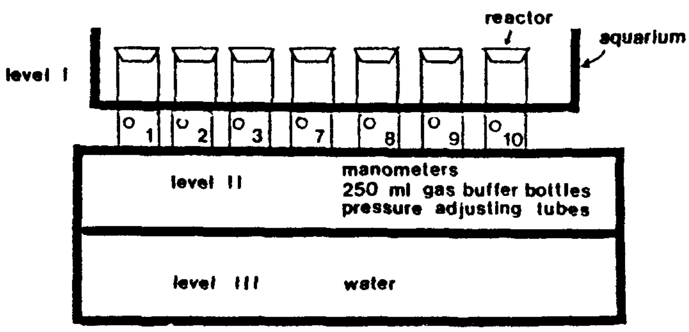

Figure A3: Front view.

Measurement of the biogas produced was accomplished by displacement of water. Figure A4 details the biogas measurement system. As the biogas collected in the space above the digesting material, it flowed into a 250 ml glass bottle (5.0 cm in diameter, 12.8 cm in height; fitted with a three-holed #10 rubber stopper) used to create a "buffer zone" in the gas system. This buffer zone was needed so that, when gas samples were withdrawn from the digesters, the pressure would not be lowered to a strong vacuum. One tube leading from this container was attached to a water-filled manometer, having a maximum/minimum pressure range of 5.0 cm water column. The other tube was attached to the water reservoir container, from which water was displaced.

The 13 water reservoir containers consisted of one-gallon glass bottles (each fitted with a two-holed #6 rubber stopper). Note that before the biogas enters the atmosphere of the bottles, it must first bubble through a test tube partially filled with water. This test tube separated the atmosphere above the digesters from that inside the bottles. Thus, when the bottles were opened for refilling with water (once every four days), the atmosphere above the digesters was not exposed to oxygen.

As biogas collected in the one-gallon bottles, it displaced the water through a siphon into one-liter collection bottles. Notice in Figure A4 that the siphon had a U-shape bend in it which prevented the siphon from being broken in case air bubbles became entrained in the tube. The "pressure adjusting tubes" were used in maintaining a relatively constant pressure in the atmosphere above the digesters; these tubes were adjusted daily according to the water level in the one-gallon bottles. As the water level in the one-gallon bottles dropped, the pressure adjusting tubes were moved downward.

The entire apparatus was contained on a moveable cart (see Figure A3) with three levels: one for the water bath and magnetic stirrers; a second for the manometers, buffer zone bottles, water reservoir bottles, and pressure adjusting tubes; and a third for the water collection bottles.

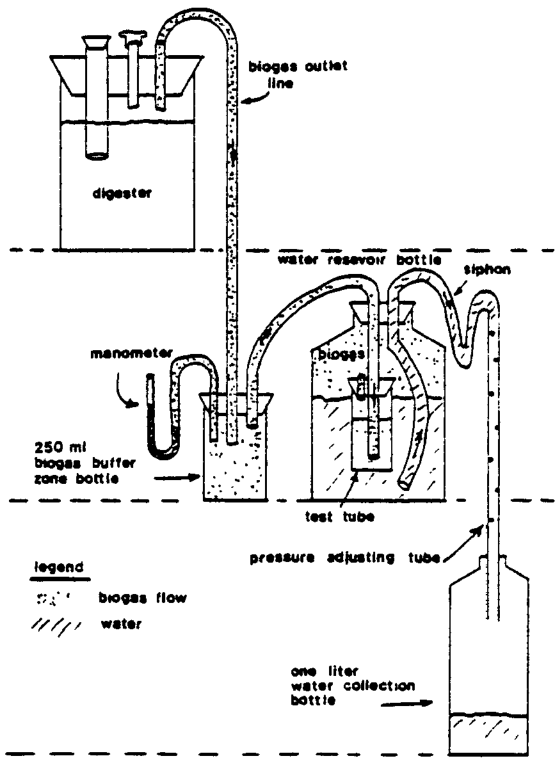

Figure A4: Biogas measurement system.

Analytical Methods

Biogas Volume. To convert mls of water displaced into mls of biogas produced at standard temperature and pressure, the following equation was used:

$$X = V\left(\frac{P_b - 20.1}{760}\right), \text{ where:}$$

X = mls of biogas produced at STP
V = mls of water displaced
P_b = barametric pressure, mm Hg, measured once daily
20.1= vapor pressure, mm Hg, of water at 22.2^o C. (approximate room temperature)
760 = standard pressure, mm Hg

Each of the 13 daily readings for mls of water displaced was corrected.

These values were also corrected according to the time of day that the readings were taken. For example, if the time between two consecutive readings was 24.5 hours, then each of the values was multiplied by 0.980 (i.e., 24/24.5); this put the biogas production measurement on an hourly basis.

Biogas Quality. Analyses of biogas samples were performed on a Carle Instruments Model 8000 Basis Gas Chromatograph, linked with a Heath Kit Servo Recorder Model #EU-20B. The gas chromatograph was equipped with a two ml sample loop and valve, as well as a column switching valve. Two columns were used in each analysis: 1) Poropak Q (10' x 1/8", 80/100 mesh), used to separate methane, carbon dioxide and air, Helium (used as the carrier gas) flow rate through this column was 38.8 ml/min; and 2) Mol Sieve 5A (6' x 1/8", 80/100 mesh), used to separate the air peak into oxygen and nitrogen; Helium flow rate through this column was 43.7 ml/min. The detector was kept at a constant 83^{o}C. Chart speed for output from the Porapak was 3"/min.; for the Mol Sieve 5A it was 2"/min.

On each sampling day, four samples were taken per digester; two were injected through the Porapak Q side, and two through the Mol Sieve 5A side. The percentage of each gas present was calculated according to the area under each peak, measured by the formula (height) x (base at one-half the height). Using a set of six standards from Scientific Gas Products, calibration curves were calculated for each gas.

pH. A Corning Model 7 pH meter coupled with a Corning #476054 glass combination electrode was used to determine pH.

Solids, Nitrogen, C.O.D. The Determination of total and volatile solids (TS and VS), total Kjeldahl nitrogen (TKN), ammonium plus free ammonia ((NH_4 + $-NH_3$) -N), and chemical oxygen demand (C.O.D.) were performed according to Standard Methods for the Examination of Water and Wastewater (12). Organic nitrogen concentrations were calculated by subtraction. Samples analyzed for C.O.D. had to be diluted first (83.33X) in order to bring them into the range specified for analysis (i.e., not greater than 2000 mg/l).

Computer Analyses. The analysis of variance of biogas production data was performed by the NWAY1 program of STATJOB, on the Univac 1110 computer of the University of Wisconsin-Madison. All other statistical analyses and computer graphics were performed on the University of Wisconsin-Green Bay Xerox Sigma 6.

EXPERIMENTAL DESIGN FOR STATISTICAL ANALYSIS OF BIOGAS PRODUCTION DATA

An experimental design utilizing analysis of variance was developed in order to compare biogas production from dairy cow manure (labeled feedstock 1) versus production from a mixture of dairy cow manure and MSW (labeled feedstock 2).

The basic design was to operate the 13 digesters first on dairy cow manure only until some sort of consistent biogas production was reached.

Then, all the digesters were to be switched to the mixed feedstock. After a sufficient acclimation period (at least 1 full SRT), the digesters would be operated until enough data was collected to make possible a comparison with the feedstock 1 phase.

This design required the investigator to make several important choices based on an examination of the data:

1) How could consistent biogas production in the feedstock 1 phase be determined?

2) When should the switch in feedstocks be made?

3) For how long a period should the digesters be run on feedstock 2 before the project is terminated?

4) How many days from each feedstock phase should be chosen for comparison?

The following criteria were developed as an aid in making these decisions:

1) Consistent biogas production means:

a. at least 10 consecutive days of no substantial variation in the overall mean; a substantial variation means a "wild fluctuation", characteristic of some sort of "line out"; and

b. the absolute quantity of biogas production (ft^3/VS_A) must be reasonably consistent with previously reported values for dairy cow manure.

2) The digesters must be operated with feedstock 2 for a period equal to or greater than their SRT (16 days) before considering use of the biogas production data for the ANOVA.

3) The design must be balanced, meaning that an equal number of days in each phase of operation must be selected for comparison.

The specific ANOVA model used to make the comparison between feedstocks 1 and 2 was:

$$Y_{ijk} = H + A_i + B_j + e_{ij} + C_k + AC_{ik} + BC_{jk} + S_{ijk}$$

where: Y_{ijk} = biogas production of the i th digester, for the j th feedstock, on the k th day

H = common mean

A_i= effect of the i th digester, i = 1, . . . , 13

B_j= effect on the j th feedstock, j = 1, 2

C_k= effect of the k th day, k = 1, . . . , 14

e_{ij} NID $(0, o_e)$ S_{ijk} MOD $(0, o^2)$

Thus, biogas production is the dependent variable; the digesters, feedstock and time are the independent variables.

This design is based on the assumption that, except for a change in the type of feedstock used, all other environmental conditions affecting performance of the digesters would remain constant. These conditions include: 1) temperature of the water bath; 2) mixing of the digesters; and 3) consistency within a feedstock phase of the quality of the feed, in terms of such parameters as TS, VS and C.O.D.

PROCEDURE

On October 1, 1977, the 13 digesters were seeded with 800 mls of a very dilute slurry containing dairy cow manure which had previously been anaerobically digested. A gas space approximately 150 mls was left at the top of the reactors. The digesters were allowed to acclimate for a period of 12 days. On October 12 (hereafter called day 1 as a reference point; see Appendix A2), daily feeding/discharge began as show in table A1, the digesters were fed increasingly greater amounts until a steady-state input/output of 50 mls was reached on day 11; building up the feeding/discharging quantity slowly was intended to prevent shocking of the digesters.

Table A1: Feed/Discharge Quantity

Day #	mls of feed/discharge
1	10
2	12
3	14
4	16
5	18
6	20
7	25
8	30
9	36
10	42
11	50
12	50
.	.
.	.
.	.
82	50 . . .project terminated

Feed/Discharge Procedure

The feed/discharge quantity of 50 mls chosen for this study represents a solids retention time (SRT) of 16 days (i.e., 50 mls in 800 mls of digester slurry). Since the digesters were completely mixed, the hydraulic retention time (HRT) was also 16 days.

Each day, at approximately the same time (between 12:00 p.m. and 2:00

p.m.), recordings were made both of the pressure in the atmosphere above the digesters and of the amount of water displaced by biogas production. Then, 50 mls of slurry were extracted from each digester and replaced with 50 mls of new feed. A 25 ml wide mouth serological pipette was used in this process.

Note that the feed/discharge tube extends below the level of slurry in the digester; thus, only a small area of the slurry was exposed to air during the feed/discharge process.

Influent Preparation: Feedstock 1

Dairy cow manure (feces and urine) was collected every five days from a local dairy farm, containing a herd of 22 Holsteins kept in a stanchion barn. Straw bedding is used in their gutters, but the straw was not collected with the manure. Approximately eight pounds of manure was taken per visit. On the same day, the manure was mixed with water (added one to one, by volume) to attain a slurry of 7% to 10% total solids. Because a pipette was used in the feed/discharge process, the slurry was blended in a high-speed commercial Waring Blender for about five minutes. The blending action created substantial amounts of foam, some of which was removed prior to use of the slurry as feed. When not in use, the blended slurry was placed in a cooler maintained at $4^{o}C$. New feed was prepared every five days.

No samples of the dairy cow manure influent were taken during this study; thus, it is not possible to state with complete certainty that the total solids content was 7% to 10%. However, in a previous study made by this investigator (13), manure was collected from a similar farm and prepared in the same manner (i.e., diluted 1:1 by volume). For 13 of the influent samples taken, the average total solids content was 7.6%, with a range of 6.1% to 9.3%.

Influent Preparation: Feedstock 2

Feedstock 2 contained two components: dairy cow manure and municipal solid waste (MSW). The dairy cow manure was prepared in the same manner as it had been for feedstock 1. On September 26, 1977, approximately 25 pounds of MSW were collected from two locations: Appleton, Wisconsin, and Madison, Wisconsin. Both cities use hammermills to shred their commercial and residential wastes; ferrous metals are then removed magnetically (with about 85% recovery). The MSW was combined in one container and, when not in use, stored in a cooler maintained at $4^{o}C$.

Additional processing of the MSW shred was necessary before it could be used in the laboratory digesters. Just prior to the start of its use, the shred was manually inspected and all large pieces of metal, plastic, rags, and cardboard were removed. The primary criterion used in the sorting process was to exclude any large and/or plastic and aluminum pieces which might damage the blender. Approximately ten of the original 50 lbs. were excluded from use.

Actual preparation of a feedstock 2 mixture was as follows: 1) One gallon of 7% to 10% dairy cow manure slurry was prepared, just as for feedstock 1. 2) This slurry was weighed and the quantity of dairy cow manure dry solids (TS) was calculated, assuming 8.5% TS in the slurry. 3) An approximately equal wet weight of MSW shred (i.e., = to the dairy manure dry solids) was added to the feedstock 1 slurry. 4) Water was added to this new mixture until a "milk-shake" consistency was achieved. This additional water was needed to account for the addition of MSW solids. 5) The dairy cow manure + MSW mixture was then blended for approximately five minutes. New batches were prepared every five days; a total of seven were prepared.

Thus, feedstock 2 contained a mixture of 50% dry weight dairy cow manure solids and 50% wet weight MSW shred solids. To determine what this ratio was on a dry weight to dry weight basis, an analysis of the MSW shred was made, with the results shown in Table A2:

Table A2: Composition of MSW Shred - Combined Sample from Appleton, WI., and Madison, WI.

	$\bar{x}$	$s_{\bar{x}}$*
% Moisture	40.2	3.87
%TS	59.8	3.87
% VS of TS	66.0	4.37
% VS of TSW	20.4	3.60
% FS of TSW	20.4	3.60

*standard deviation, from 3 replicate samples

If the %TS in MSW shred was 59.8%, then the ratio of dairy manure solids to MSW solids was 1.0/0.598, i.e. 1.67/1.00. In other words, feedstock 2 contained 63% dairy manure solids, 37% MSW shred solids, on a dry weight/dry weight basis.

Assuming that 83% of the dairy manure total solids was volatile (1), then the ratio of dairy manure volatile solids to MSW shred volatile solids was (0.83) (1.67) / (0.66) (1.00), i.e. 2.10/1.00. This translates to 68% dairy manure volatile solids, 32% MSW shred solids. Table A3 summarizes this information:

Table A3: Composition of Feedstock 2

	Percentage		Ratio
	Dairy Cow Manure	MSW	(Dairy Cow Manure) / MSW
Dry Weight - Solids	63%	37%	1.67/1.00
Dry Weight - Volatile Solids	68%	32%	2.10/1.00

Biogas Sampling

Starting on day #2, and every seventh day thereafter, samples of biogas above each digester were withdrawn through the rubber septum (see Figure 2) and immediately injected into the 2 ml sample loop of the gas chromatograph. A 5 ml gas tight syringe was used to take the samples. The septums were replaced at the midpoint of the project.

Influent and Effluent Sampling

On the same day that biogas analyses were carried out, the pH of the effluent from each digester was measured.

In the period from day 57 through day 81, five influent and nine effluent samples were taken and frozen. During January, 1978, they were analyzed for total and volatile solids, total Kjeldahl nitrogen, ammonium and free nitrogen, and chemical oxygen demand. The influent samples were representative of a particular batch of feedstock 2, used over a five day period, at five day intervals. The effluent were a composite of all 13 digesters for one particular day (i.e., the effluent from all 13 digesters was mixed together and a sample from this was frozen).

Table A4 provides a summary of most of the background information provided thus far:

Table A4: Summary of Background Information

Digester Specifications	
# of digesters used	13
height of reactor	17.0 cm
diameter of reactor	8.0 cm
total useable volume	950 ml
slurry volume	800 ml
gas space	150 ml
mixing	1 min./hr.
temperature	$35^oC + 2^oC$
steady state feed/ discharge quantity	50 mls
SRT	16 days
Dates	
duration of project	82 days (Oct. 12, 1977 to June 1, 1978)
# of days of feedstock 1	47 (day 1 thru day 47)
# of days of feedstock 2	35 (day 48 thru day 82)
# of days used in ANOVA	
feedstock 1	14 (day 34 thru day 47)
feedstock 2	14 (day 69 thru day 82)

RESULTS

Biogas Production Data

All 13 digesters were operated on feedstock 1 from day 1 thru 47, and on feedstock 2 from day 48 thru 82. Table A5 gives the mean, standard deviation, and range of biogas production for each day; Figure A5 displays the means graphically.

Following the initial start-up period, the biogas production leveled off starting on day 13, and remained consistent at approximately 452 mls/day until day 27, when a "wild" fluctation began. Production leveled off again starting on day 24, but at a definitely higher level. Thereafter, overall production was quite consistent right through the day before the influent was changed to feedstock 2.

The first loading of feedstock 2 caused a definite drop in the average biogas production, a predictable response to a new feed, considering the fact that the percentage of MSW shred was not increased gradually. However, production increased the next day (49) and remained stable through day 59 when a sharp drop for 2 days was followed by the largest average production for a single day for the entire project. The amplitude of this fluctuation was probably aggravated by the fact that between day 60 and 61, the stirrers were accidentally left off; when turned on again, production boomed the next day. Beginning with day 64, one full SRT after the switch in feedstocks, production leveled off and remained fairly consistent. The digesters were operated on feedstock 2 for 18 more days (through day 82) before the project was terminated.

An inspection of the graphs of biogas production for each individual digester showed one phenomenon fairly common to each: spiking. That is, one or two days of increasingly higher production, followed again by a drop. This spiking cycle was common for production across both feedstocks. One might expect (on the basis of a reduction in variance by a factor of 1/13) that an averaging of the data for each day would result in a series of means showing a much lesser degree of spiking. However, this is not what happened (see Figure A5). The amplitude of the spiking appears to be every bit as great for the means as for each digester.

ANOVA

Using the criteria outlined in section C, two sets of data (one each from the different feedstock phases) covering 14 day periods were selected for analysis of variance. For feedstock 1, days 34-47 were used; for feedstock 2, days 69-82 were used. Results from the ANOVA and table of two-way means are shown in Tables A6 and A7, respectively.

The ANOVA shows that the effect of time on biogas production is statistically significant (p 0.00.), meaning that the digesters behave differently from day to day. However, because the interaction of time x feedstock is also statistically significant (p 0.001), the averages for each 14 day period should not be combined. In other words, biogas production in the feedstock 2 phase was lower than in the comparable phase for feedstock 1. Table A7 shows the grand mean for feedstock 1 to be 583 mls/day; for feedstock 2 it is 568 mls/day, a difference of 15 mls/day.

TABLE A5: BIOGAS PRODUCTION DATA - AVERAGE FOR 13 DIGESTERS

FEEDSTOCK 1				FEEDSTOCK 2			
Day No.	$\bar{x}$	$s_{\bar{x}}$	Range	Day No.	$\bar{x}$	$s_{\bar{x}}$	Range
1	11	6.2	20	48	450	42.0	158
2	43	19.5	63	49	645	88.5	287
3	59	9.9	39	50	559	46.4	163
4	83	12.1	49	51	611	42.2	145
5	93	13.9	55	52	586	32.8	117
6	144	11.5	38	53	516	44.5	185
7	147	17.2	76	54	573	22.3	77
8	165	14.3	54	55	673	30.8	127
9	225	19.2	85	56	605	31.9	100
10	280	28.8	122	57	562	40.3	142
11	267	28.4	95	58	599	49.4	167
12	366	18.2	68	59	524	26.7	87
13	445	35.7	122	60	455	20.8	73
14	470	27.7	93	61	385	21.4	76
15	384	28.1	83	62	731	89.3	271
16	438	25.4	82	63	478	38.1	108
17	430	33.7	98	64	576	32.4	110
18	466	34.1	96	65	618	24.3	94
19	436	25.4	97	66	495	37.2	134
20	512	56.3	252	67	558	21.4	74
21	437	32.0	112	68	570	38.4	167
22	483	27.4	84	69	494	40.7	150
23	387	27.9	90	70	572	33.4	124
24	463	26.8	104	71	589	32.3	107
25	519	33.7	119	72	509	34.1	107
26	455	31.5	98	73	582	24.3	83
27	688	99.3	311	74	615	32.9	114
28	627	42.3	121	75	489	32.4	113
29	582	48.4	183	76	532	23.3	85
30	554	39.7	114	77	512	32.6	115
31	428	27.8	86	78	627	24.7	85
32	413	21.8	70	79	532	27.7	86
33	453	33.0	110	80	624	36.2	125
34	535	33.3	123	81	640	23.7	71
35	643	34.4	143	82	638	34.8	124
36	549	32.1	96				
37	627	41.1	147				
38	641	26.7	80				
39	518	24.1	82				
40	612	16.9	64				
41	507	48.1	178				
42	593	21.8	77				
43	639	19.6	57				
44	524	28.2	105				
45	581	25.7	99				
46	623	22.6	71				
47	569	34.6	105				

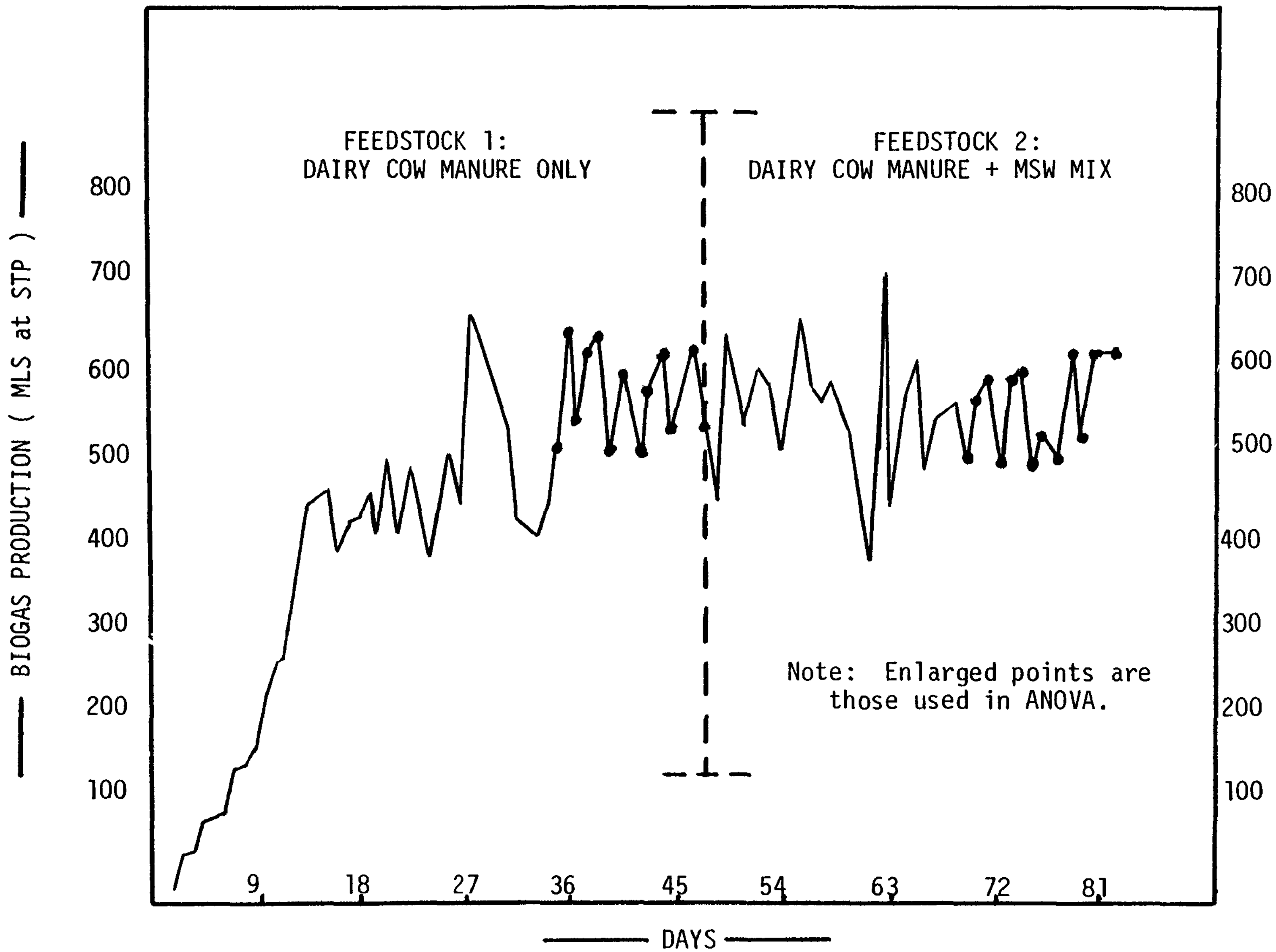

FIGURE A5. AVERAGE BIOGAS PRODUCTION FOR 13 DIGESTERS

TABLE A6: ANALYSIS OF VARIANCE OF BIOGAS PRODUCTION DATA

Source	d.f.	s.s.	m.s.	F.
Digesters	12	71,996.1	5,999.7	4.567
Feedstock	1	18,973.6	18,973.6	14.444
Error (a)*	12	15,763.6	1,313.6	----
Time	13	539,106.9	41,469.8	68.376
Time x Feedstock	13	397,730.3	30,594.6	50.445
Time x digesters	156	137,780.4	883.2	1.456
Error (b)*	156	94,613.6	606.5	----
Total	363	1,275,968.7		

* Error (a) = Digester x Feedstock
Error (b) = Time x Digester x Feedstock

TABLE A7: A COMPARISON OF MEANS, BY FEEDSTOCK, OVER TIME

	TIME*														
Feedstock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	$\bar{x}$
1	535	643	549	627	641	518	612	507	593	639	524	581	623	569	583
2	494	572	589	509	582	615	489	533	512	627	534	625	640	638	568
$\bar{x}$	515	608	569	568	612	567	550	520	553	633	528	603	632	603	576

* Time 1 in this table corresponds to day 34 for feedstock 1, day 69 for feedstock 2; time 14 corresponds to day 47 and 82, respectively.

The statistical significance of the time x feedstock interaction is not too surprising because two distinctly different 14 day periods were compared. However, the time x digester interaction is <u>not</u> statistically significant (p 0.001); meaning that the behavior of the digesters as a group varies similarly over time; i.e., the digesters are not acting autonomously--each changing in its own way; rather, the digesters change over time as a group. Thus, the change in biogas production over time cannot be attributed to random variations among the digesters. This suggests that the changes are caused by the environment of the digesters, which includes not only the feedstock but also several other independent variables not entered into the analysis; namely the consistency of the influent over time (as measured by parameters such as %TS, %VS, C.O.D.).

Biogas Composition

Biogas composition was not significantly affected by the change in feedstocks, as shown in Table A8 and Figure A5. Once steady-state operation was reached, the percent methane ranged from 50.5% to 55.4% for the duration of the project, with an overall average of 53.3%. During the feedstock 1 operation, the average percent methane for all 13 digesters was 54.1%; for the feedstock 2 phase, the average was 52.3%.

In all of the analyses, an air peak, split into nitrogen and oxygen, was calculated. However, in a laboratory experiment headed by Klien (14), tests demonstrated that virtually all the air present in their biogas collectors resulted from contamination during feeding and was not a product of the digestion process. All air was found to be expelled from the digesters within ten minutes after feeding, so interference with the digestion process was negligible.

In this study, the $\%N_2$ and $\%O_2$ will be reported; however CH_4/CO_2 have also been calculated, which discounts the presence of air. For the feedstock 1 phase, the ratio of CH_4/CO_2 was 1.34; for the feedstock 2 phase, it was 1.23.

Table A8: AVERAGE BIOGAS COMPOSITION FOR 13 DIGESTERS

Day No.	CH_4/CO_2	$\%CH_4$	$\%CO_2$	$\%N_2$	$\%O_2$
2	2.62	39.5	15.1	-	-
9	1.45	54.9	37.8	6.44	1.04
16	1.41	55.4	39.3	4.32	1.04
23	1.38	54.5	39.5	5.15	0.94
30	1.21	52.4	43.4	3.63	0.72
37	1.27	53.8	42.5	3.07	0.67
44	1.31	53.5	40.9	4.69	0.92
51	1.13	50.5	44.5	4.18	0.83
58	1.15	50.5	44.1	4.56	0.90
65	1.26	52.7	41.7	4.65	0.95
72	1.34	54.3	40.4	4.31	0.94
79	1.28	53.7	41.9	3.46	0.91
$\bar{x}$, 9-79	1.29	53.3	41.5	4.39	0.90
$\bar{x}$, 9-44*	1.34	54.1	40.6	4.55	0.89
$\bar{x}$, 51-79#	1.23	52.3	42.5	4.23	0.90

* represents the average for the period covering steady-state operation with feedstock 1.

\# represents the average for the period of operation covering feedstock 2.

Influent/Effluent Analyses

pH. All of the digesters, except #12 and #13, showed an acid pH at the onset of the experiment (day 2). Once steady-state operation was reached, pH in all of the digesters became slightly above neutral. Throughout the remainder of the project (day 9-82), the pH of each digester fell in the range of 7.0 to 7.4, with the overall mean closest to 7.2. The switch from feedstock 1 to feedstock 2 appeared to have no effect on pH.

Total and volatile solids. Samples of influent and effluent were analyzed for TS and VS only during the feedstock 2 phase, from day 57-82. Results are summarized in Table A9 and Figure A6.

For the five influent samples analyzed, the TS averaged 4.93%, ranging from 3.91% to 5.41%. This is a surprising result because the influents appeared to be very viscous after they were homogenized in a blender. The value of 4.93%TS is well below the desired range of 7% to 10% TS for an influent.

Figure A6 shows that after an initial drop in influent %TS, there was a very definite increase in the last three batches. This trend is significant because it appears to correspond to a gradual increase in biogas production for the same period (see Figure A6).

The %VS in the influent closely followed the %TS; for the five batches sampled, 84.7% of the total solids were volatile (4.18% VS of TSW). This value is higher than the corresponding one for the dairy cow manure, which normally averages 83% VS of TS. Organic loading rate was calculated to be an average of 0.11 lb VS/ft^3 day^{-1} (1.72 g VS/l day^{-1}).

Total solids in the effluent decreased steadily in the period when samples were taken, as did the volatile solids. The overall mean for nine samples was 4.17% TS, 3.45% VS (82.6% VS of TS). Four of the samples (days 70, 73, 78 and 81) fall into the same time frame as the biogas production data used in the ANOVA (day 69-82). Because more than one full SRT had passed from the time these four samples were taken, they are probably more informative than the average for all nine samples. The mean %TS in these four was 3.94%; the mean %VS was 3.23% (81.9% VS of TS).

Volatile solids reduction increased over time, indicating improving efficiency in digestion as the reactors became acclimated to feedstock 2. The overall %VS destruction was 17.0%, ranging from 9.5% to 31.7%. For the 12 day period, day 70-81, the average was 24.6% VS destroyed.

Using the average value discussed above, it was possible to calculate several important values shown in Table A10.

Thus, when biogas production is measured on the basis of ft^3/lb TS_A, ft^3/lb VS_A, and ft^3/lb VS_D the values are slightly higher for feedstock 1 than for feedstock 2.

TABLE A9. SUMMARY OF RESULTS - CHEMICAL ANALYSES

INFLUENT

Date Range from	Date Range to	Day No. from	Day No. to	$(NH_4^+-NH_3)$ mg/l-N	Organic N mg/l-N	TKN mg/l-N	%TKN as $(NH_4^+-NH_3)$	C.O.D. mg/l	%Total Solids	%VS of TS	%VS of Total Sample	Loading Rate lbs VS/ft^3/day (g VS/l/day)
12-7-77	12-11-77	57	61	87.9	608	696	13	51,000	4.93	87.19	4.29	0.11 (1.77)
12-12-	12-16-	62	66	310	810	1120	28	52,000	4.60	84.89	3.91	0.10 (1.61)
12-17-	12-21-	67	71	123	907	1030	12	53,000	4.73	84.40	4.00	0.10 (1.64)
12-22-	12-26-	72	76	584	956	1540	38	52,000	4.99	83.78	4.18	0.11 (1.72)
12-27-	12-31-	77	81	152	948	1100	14	60,000	5.41	83.27	4.51	0.12 (1.86)
			$\bar{x}$	251	846	1100	21	54,000	4.93	84.71	4.18	0.11 (1.72)

EFFLUENT

Date	Day No.	$(NH_4^+-NH_3)$ mg/l-N	Organic N mg/l-N	TKN mg/l-N	%TKN as $(NH_4^+-NH_3)$	C.O.D. mg/l	%C.O.D. Reduction	%Total Solids	%VS of TS	%VS of Total Sample	%VS Destroyed
12-7-77	57	193	1020	1210	16	56,000	-	4.60	83.11	3.83	10.7
12-9-	59	178	1000	1180	15	54,000	-	4.50	85.05	3.82	11.0
12-13-	63	149	981	1130	13	56,000	-	4.27	82.79	3.54	9.5
12-15-	65	188	962	1150	16	50,000	3.9	4.26	82.83	3.53	9.7
12-17-	67	226	944	1170	19	49,000	7.6	4.17	82.33	3.44	14.0
12-20-	70	228	932	1160	20	45,000	15	4.06	82.23	3.34	16.5
12-23-	73	284	906	1190	24	45,000	13	4.10	82.28	3.38	19.1
12-28-	78	375	885	1260	30	42,000	30	3.79	81.55	3.08	31.7
12-31-	81	356	874	1230	29	46,000	23	3.82	81.33	3.11	31.0
Overall $\bar{x}$		242	945	1190	20	49,000	15	4.17	82.61	3.45	17.0
$\bar{x}$ for 70-81		311	899	1210	26	45,000	20	3.94	81.85	3.23	24.6

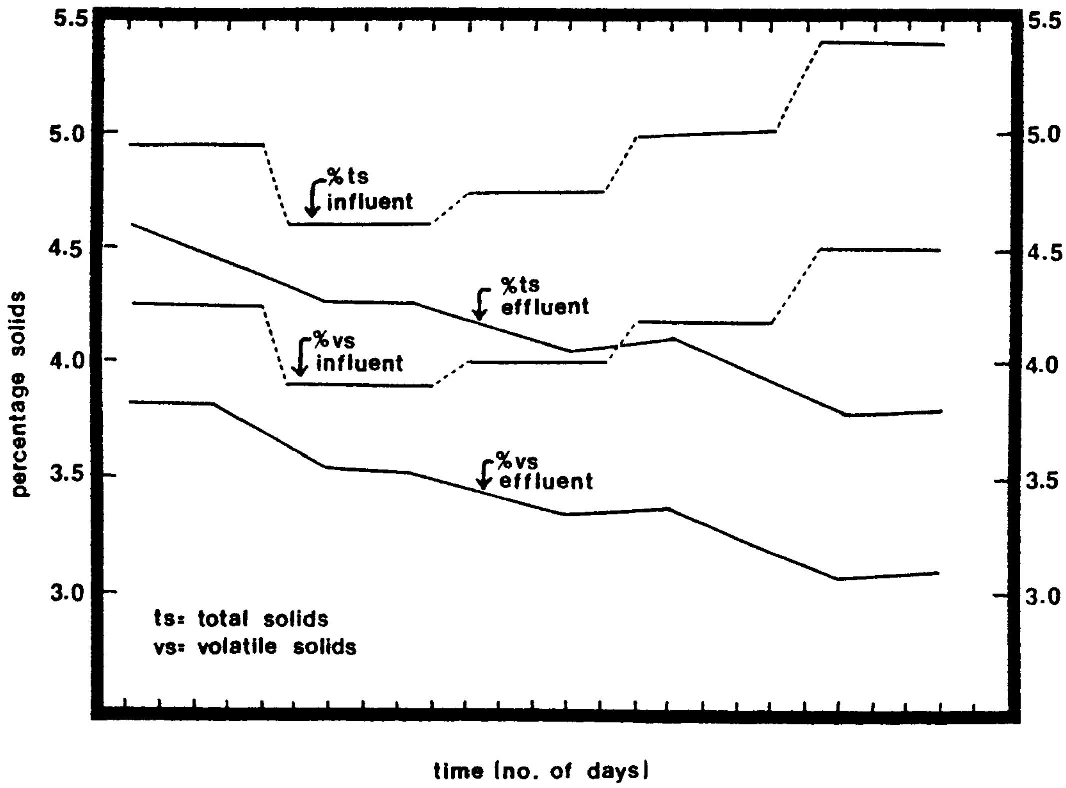

FIGURE A6. TOTAL AND VOLATILE SOLIDS - FEEDSTOCK 2

Nitrogen. TKN values for the influent varied substantially, ranging from 696 mg/l to 1540 mg/l. Ammonia levels in the influent closely followed the TKN. For the five samples analyzed, TKN averaged 1100 mg/l, (NH_4 + -NH_3) -N averaged 251 mg/l (see Figures A7 and A8.).

The effluent TKN and ammonia followed a much more consistent pattern than the influent. Most significantly, Figure A8 shows a definite increase over time of the percentage of TKN in the inorganic form, suggesting improved efficiency of digestion farther into the feedstock 2 phase. This pattern correlates well with the decrease over time of %TS and %VS (see Figure A7), as well as C.O.D. (see below).

For the period day 70-81, effluent TKN averaged 1210 mg/l, (NH_4 + -NH_3) -N averaged 311 mg/l.

Chemical Oxygen Demand. Figure A9 shows the change over time in C.O.D. concentrations for the influent and effluent. The average influent value was 54,000 mg/l. Values for dairy cow manure slurry have been reported in the range of 70,000 mg/l to 115,000 mg/l (13). The discrepancy is explainable by the relatively low %VS in feedstock 2, since %VS and C.O.D. are directly related.

Initially the effluent C.O.D. exceeded the influent C.O.D., probably

Table A10: COMPARISON OF BIOGAS PRODUCTION EFFICIENCY

	FEEDSTOCK 1	FEEDSTOCK 2
measured biogas production mls of biogas/ml influent %TS in influent %VS of TS in influent %VS destruction	 11.7 * 7.6 ≠ 83.0 ≠ 24.0 ≠	 11.4 * 4.93 84.7 24.6
ft^3 biogas/lb TS_A (m^3/Kg TS_A)	3.79 0.236	3.69 0.229
ft^3 biogas/lb VS_A (m^3/Kg VS_A)	4.56 0.285	4.35 0.270
ft^3 biogas/lb VS_D (m^3/Kg VS_D)	18.2 1.14	17.7 1.10

* based on the average biogas production results from the ANOVA

≠ no samples of influent or effluent were taken in the feedstock 1 phase; these values represent averages from a previous study(13), in which the same type of influent was used; they also are consistent with results from other, similar studies (1).

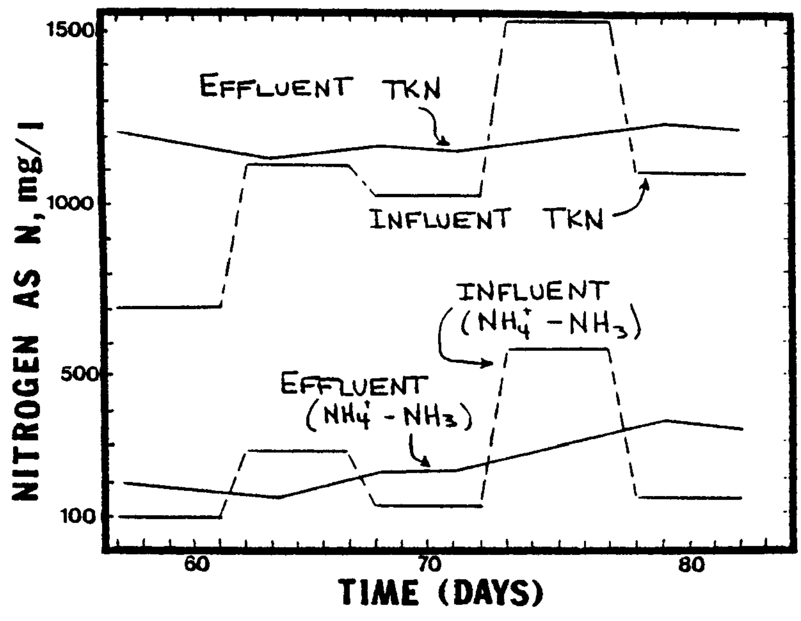

Figure A7. Ammonia and TKN - Feedstock.

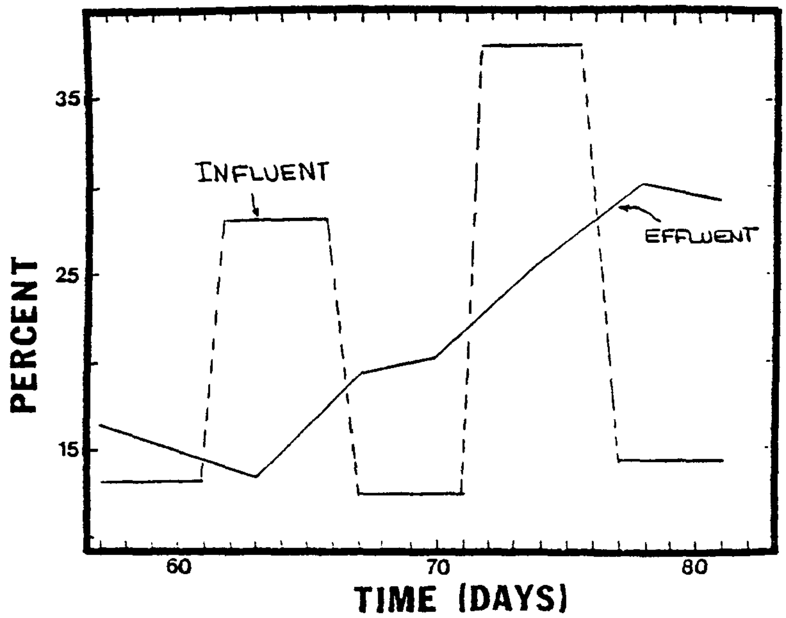

Figure A8. Percent of TKN in the form (NH_4^+ - NH_3) - N for Feedstock 2.

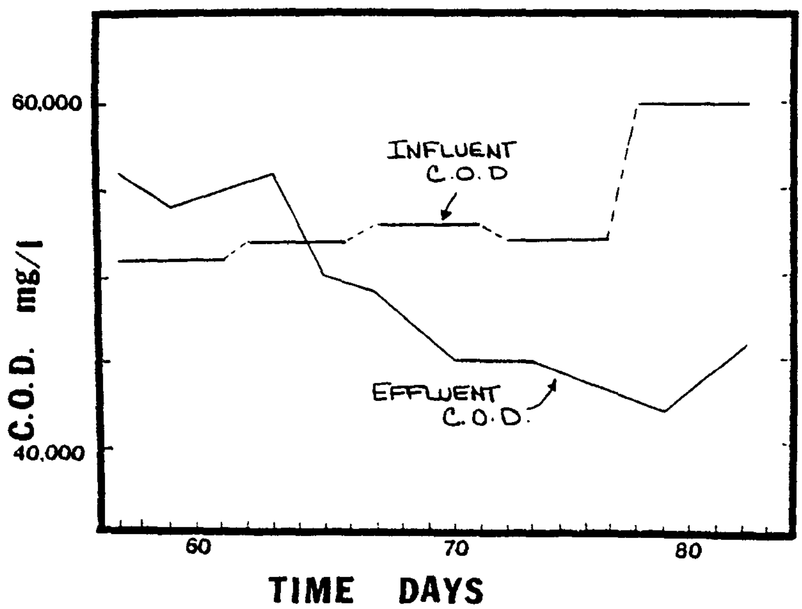

Figure A9. Chemical Oxygen Demand - Feedstock.

because of a build-up of organic material following the switch to feedstock 2. However, the effluent C.O.D. dropped consistently after day 63, before leveling off at approximately 45,000 mg/l. The % C.O.D. reduction averaged 20% for the period day 70-81.

Odor. A homogenous blend of dairy cow manure and the organic fraction of municipal solid waste has a very offensive odor, much more so than dairy cow manure alone. Following digestion of feedstock 2, the reduction in odor was substantial, indicating stabilization of much of the volatile organic compounds.

Table A11 provides a summary of the major findings of this study.

TABLE A11: SUMMARY OF RESULTS

BIOGAS PRODUCTION & COMPOSITION		
	FEEDSTOCK 1	FEEDSTOCK 2
$ft^3/lb\ VS_A$	4.56	4.35
$ft^3/lb\ VS_D$	18.2	17.7
CH_4/CO_2	1.34	1.23
FEEDSTOCK 2 - COMPOSITION		
	PERCENT	RATIO
Dairy cow manure(TS)	63%	
MSW (TS)	37%	1.67
Dairy cow manure (VS)	68%	
MSW (VS)	32%	2.10
FEEDSTOCK 2 - ORGANIC LOADING RATE		
$lbs\ VS/ft^3\ day^{-1}$	0.11	
$g\ VS/l\ day^{-1}$	1.72	
FEEDSTOCK 2 - CHEMICAL ANALYSIS		
	INFLUENT	EFFLUENT
% TS	4.93	3.94
% VS of TS	84.7	81.9
% VS of TSW	4.18	3.23
% VS_D	-	24.6
TKN (mg. l)	1100	1210
$(NH_4 + -NH_3)$-N (mg/l)	251	311
C.O.D. (mg/l)	54,000	45,000

DISCUSSION & CONCLUSIONS

A search of the recent literature on anaerobic digestion of farm wastes found no previous work dealing specifically with the biodegradability of a mixture containing dairy cow manure and the organic fraction of municipal solid waste. However, there has been a significant amount of research on the anaerobic digestion of dairy cow manure, which is summarized in Table A12.

Relative to most types of organic material, the anaerobic biodegradability of dairy cow manure is quite low, for an obvious reason: Readily digestible material is broken down in the animal's rumen, and hence its excreta contains only that fraction of the animal's feed intake which is difficult to decompose, such as intricate poly-saccharide-lignin complexes. In laboratory experiments, Morris, Jewell and Roehr (20) found the refractory fraction (R) of dairy cow manure to be 0.575, i.e. the biodegradability of dairy cow manure was 42.5% of the influent volatile concentration.

Likewise, about 30% to 60% of the organic portion of refuse is not fermentable to methane and remains as a stable refractory residue (21). Cellulose must be solubilized before it can be degraded. Because MSW is not a good source of the enzymes which break down cellulose molecules, the only point of attack for the anaerobic bacteria is at the partially dissolved portion of the fibrils at the surface of the cellulose fibers (22).

Thus, the organic fraction of MSW and dairy cow manure appear to have a similar level of anaerobic biodegradability. For this reason, the addition of MSW to dairy cow manure should not substantially decrease the efficiency of biogas production.

Table A13 provides a summary of biogas production from various combined wastes. Of particular interest is the work done by Klien (23) with chicken manure and components of municipal solid waste. Chicken manure has a high concentration of nitrogen compared to other manures; its use with highly carbonaceous refuse therefore improves the carbon/nitrogen ratio of the feed much more so than other manures.

This study has demonstrated the feasibility of anaerobically digesting a mixture of dairy cow manure and the organic fraction of municipal solid waste, with a very small reduction in biogas production efficiency. Future research must be addressed to the following areas:

1) What is the maximum of MSW which can be added to dairy cow manure before biogas production is substantially reduced?

2) What is the affect of changes in the organic loading rate and solids retention time on the anaerobic biodegradability of a dairy cow manure and MSW mixture?

3) How does the presence of residual MSW in the digester effluent affect the potential uses of this material as a fertilizer or as a component in refeed?

4) How much can pretreatment (by mechanical and/or biological means) of the MSW improve the biodegradability of the mixture as a whole?

5) What are the barriers to practical application of a waste management/resource recovery system which combines animal manures and MSW for a treatment in farm-scale anaerobic digesters?

Table 12 Summary of Data on Anaerobic Digestion of Dairy Cow Manure

Biogas Production $ft^3/lb\ VS_A/day$ ($m^3/kg\ VS_A/day$)	Biogas Production $ft^3/lb\ VS_D/day$ ($m^3/kg\ VS_D/day$)	Loading Rate lb VS/ft^3/day (g VS/1/day)	%CH-4	Temp. (°C)	SRTor HRT (days)	Scale	Design	Comment	Ref No.
0.192 (0.012)	2.24 (0.140)	1.74 (27.9)	59*	32.5	2.5	lab	conven	-	1
1.73 (0.108)	9.02 (0.563)	0.874 (14.0)	60*	32.5	5	lab	conven	-	1
2.77 (0.172)	- -	1.09 (17.4)	-	60	5	lab	conven	-	1
3.68 (0.230)	11.6 (0.721)	0.436 (6.98)	65*	32.5	10	lab	conven	-	1
2.21 (0.137)	- -	0.544 (8.72)	48*	60	10	lab	conven	-	1
5.51 (0.344)	15.2 (0.950)	0.218 (3.49)	63*	32.5	20	lab	conven	-	1
5.61 (0.350)	15.6 (0.972)	0.145 (2.33)	63*	32.5	30	lab	conven	-	1
0.817 (0.051)	16.3 (1.02)	0.231# (105@)	50*	22.5	10	lab	batch	-	1
2.13 (0.133)	16.7 (1.04)	0.461# (209@)	55*	22.4	20	lab	batch	-	1
2.48 (0.155)	18.7 (1.17)	0.692# (314@)	56*	22.5	30	lab	batch	-	1
4.47 (0.279)	14.8 (0.927)	0.236# (107@)	55*	32.5	10	lab	batch	-	1
6.41 (0.400)	17.0 (1.06)	0.472# (214@)	52*	32.5	20	lab	batch	-	1
7.11 (0.444)	17.3 (1.03)	0.705# (320@)	57*	32.5	30	lab	batch	-	1
1.39 (0.087)	6.87 (0.429)	0.290 (4.65)	61*	22.5±2.5	15	lab	plug	-	1
3.16 (0.197)	9.10 (0.568)	0.145 (2.33)	67*	22.5±2.5	30	lab	plug	-	1
5.56 (0.347)	13.8 (0.859)	0.072 (1.16)	67*	22.5±2.5	60	lab	plug	-	1
1.23*(0.077*)	11.0 (0.69)	0.132 (2.10)	52	23	25.7	lab	conven	intermittent mixing	15
2.49*(0.155*)	16.2 (1.01)	0.132 (2.10)	64	35	26.3	lab	conven	" "	15

Table 12 continued

Biogas Production ft^3/lb VS_A/day (m^3/kg VS_A/day)	ft^3/lb VS_D/day (m^3/kg VS_D/day)	Loading Rate lb VS/ft^3/day (g VS/1/day)	%CH-4	Temp. (°C)	SRTor HRT (days)	Scale	Design	Comment	Ref No.
1.67*(0.104*)	16.1 (1.01)	0.202 (3.10)	64	23	26.3	lab	conven	intermittent mixing	15
2.33*(0.145*)	14.3 (0.89)	0.215 (3.40)	58	35	25.3	lab	conven	" "	15
2.68*(0.167*)	6.39 (0.40)	0.155 (2.50)	65	35	20	lab	conven	natural mixing	16
2.97*(0.185*)	6.15 (0.38)	0.176 (2.8)	65	35	16.6	lab	conven	" "	16
1.96*(0.122*)	4.11 (0.26)	0.185 (3.0)	65	35	16.6	lab	conven	" "	16
2.65*(0.165*)	4.97 (0.31)	0.216 (3.5)	65	35	16.6	lab	conven	" "	16
1.05*(0.065*)	4.80 (0.30)	0.120 (1.9)	66	32.5	10	lab	conven	dairy bull manure used	17
1.36*(0.084*)	5.08 (0.32)	0.12 (1.9)	65	32.5	15	lab	conven	" "	17
1.23*(0.076*)	6.33 (0.40)	0.24 (3.8)	65	32.5	10	lab	conven	" "	17
1.57*(0.097*)	8.88 (0.56)	0.24 (3.8)	61	43.6	15	lab	conven	" "	17
0.88 (0.055*)	1.94*(0.121*)	0.10 (1.60*)	77	35	12	lab	conven	-	18
0.79 (0.049*)	1.77*(0.110*)	0.10 (1.60*)	79	35	20	lab	conven	-	18
0.58 (0.036*)	1.53* (0.096*)	0.18 (2.88*)	77	35	12	lab	conven	-	18
1.05 (0.066*)	1.97*(0.123*)	0.18 (2.88*)	74	35	20	lab	conven	-	18
5.6 (0.349*)	12.4*(0.777*)	0.50 (8.01*)	60*	35	15	lab	conven	high loading rate	19
4.82 (0.301)	21.5 (1.34)	0.18 (2.88)	55	35	30	pilot	conven	-	13

Notes on Table 12:

* Calculated from author's data
≠ lb VS/reactor
@ gm VS/reactor

1. Scale was defined as one of the following categories:

   a. laboratory
   b. pilot
   c. full-scale

2. Three types of design were considered:

   a. Conventional (CONVEN), meaning vertically placed, completely mixed, frequency of feeding often varies.
   b. Batch, meaning the reactor is loaded once only.
   c. Plug flow (PLUG), meaning horizontally placed.

Table 13: BIOGAS PRODUCTION FROM COMBINED WASTES

Material	Proportion	ft^3 biogas/lb VS_A	$\%CH_4$ of biogas
Chicken Manure [a]	100%	5.0	59.8
Chicken Manure [a] Paper Pulp	31% 69%	7.8	60.0
Chicken Manure [a] Newspaper	50% 50%	4.1	66.1
Chick Manure [a] Grass Clippings	50% 50%	5.9	68.1
Steer Manure [b]	100%	1.4	65.2
Steer Manure [b] Grass Clippings	50% 50%	4.3	51.1
Dairy Cow Manure [c]	100%	4.6	57.3
Dairy Cow Manure [c] MSW	63% 37%	4.4	55.2
MSW [d]	100%	3.78	52.1
MSW [e] Sewage Sludge	90% 10%	4.47	67.3
MSW [e] Sewage Sludge	75% 25%	5.44	48.5
Sewage Sludge [f]	100%	5.12	68

Notes:

a. Laboratory experiments by Klien, Ref. No. (23).

b. In New Alchemy Institute Newsletter 3, Ref. No. (25).

c. This study.

d. Laboratory experiments by Pfeffer and Khan, digestion at 60°C with no pre-treatment, Ref. No. (24).

e. Laboratory experiments by Swartzbaugh, et al; average of results, Ref. No. (22).

f. Reported by Meynell, Ref. No. (26).

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APPENDIX B

FEASIBILITY OF DEHYDRATING ANAEROBIC DIGESTER EFFLUENT FOR REFEEDING

(Preliminary Study)

OBJECTIVES

Refeeding animal waste is economically attractive. The refeed value of waste is higher than its soil amendment value; it does not change the quality of the manure as fertilizer, and the ultimate disposal is via the soil anyway.

The low solids concentration in the effluent from anaerobic digesters prohibits the immediate use of the sludge as a refeed or a feed-ingredient, except as a possible source of food supplement in a watering system as practiced in swine operations. (1) Thus, an economical method of decreasing the moisture content is of prime concern in refeeding anaerobically digested sludge.

The preliminary study focused on finding a low-cost filter that could be used on small and intermediate size farms in conjunction with anaerobic digesters. The moisture content should be decreased to a level where the manure can be used as a feed-ingredient or to a level where further dehydrating with other methods, such as heat treatment, would become economically feasible. Figure B1 shows the cost of drying chicken manure at different moisture contents down to 10 percent moisture. The graph indicates that removing moisture by heat treatment is extremely expensive for mixtures of high moisture content. The moisture content of anaerobically digested manure is approximately 95 percent water. Zero-20 percent moisture removal is necessary before refeeding.

PROCEDURE

Several companies were contacted for filters, but most of the products were considered too costly or were not applicable to the desired process. (Table B1) Three products were selected for further testing. These were:

1) The trommel, a rotary vacuum drum filter produced by Technical Fabricators, Incorporated, New Jersey.

2) A series of different materials for vacuum filters, produced by the Eimco Corporation from Palantine, Illinois.

3) The Kason vibroscreen from Kason Corporation, Newark, New Jersey.

Samples from the digester at Green Bay were sent to Technical Fabricators and Kason Corporation, while tests were run in Green Bay on the filters from the Eimco Corporation.

The Eimco Corporation sent an "Eimco filter test leaf kit" on which our samples were run. Two filters were feasible: Eimco filters #NY-415 and POPR-898. The testing procedure consisted of a form time, which is the time during which the filter is actually in the slurry, and a dry time, during which drying air is pulled through the formed filter cake. The cycle time is the form time plus the dry time. The form time was kept constant at one minute, while the dry time was varied (1, 14, 29, and 59 minutes were used). A dry time of more than twenty-nine minutes proved inefficient. The optimum dry time lies between 14 and 29 minutes (Table B2). The samples had a solids content or an increase of 6.6 percent. A further analysis was performed on one sample cake and its filtrate (Table B3).

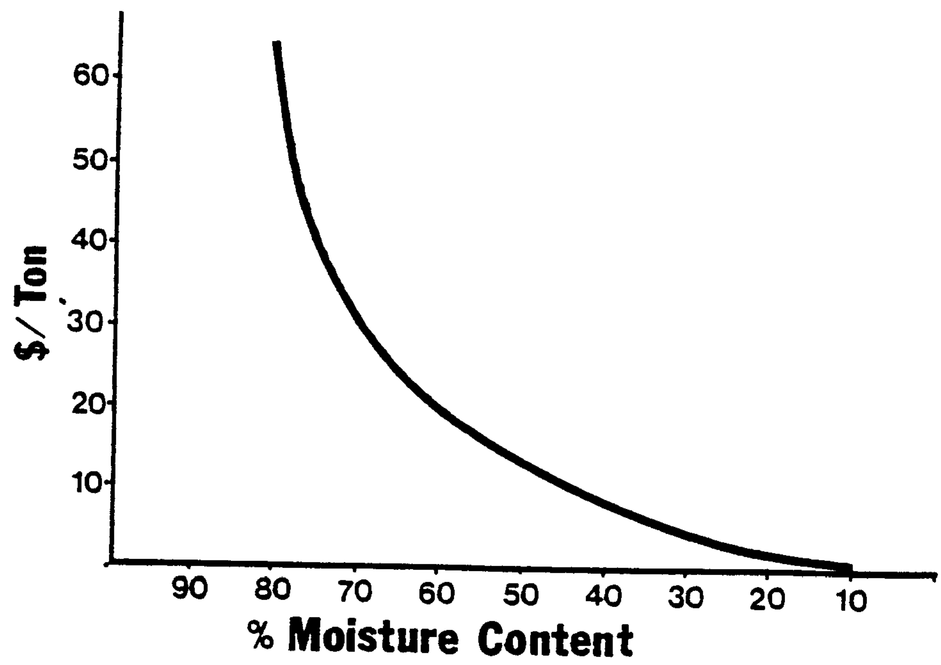
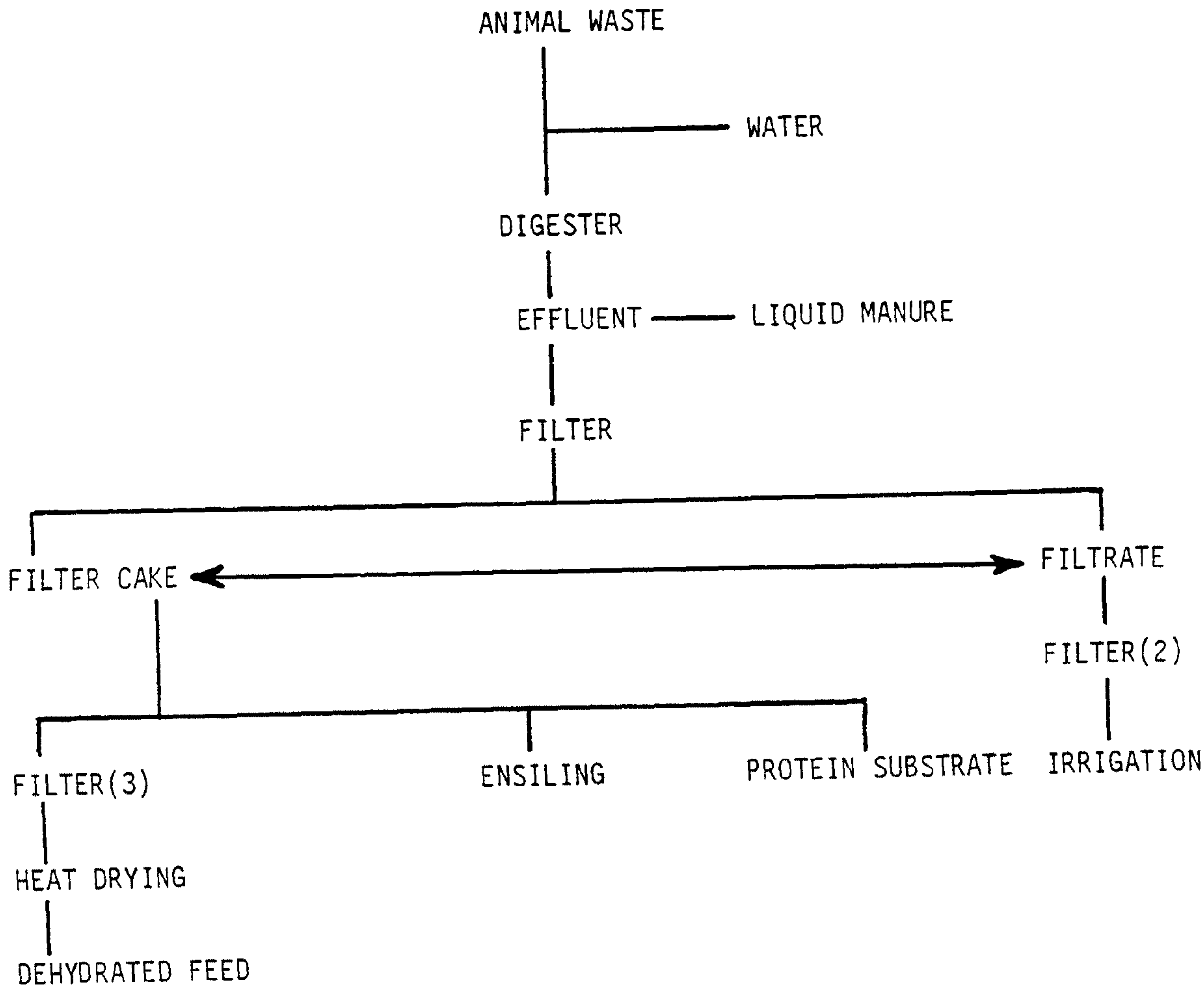


Figure B 1: Cost of drying waste at various moisture contents (heating oil at $.50/gal)

TABLE B1. COMPANIES SELLING SOLIDS CONCENTRATION EQUIPMENT

Company	Type of Equipment	Approximate Cost
Hercules, Wilmington, DE	Folcculant polymers	
C. E. Bauer, Springfield, OH	Hydrasive Screens	700-12,000
Fait-Andritz, Austria RE: Crane Corporation, Appleton, WI	Pressure filters	75,000-190,000
Industrial Filter & Pump Cicero, IL	Pressure filters	14,000-20,000
Komline Sanderson, Peopack, NJ	Rotary vacuum filter Belt press filter	25,000 40,000
Pennwalt Corporation, Sharples Division Oak Brook, IL	Decanter centrifuge	15,000-16,000
Rotex, Cincinatti, OH	Vibrating screen	3,300-4,900
Kason, Newark, NJ	Vibrating screen Cross-flow sieve	3,500 3,200
Zimpro, Rothchild, WI	Filter press Gravity thickener	
Parkson Corporation Fort Lauderdale, FL RE: Davco Incorporated, St. Paul, MN	Gravity thickener	15,000
DeLaval Separator Company Poughkeepsie, NY	Basket Centrifuges Solid bowl centrifuges	
Star Tank & Filter Company Bronx, NY	Plate and Frame filter presses	25,000
Technical Fabricators, Piscataway, NJ	Rotary drum filter (using newsprint)	20,000
Dart-Hoesch Filtration, Paramus, NJ	Pressure Filter	25,000



1. Extra cake that has to be disposed of can be mixed with the filtrate and irrigated on the field.

2. This filter may be required if the filtrate proves to have solids with a high nutritional value.

3. Further reduction of the moisture content by means of a filter or press would reduce the cost of heat drying considerably.

FIGURE B2: POSSIBILITIES FOR USING EFFLUENT AS REFEED

TABLE B2: LEAR FILTER TEST DATA (EIMCO CORPORATION)

#Eimco Filter#	Thread count	Form time (min)	Dry time (min)	Total cycle time (min)	Vacuum (in hg)	Cake Formation ($lbs/hr/ft^2$) Wet Solids	Dry Solids	Filtrate Formation rate ($lbs/hr/ft^2$)
1 NY-415	40x40	1	29	30	11	1.1	0.15	0.19
2 NY-415	40x40	1	59	60	11	0.55	0.075	0.11
3 POPR-898	24x21	1	29	30	11	1.3	0.15	0.20
4 POPR-898	24x21	1	59	60	11	0.62	0.085	0.082
5 NY-415	40x40	1	29	30	15	0.95	0.13	0.21

Note 1: Doubling the total cycle time from 30 minutes to 60 decreases the rate of formation by about half.

Note 2: Several other filters were used but these did not work. These were -PO-808 with thread count, 40x23 -POPR-859 withhthread count, 68x30 -POPR-907 with thread count. 68x29 -PO-808Hf with thread count 48x30

TABLE B3: ANALYSIS OF SAMPLE CAKE AND FILTRATE (EIMCO LEAF FILTER)

	Cake	Filtrate
% Solids	13.6%	2.9%
% Volatile solids of total solids	80.0%	64.3%
% Volatile solids of total sample	10.9%	1.86%
% Fixed solids	2.72%	1.04%
% Total nitrogen	.36%	.17%
% Ammonia nitrogen	---	

Note that the filtrate still contains 2.9% solids.

Samples were sent to the Kason Corporation in order to run tests with their vibroscreen filter. The report is attached. The returned samples were then analyzed in the Green Bay Labs. (See Table B4)

TABLE B4. ANALYSIS OF VIBROSCREENED FILTER SAMPLE

(KASON CORPORATION)

	Unfiltered Sample	Recovered Solids	Filtrate
% Total Nitrogen	.22%	3.32%	.20%
% Crude protein	1.37%	2.08%	1.26%
Mg/1 Ammonia Nitrogen	885.		920.
% Solids	6.66%	13.6%	3.44%
% Volatile Solids of total solids	78.23%	84.1%	65.4%
% Fixed Solids of total solids	21.77%	15.9%	34.6%
% Volatile Solids of Total Sample weight	5.21%	11.4	2.23%
% Fixed solids of Total Sample Wieght	1.45%	2,16%	1.19%

A separate analysis of a sample showed a solids concentration of 16.4%.

CONCLUSIONS

The results indicate that the use of filters could reduce the moisture content from 95 percent to 85 percent. This is equivalent to the moisture content of raw manure. Reviewing the literature on use of manure as a refeed indicated that the nutritional value of the effluent is lower than the value for whole manure.[3] A more concentrated effluent (less moisture) may be desirable in order to obtain similar feeding value in the same volume. Figure B2 shows various possibilities of using the effluent as a refeed.

The effluent from an anaerobic digester contains about 95 percent moisture. The effluent can be used directly in the aqueous phase of a liquid manure feeding system, as was done with swine manure from an oxidation ditch at the University of Illinois by Harmon.[4] He noted that both gain and efficiency values were significantly greater for pigs receiving the manure, but he also stated that nutrient intake cannot be greatly reduced because the liquid manure is 95 percent water. (Aeration probably would be required before refeeding anaerobic digester effluent.)

Running the effluent through a filter would give two products: a filter cake, containing about 85 percent moisture, and a filtrate containing about 97 percent moisture. It may be important to investigate the refeeding value of the 3 percent solids that are still in the filtrate. Harmon noted in his report a linear increase in amino acid concentration as particle size decreases. This is the reason a second filter was suggested before irrigation in order to filter out the smaller size particles.

The filter cake is the basic product for refeeding. Filter cake that cannot be recycled can be mixed with the filtrate and disposed of through irrigation. The filter cake has approximately the same moisture content as manure, depending on the efficiency of the filtering process. Therefore, literature on recycling straight manure can be used to find an optimum system.

On the other hand, previous studies indicated a lower nutritional value for effluent compared to the influent (straight manure plus water) so that some modifications will be necessary. The filter cake can be used in various ways but three possibilities were selected here.

One possibility is to further dehydrate the filter cake in order to obtain a dehydrated feed. Heat drying is an expensive method, unless a readily available and cheap source of energy such as waste heat from the digester or solar heat can be applied. Filtering or pressing before heat drying may also prove to be economically sound. The cost of dehydration between 85 percent and 70 percent is still very high. Heat treatment, however, has some major advantages. The process assures the removal of pathogens and the product has a higher chance of being accepted by the FDA as a feed ingredient. The dehydrated feed could be packaged for sale on the market.

Ensiling of whole manure has been extensively studied by Dr. W. B. Anthony at the Auburn University in Alabama. According to Anthony, ensiling raw manure is the most promising way of recycling. It may also prove to be the most effective way of refeeding digester effluent. Anthony see six major advantages in ensiling:(5)

1. All the nutritive value in the waste is retained for feeding.

2. Ensiling is an effective process for eliminating pathogenic organisms such as Salmonella and parasitic nematodes. There is also a reduction in the number of Coliform bacteria.

3. It materially improves the esthetic aspect of using waste as a livestock refeed.

4. Ensiling offers an important aid in pollution abatement.

5. It requires no major investment in facilities. Ensiling is the lowest cost treatment process currently available.

6. Ensiling proves to be applicable to small and intermediate size operations.

The filter cake could also be used as a substrate for protein production by both unicellular organisms and invertebrates (algae, yeasts, fungi, mixed cultures of microorganisms, housefly larvae and earthworms.)

The algae are the most efficient in converting the manure into usable feed-grade protein. Drawbacks in algal recovery systems include: The amount of space required to process large amounts of manure, the apparent high capital outlay to establish the systems and the climatic and topographic limitations on pond function and location. The technology is feasible however, and if adequate markets for algal protein could be established, this approach may ultimately be practical in geographic locations that allow year-round operation of ponds.(6)

The immediate future of anaerobic digesters is largely dependent on benefits other than the methane gas. Our preliminary study indicates that the effluent from anaerobic digesters can be effectively dehydrated with filters to a level where its moisture content is about equal to the moisture content of raw manure. This opens up a multitude of possibilities for the use of the filter cake as a refeed or feed-ingredient.

Further research is needed in order to determine the effect of the digestion process on the effluent, and to determine the nutritional value in the filter cake as well as in the filtrate. The possibility that a significant amount of nutrient is lost in the filtrate needs to be explored and related to the cost effectiveness of centrifugation or other recovery options.

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3. Previous study under this grant on amino acid availability in the effluent compared to the availability in the influent.

4. See 1

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APPEMDIX C

COMPARISON BETWEEN INFLUENT AND EFFLUENT OF ANAEROBIC DIGESTERS AS REFEED

Bacterial growth and methane formation alter the composition of manure during anaerobic digestion and have an effect on the refeeding value of the manure.

A preliminary study was conducted at UW-Green Bay in order to determine the extent of this change in nutritive value. The study consists of two parts. The first part is a rough determination of the composition and the second is a more in-depth study on the amino acid content.

PROCEDURE

Four samples were collected from the UWGB digester that was running on dairy cow manure. These four samples were used for every analysis described in this study. Samples A and B are the influent and effluent collected on July 11, 1977. Samples C and D are the influent and effluent collected on July 18, 1977.

The influents A and C are compared to the effluents B and D.

Nutritive Composition--

A rough nutritive analysis consisted of the determination of the ash, crude protein, fat and carbohydrate contents on a dry weight basis. Ash or mineral content was determined by igniting the dried samples for two hours at 600°C.

Crude protein was obtained from the Kjeldahl Nitrogen method. Fat content was determined through an ether extraction in an Soxhlet apparatus for 20 hours. The carbohydrate content was calculated by adding up the ash, crude protein, and fat content and subtracting this total from 100 percent.

TABLE C1. NUTRITIVE ANALYSIS OF SAMPLES

	INFLUENT A	EFFLUENT B	INFLUENT C	EFFLUENT D
Ash	25.0	21.8	22.0	23.1
Crude Protein	10.3	11.4	11.2	12.0
Fat	2.2	1.5	2.5	1.1
Carbohydrate	62.5	65.3	64.3	63.8

Table C1 suggests that a decrease in fat content and an increase in crude protein may be expected. The impact that this may have on the refeeding value should be explored further. The protein percentage seems quite low. Optimum percent of ration of protein in feed for growing chickens and turkeys is 16 and 20 percent, and even higher for starting poultry. (1)

Amino Acids--

Proteins are polymerized units of amino acids which vary in relative amounts and sometimes in kind from protein to protein. These amino acids are obtained as the hydrolytic end products when proteins are boiled for many hours with strong acids, or, when they are acted upon by certain enzymes. They are also the end products of protein upon digestion, and the building stones from which body protein is made, as well as intermediary products in protein catabolism. (2)

A total amino acid analysis and two enzyme analyses were run on our samples. (3) The total amino acid analysis (T.A.A.) indicate the availability of the specific amino acids. The latter is thus, more important in determining the value as a feed.

Total Amino Acid--One T.A.A. analysis was run on each sample. The samples were nitrogen-purged before analysis. The results are shown in Table C2. The results do not indicate a difinite trend. Columns 5 and 6 are the averages of the influent and effluent samples respectively. These results can be compared with data for either feeds. In our study, we included the analysis for essential amino acids from alfalfa and cornmeal. (4) The results of the manure samples, both for the influent and the effluent, are in a similar range.

Enzyme Amino Acid--The chemical changes within the digester may cause the amino acids to be less available in intestinal digestion. A pepsin pancreatin digest index of protein quality evaluation (5) was used to determine the extent of the change in availability.

The Table C3 contains the results for these analyses. Each sample was analyzed twice (A_1, A_2).

Run I may contain an inaccuracy of about 10 percent because the sample was not brought up to volume before final analysis.

Sample B_2 had been fat extracted and this may have caused the amino acids to be available than the nontreated sample

TABLE C2. TOTAL AMINO ACIDS IN INFLUENT/EFFLUENT SAMPLE

	A	B	C	D	Influent A+C/2	Effluent B+D/2	Alfalfa	Cornmeal
Aspartic Acid (ASP)	.93	.96	.86	1.08	.90	1.02		
Threonine (THR)	.46	.48	.48	.56	.56	.52	.62	.34
Serine (SER)	.40	.42	.43	.48	.42	.45		
Glutamic Acid (GLU)	1.16	1.15	1.16	1.31	1.16	1.23		
Proline (PRO)	.57	.46	.42	.53	.50	.50		
Glycine (GLY)	.55	.59	.53	.65	.54	.62		
Alanine (ALA)	.66	.67	.68	.78	.67	.73		
Valine (VAL)	.53	.46	.45	.60	.49	.53	.72	.41
Methionine (MET)	.24	.24	.20	.27	.22	.26	.13	.12
Isoleucine (ILE)	.46	.48	.47	.55	.47	.52	.96	.41
Leucine (LEU)	.71	.79	.77	.85	.74	.82	1.10	1.03
Tyrosine (TYR)	.35	.23	.17	.43	.26	.33		
Phenylaline (PHE)	.51	.46	.40	.77	.46	.62	.65	.38
Lysine (LYS)	.57	.55	.59	.60	.58	.58	1.08	.32
Histidine (HIS)	.17	.19	.18	.18	.18	.19	.25	.23
Arginine (ARG)	.31	.35	.38	.36	.35	.36	.76	.40
Total	8.58	8.48	8.17	10.0	8.41	9.28		
NH_3	.31	.32	.30	.36				
$+NH_3$	8.89	8.80	8.47	10.36				
Nitrogen					1.72	1.87	2.49	1.53

Data are on a weight over weight basis and expressed as %. (w/w x 100)
Tryptophan was not analyzed for.

TABLE C3: CONCENTRATION IN (W/W x 100) OF 8 runs.

Asp	.56	.35	.28	.11	.39	.34	.23	.10
Thr	.23	.11	.09	.09	.13	.23	.04	/
Ser	.26	.13	.18	.08	.15	.27	.07	.02
Glu	.74	.46	.21	.19	.43	.84	.30	.11
Pro	.05	.06	.17	/	.05	.44	.09	.47
Gly	.16	.09	.21	.11	.11	.26	.08	.63
Ala	.53	.33	.41	.26	.29	.74	.19	.96
Val	.51	.26	.19	.18	.24	.55	.16	.46
Met	.20	.13	.06	.21	.11	.42	.04	.18
Ile	.41	.22	.12	.18	.17	.54	.09	.25
Lev	1.07	.59	.40	.48	.63	1.22	.33	.48
Tyr	.47	.43	.29	.50	.25	.88	.13	.63
Phe	.49	.37	.27	.39	.34	.77	.21	.54
Lys	.65	.22	.27	.36	.35	1.12	.19	.05
His	.05	/	/	/	/	/	/	/
Arg	.43	.36	.14	.29	.25	.36	.05	/
Total	6.81	4.11	3.29	3.42	3.89	8.98	2.2	4.88

The standard for run 2 gave erroneous results that had to be discarded although the samples gave acceptable results.

Table C4 takes an overview of the results. Column 1 and 2 contain the sum of all the influent and effluent samples. Columns 3 and 4 divide this total by four in order to obtain an average concentration for the influent and effluent.

The total of these columns indicate that the amino acids are less available in the effluent than in the influent. (5.97 percent vs. 3.46 percent) Column 7 compares the availability of the effluent and influent for each amino acid. Only two amino acids, proline and glycine seem to be more available in the effluent. Overall, the amino acids in the effluent have an availability that is about 65 percent the availability in the influent.

Columns 5 and 6 compare E.A.A. vs. T.A.A. (the averages). The enzyme analysis for the influent recovers about 80 percent of the total amino acids present, while there is about a 42 percent recovery for the effluent. Note that the enzyme analysis releases about twice as much tyrosine as the TAA. This seems incorrect at first, but it is possible that tyrosine is formed during the enzyme analyses.

TABLE C4: OVERVIEW OF RESULTS FROM AMINO ACID STUDY

	INFL $A_1+A_2+C_1+C_2$	EFFL $B_1+B_2+D_1+D_2$	Infl Avg	Effl Avg	(Enz x 100 INFL Total	Enz x 100 EFFL Total	Effl x 100 = Infl)
ASP	1.64	.72	.41	.18	45.6	17.6	43.9
THR	.7	.22	.18	.06	38.3	11.5	33.3
SER	.81	.35	.20	.09	47.6	20.0	45.0
GLU	2.47	.81	.62	.20	53.4	16.3	32.3
PRO	.60	.73	.15	.18	30.0	36.0	120.0
GLY	.62	1.03	.16	.26	29.6	41.9	162.5
ALA	1.89	1.82	.47	.46	70.1	63.0	97.9
VAL	1.56	.99	.39	.25	79.6	47.2	64.1
MET	.86	.49	.22	.12	100.0	46.2	54.5
ILE	1.34	.64	.34	.11	72.3	30.8	47.1
LEV	3.51	1.69	.88	.42	119.0	51.2	47.7
TYR	2.03	1.55	.51	.39	196.1	118.2	76.5
PHE	1.97	1.41	.49	.35	106.5	56.5	71.4
LYS	2.34	.87	.59	.22	101.7	37.9	37.3
HIS	.05	--	.01	--	----	----	----
ARG	1.40	.68	.35	.12	100.0	33.3	34.3
		TOTAL	5.97	3.46	E=1189.8 x = 79.3	E = 627.6 x = 41.8	x = 64.5%

An observation from Table C3 is that there are a few amino acids that are higher in the influent for all cases. Comparing A_1 with B_1, A_2 with B_2, C with D, and C_2 with D_2, we find that the following amino acids are always higher in the influent:

Aspartic acid and Glutamic acid;
Threonine, valine, isoleucine and leucine.

It is interesting to see that both acids are present and that all the other amino acids belong to the monoaminomonocarboxylic acids and that they are more complex compounds of this group.

Iscoeucine, leucine, threonine and valine are considered essential amino acids in animal feeds. This may be important in evaluating the difference in availability between influent and effluent.

No amino acids are lower in the influent for all cases.

DISCUSSION

Our pilot study indicates that the amino acids may be less available in the effluent and therefore the effluent may be considered a lower quality refeed. It may suggest that the amino acids in the effluent may be part of the bacterial cell more than in the influent, and that the cell wall resists the enzymatic hydrolysis.

It would be interesting to treat the effluent in order to recapture the cell walls and investigate whether the amino acids are more available after the treatment.

In vitro analyses indicate a lower quality refeed but actual refeeding will reveal more about the quality of the effluent and the influent.

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Appendix D

THE FEASIBILITY OF INCREASING METHANE GAS PRODUCTION FROM ANAEROBIC DIGESTERS VIA HYDROGEN PRODUCING ALGAE

INTRODUCTION

The intent of this study is to investigate the potential for increasing methane production from an anaerobic digester algal system. Our purpose here is to increase the volume of methane gas produced for a given volume of manure introduced into the digester. This could considerably increase the economic feasibility of anaerobic digesters for small-midsize dairy farms.

At the present time we can suggest investigations into two alternatives which couple the anaerobic and hydrogen producing algal systems symbiotically. With one alternative hydrogen producing algae would be introduced directly into the anaerobic digester, where any hydrogen evolved would be used by methanogenic bacteria in the formation of methane. This relationship has been observed by J.W. Czerkawski et. al. (1971). He found that introduction of hydrogen into the gas phase of an artificial rumen, essentially an anaerobic digester, increased methane production directly in proportion to the amount of hydrogen added. This relationship is graphically displayed in Figure D1.

However, whether an anaerobic digester provides a suitable environment for hydrogen production from algae is yet to be determined and will comprise the main focus of this study.

Another alternative system would consist of introducing hydrogen producing algae into an anaerobic container separate from the digester, which provides an optimum environment for hydrogen production. The hydrogen produced within this container could then be pumped into the anaerobic digester to be used by the methanogenic bacteria, or simply mixed with the methane gas to be burned directly.

HYDROGEN PRODUCTION EXPERIMENTS

Choosing the Algae

Choosing a specific type of algae for purposes of experimentation was essentially a choice between greens and blue-greens, since all research we

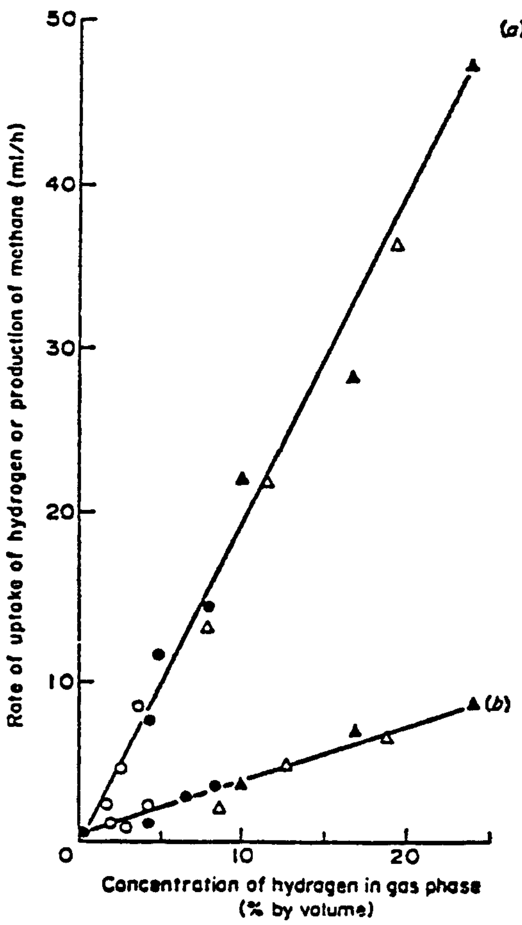


FIG. 1. Relationships between the concentration of H in the gas phase and (a) the rate of uptake of H and (b) the rate of production of methane by strained rumen contents. Results were obtained from the experiment summarized in Table 1. Initial volumes of H (ml/vessel) were: (○), 35; (●), 86; (△) 197; (▲), 256.

FIGURE D1: HYDROGEN AND RUMEN METHANE PRODUCTION

could find was directed to one or the other. In the beginning of the study we decided to work with both greens and blue-greens. However, due to time constraints, we were forced to specialize. We chose green algae for a number of reasons: (1) we were interested in adding algae directly into the anaerobic digester for two reasons; a) if it worked, this seemed like the most efficient arrangement; b) past studies have shown hydrogenase-containing algae to produce H_2 in nitrogen, argon, and helium atmospheres. We wanted to see what would happen in a methane atmosphere. Blue-greens are known to produce H_2 and O_2 simultaneously, however, methanogenic bacteria within the digester are inhibited by the slightest amount of O_2. Green algae produce only hydrogen and some CO_2. (2) blue-green algae produce the greatest amount of hydrogen at high light intensities, therefore, they would be severely limited within a digester due to the opaqueness of the digesting medium. Green algae are known to produce hydrogen in the dark. (3) when considering the production of hydrogen in a separate container, again we saw a problem with blue-greens. Because blue-greens produce O_2 and H_2 simultaneously, separation of the O_2 from the gas would be necessary before piping into an anaerobic digester. Gas produced from green algae could be piped directly into the digester.

These reasons for choosing green algae in no way preclude future studies with blue-greens. Blue-greens have been shown to produce hydrogen in quantities eight times greater than that of green algae. We were not aware of this information at the time of our choosing.

The green algal species used in the following experiments is Scenedesmus obliquus. We chose this species because it was available and also the most widely studied in the literature.

Hydrogen Experiments

A number of experiments have been designed to investigate the potential of the digester-algosystems mentioned briefly in the introduction, and more specifically in Section V. These experiments will take place during the course of the summer.

Experiment 1: materials and methods

Scenedesmus obliquus algae will be introduced directly into lab anaerobic digesters to investigate the change they might cause on methane production. The lab digesters will be described in detail at the end of the hydrogen production section. The procedure and conditions for the experiment are listed.

1) There will be eight lab anaerobic digesters all operating at 35 C and using equal volumes of cow manure as a substrate. By treating each digester the same we hope to attain a low variance in gas production rates between all the digesters. We will attempt stabilization of the digesters at a 20-day retention time. The mixing rate is yet to be determined.

2) A mixture of cow manure and algae will be added to four of these digesters, at a rate to be determined from experiment (3). The other four digesters will act as a control group, and each digester will have a history for use as a comparison. The algae to be used in this experiment will be cultured in manure substrate medium.

3) The quantity and composition of gas will be measured regularly, using gas chromatography techniques. Primary emphasis will be directed to measuring methane increases, since the hydrogen is theoretically converted to methane via anaerobic microbes. However, we do have hydrogen analyzing equipment, and this will be used to measure hydrogen in the gas, first by spot checks, and then, if necessary, regular measurement will ensue.

Discussion of Experiment 1

It is important to discuss how we hope to determine any change in gas production with statistical significance, and what this would mean if a change did occur. For purposes of statistical significance we hope to stabilize the digesters to a point where we can predict, within a few mls, the quantity and composition of gas which each digester will produce with respect to itself over time. The digesters will then be compared to each other for gas composition and quantity. However, if we do find changes in quantity and composition of the gas, this does not with any certainty, indicate that hydrogen from the algae has caused this change. For example, it may simply be the result of gas production from the decomposition of the algae within the digester. Studies by Golueke C.G. et al (1957) found that anaerobic digestion of a mixed culture of Scenedesmus and Chlorella algal species produced two to four cubic feet per pound of volatile matter less than anaerobically digested raw sludge. The percentage of methane was, however, similar. Therefore, with this information, it appears that a gas production increase would most likely be a result of hydrogen conversion to methane. However, more information would be necessary before any tight conclusions are attempted.

We could also look at the composition of the gas production. If the relative concentration of methane increases, this might be due to increased hydrogen in the gas phase. Smith P.N., et al (1976), found that hydrogen and carbon dioxide were very rapidly converted to methane during anaerobic digestion of organic molecules. This could effectively decrease the relative composition of carbon dioxide in the gas phase. This would show a relative methane increase. However, Smith also found that methane formation from other substrates was decreased during the formation of methane via hydrogen. This might decrease the relative methane concentration, Czerkawski I.W. (1972), found that increased hydrogen in the gas phase of an anaerobic digester directly increased methane production. This might suggest that, even though methane formation from other substances is decreased, the amount decreased is small relative to the amount produced from the hydrogen added (see figure 1). Clearly, there is considerable difficulty in the analysis of where the gas production changes are coming from. Experiments 3 and 4 will be designed to deal with this puzzle.

Experiment 2

This experiment will be set up in essentially the same manner as experiment 1. The only difference will be the introduction of hydrogen gas into the digester instead of algae. This experiment could give us some indication of what happens with the direct introduction of hydrogen in the digester. The technique for introduction, or the amount of hydrogen to be introduced, have not yet been determined.

Experiment 3

This experiment will also be set up essentially the same as experiment 1. The difference will be the control group. Known non-hydrogen producing algae will be added to four digesters for use as a control group. Hydrogen producing algae will be added to the other four digesters. Equal amounts of algal biomass will be added to each digester. The main difficulty we perceive with this experiment is getting a non-hydrogen producing algal species similar enough in chemical makeup to the hydrogen producing algae, so both species have similar decomposition characteristics.

From this experiment we hope to gain insight as to whether any changes in methane production are a result of hydrogen production, or just fermentation. This experiment will probably not occur this summer simply because experiments 1, 2, and 4, are of higher priority, and will most likely take up all available time.

Experiment 4

This experiment will investigate the hydrogen producing potential of Scenedesmus obliquus in varied conditions of lighting, temperature, and in different mediums. The purpose for this experiment will be to (1) show us whether the algal species we have actually produce hydrogen, (2) what concentrations of algae we should add to the digesters in experiment 1 to obtain results, and (3) how these algae produce hydrogen in varied conditions of light and temperature, and culture medium.

In this experiment, various concentrations of algae will be introduced into containers with various mediums. These mediums will be described later. The atmosphere within the container will then be filled with nitrogen gas or argon to provide an anaerobic environment. Various light intensities and mixing rates will be applied.

As discussed in section 2, light is an important variable in determining hydrogen production rates. Mixing will be used with light experiments to maximize the exposure of algae to light in the dark manure based medium. Temperature is also an important variable in hydrogen production from algae. A temperature of 35°C will be used as a basis for comparison to an anaerobic digester system which is also at 35°C. Experiments will also be run at 25°C for comparison. Temperature control will be accomplished with a water bath.

Pressure change will be measured with a manometer. Gas composition will be measured with gas chromatography. The quantity of gas produced will be determined by relating the manometer pressure to the volume of air space within the container. Figure D2 is a sketch of this system.

Two different test mediums will be used: (1) Cow manure taken from an active anaerobic digester; this will give us some indication of what will happen when adding hydrogen producing algae to the digester, and (2) buffered water, since this is the most widely used test medium in the literature. From this we can compare the gas production we get to that of experiments already undertaken with similar conditions. In this way we can test our technique. We can then compare results from this test medium to those of the digester effluent medium. Note: a blank will be set up every time a test medium is used.

Description of Systems Operation

The digesters are of the continuous feed type. Digested manure is first removed from the feed tube with a largemouth 10ml pipette. An equal amount of raw manure is introduced. Presently, the digesters are fed 5ml per day. We will increase feeding rate gradually until we reach a 20-day retention time. The digesters are presently mixed for 12 minutes every four hours, with magnetic stirrers operated by an electric timing device.

As gas is produced, it flows in the direction of the orange lines as shown, the pressure within the digester is checked by a manometer. Once the gas flows through the test tube, it is cut off from the digester atmosphere. The purpose of this is to allow measurement of the composition changes within the digester. For example, if the atmosphere in the gallon bottle was not cut off from the atmosphere of the digester, all the gas would mix together and we would have no indication of the composition change. As pressure in the gallon bottle builds up, water is forced up through the water outlet tube. The pressure adjustment tube is moved up or down in the holder to increase or decrease pressure within the system. The water is adjusted daily to atmospheric pressure. The water then falls into the glass jar at atmospheric pressure and is measured daily.

These lab anaerobic digesters have been operative for approximately two months to date. During this time period we have manipulated feeding rates and mixing rates in an attempt to stabilize the system. Ideally, for purposes of experimental control, all eight digesters should be operating at the same gas production rates. The system presently shows signs of stabilizing, and we anticipate approximately one month before we can begin experiments, if this trend continues.

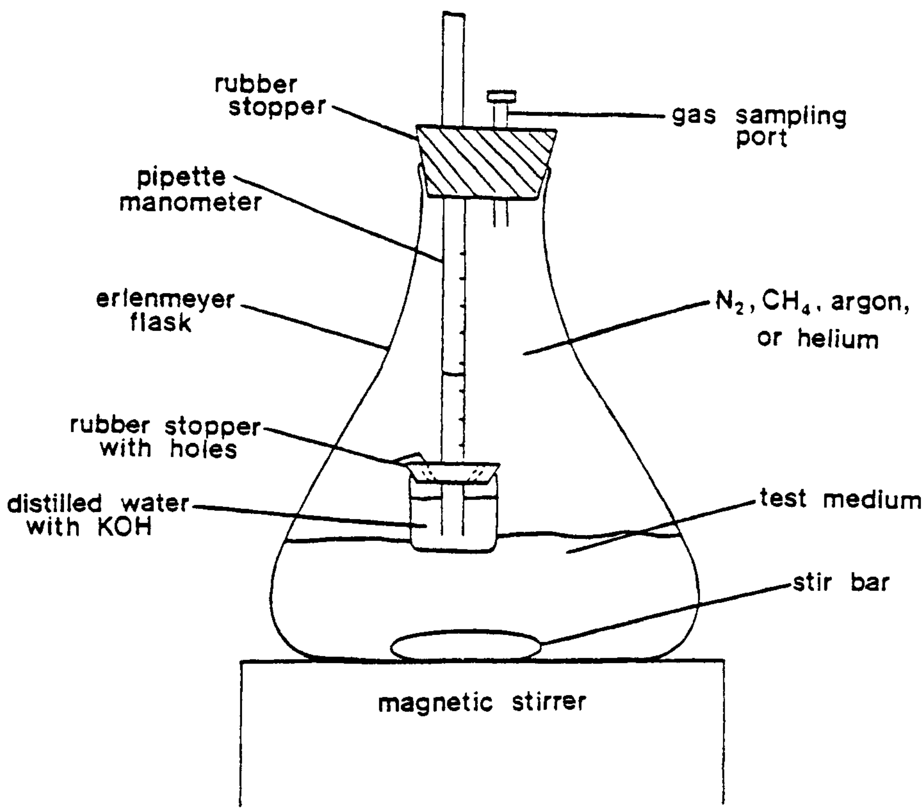


Figure D2: Schematic of laboratory digester for combined algae/manure cultures.

Lab Digesters

A series of eight anaerobic digesters were set up in a water bath and maintained at 35°C. See sketch below.

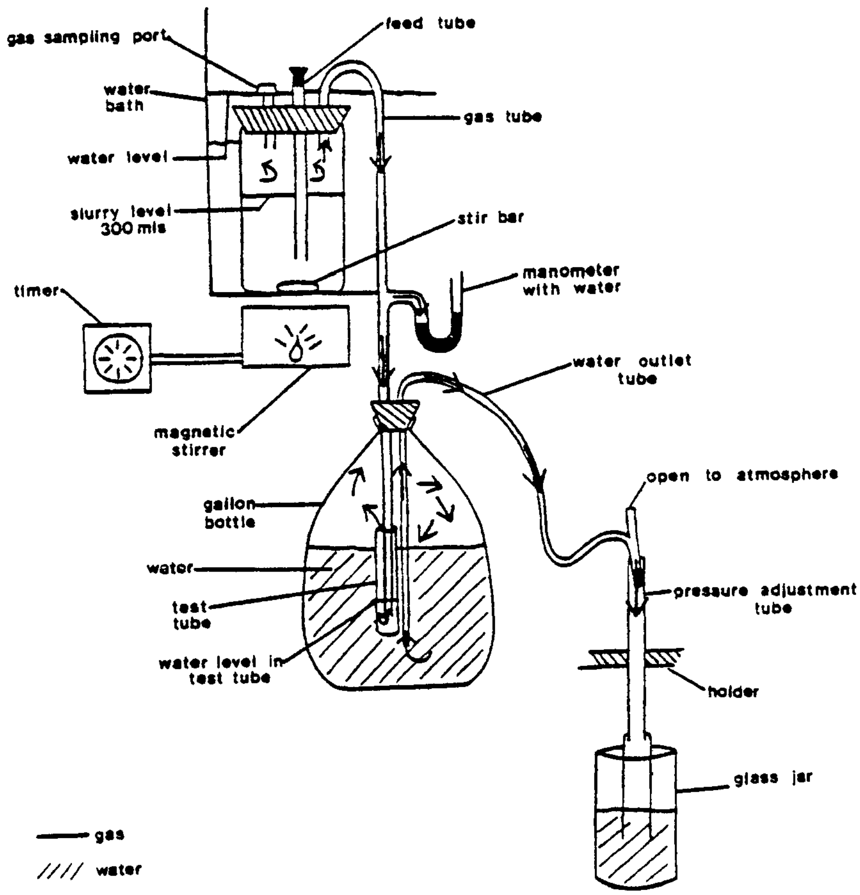


Figure D3: Schematic of gas measuring system.

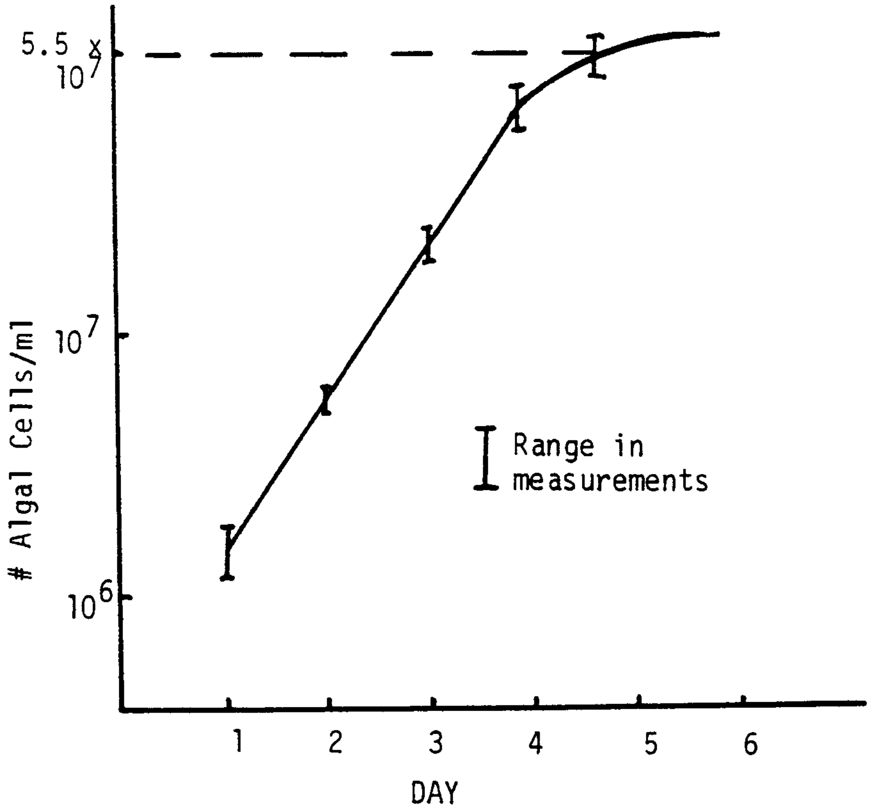
Algae Culturing Experiments

The primary focus of the algal culturing experiments was to provide cow manure grown algae for the hydrogen production experiments. Having cow manure grown algae was of high priority for purposes of adapting algae to the cow manure prior to introduction into the lab anaerobic digesters. Therefore, it was necessary to design experiments to examine the algae producing potential of the manure. These experiments were accomplished under controlled laboratory conditions and therefore are not reflective of algae grown in the natural habitat. These experiments were designed to examine the relative growth of Scenedesmus obliquus in various concentrations of manure substrates. Scenedesmus obliquus grown on a known medium was used as a control.

The following experiments are to be considered preliminary to future research in this area. In most cases these experiments are only capable of predicting a relatively subjective indication as to the nature of certain specified growth parameters for algae growth on manure substrates. These experiments were generally not repetitive enough for conclusive results.

Experiment 1 - Scenedesmus obliquus grown on TAP nutrient medium.

The average cell population/ml/day was recorded and graphed.



Experiment 2a - Scenedesmus obliquus growth on various concentrations of lagoon supernatant

Bottle 1: 90 mls of distilled water and 10 mls of lagoon supernatant
Bottle 2: 80 mls of distilled water and 20 mls of lagoon supernatant
Bottle 3: 100 mls of undiluted lagoon supernatant

(see graph following page)

FIGURE D4: AVERAGE CELL POPULATION IN EXPERIMENT 1

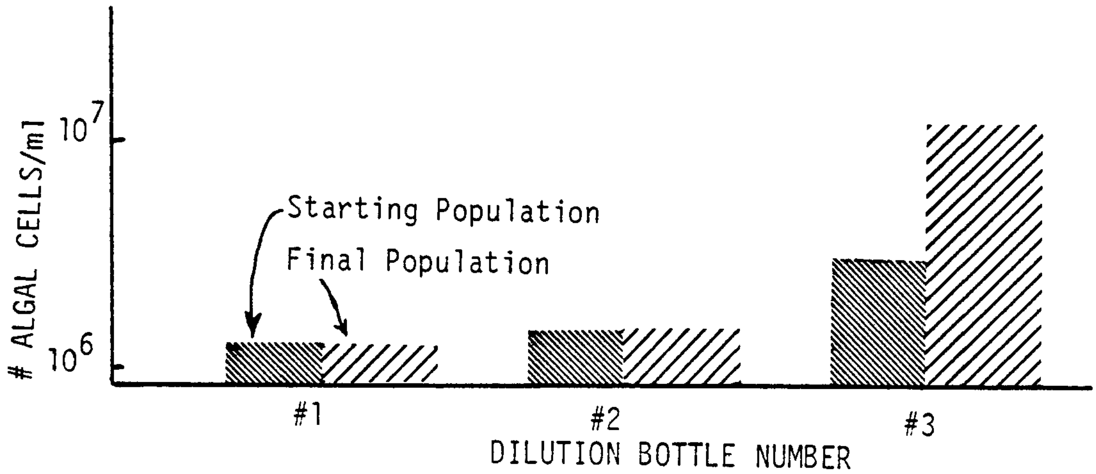


Figure D5. Results of Experiment 2a.

Experiment 2b - Scenedesmus obl. growth on undiluted lagoon supernatant with NH_4Cl added.

Bottle 1: 50 mls of undiluted lagoon supernatant + .4 gms sodium bicarbonate + .01 gms of NH4Cl.

Bottle 2: 50 mls of undiluted lagoon supernatant + .4 gms sodium bicarbonate.

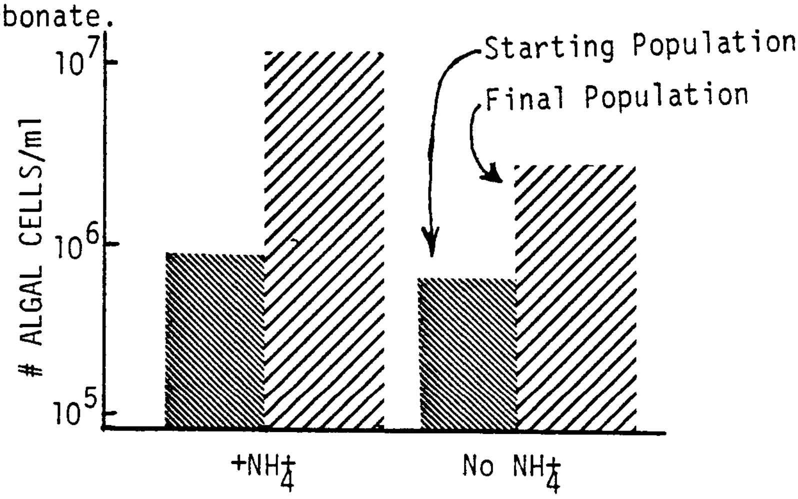


Figure D6. Results of Experiment 2b.

Experiment 3a - Scenedesmus obl. growth on low dilutions of strained anaerobic digester effluent.

Bottle 1: 25 mls of a mixture of distilled water and strained anaerobic digester effluent in proportions of 10/1, total volume of solution to total volume of effluent.

Bottle 2: 25 mls of the same mixture in proportions of 20/1.

Bottle 3: 25 mls of the same at 40/1

Bottle 4: 25 mls of the same at 80/1

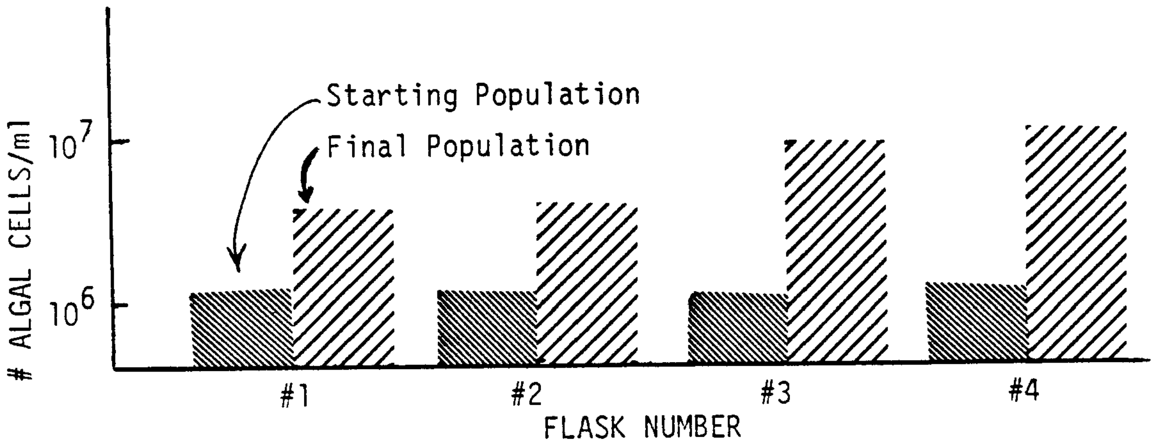


Figure D7. Results of Experiment 3a.

Experiment 3b - Scenedesmus obl. growth on high dilutions of strained anaerobic digester effluent.

Bottle 1: 50 mls of a mixture of distilled water and strained anaerobic digester effluent in proportions of 50/1, total solution to total volume of effluent.
Bottle 2: 50 mls of the same mixture at 100/1
Bottle 3: 50 mls of the same at 200/1
Bottle 4: 50 mls of the same at 400/1

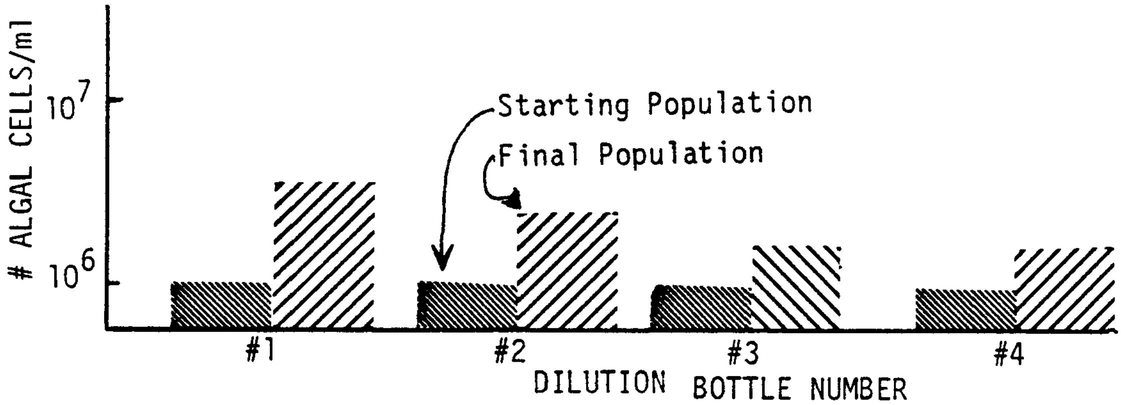


Figure D8. Results of Experiment 3b.

Experiment 3c - Scenedesmus obl. growth on strained digester effluent with NH_4Cl added.

Bottle 1: 50 mls of distilled water and anaerobic digester effluent mixture, 200/1 total solution/effluent, .4 gms of sodium bicarbonate, .01 gms of NH_4Cl.

Bottle 2: the same without the NH_4Cl.

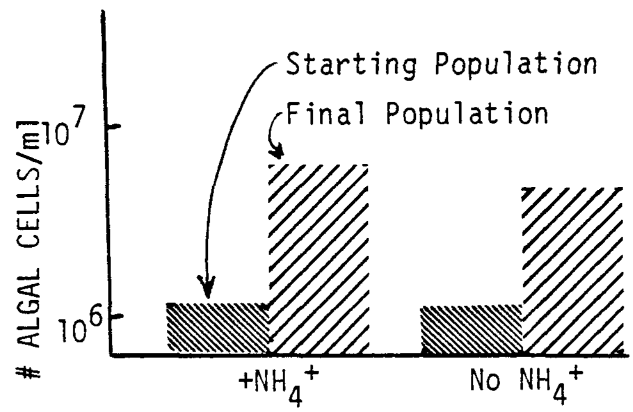


Figure D9. Results of Experiment 3c.

Discussion of Results

These preliminary results suggest that Scenedesmus obliquus algae grown on manure substrates can attain population densities on the same order of magnitude as when grown on TAP nutrient solution. For example, maximum algae cells/ml of solution counted for TAP grown algae was 5.5×10^7 in experiment 1. In experiment 3a algae grown on an 80/1 dilution of strained digester effluent, and in experiment 2a algae grown on undiluted lagoon supernatant attained populations of 1×10^7.

When NH_4 was added to the strained digester effluent in experiment 3c, no significant population increases were recorded when compared to the same medium without the NH_4 added. However, in experiment 2b, with undiluted lagoon supernatant, the greatest algal population density was attained when NH_4 was added. This might indicate that NH_4 concentrations in the lagoon supernatant may be limiting to algal growth. Chemical analysis of the lagoon supernatant have found NH_4 concentrations to vary between 15 and 46 ppm. The concentration of NH_4 in TAP nutrient medium is 200 ppm. Krauss and Thomas (1954) used 139 ppm NH_4 concentrations in the mass culture of Scenedesmus obliquus. This information clearly adds support to the observation that NH_4 added to lagoon supernatant in experiment 2b increased algae population density over supernatant with no NH_4 added. However, it is interesting to note that the maximum population density in experiment 2a with undiluted lagoon supernatant, no NH_4 added, was approximately equal to the population densities achieved in experiment 2b, with undiluted supernatant and NH_4 added. The reasons for this inconsistancy remains a puzzle. However, this fact questions the validity of the two experiments.

Extrapolations

An attempt will be made in this section to give the reader some idea of the volume of hydrogen to be expected from a one acre algae production unit. It must be noted here that all calculations will be based on optimum conditions for hydrogen production, algal culturing, and conversion efficiency.

The maximum rate of hydrogen production from green algae recorded to date has been shown to be approximately 4μl H_2/mg of dry weight/hour, or .064 cubic feet H_2/lb dry weight per hour. Peak production lasts only for a few hours, however, for the sake of simplicity we will assume algae always operate at peak production. This would require introduction of new algae into the hydrogen producing unit every few hours. For optimum conditions we will assume system 11 of the following section is used.

The amount of algae that can be produced on one acre of land using anaerobic digester effluent as a growth medium was predicted by Rowe (1976). He predicted that 28,704 pounds of algae, dry weight, could be produced during the summer season (92 days) on one acre of land. These predictions were based on algae production rates on swine manure by Boersma et al.(1975). If we assume algae are producing hydrogen for 12 hours/day in the summer, then we might expect:

$$.064 \text{ ft}^3 \text{ H}_2\text{/lb-hr} \times 28{,}704 \text{ lbs/acre} \times 12 \text{ hrs/day} = 22{,}040 \text{ ft}^3 \text{ H}_2\text{/day.}$$

or, 2.028×10^6 ft^3 of H_2 for the 92 summer days.

If we introduced this gas into a digester with 100% conversion efficiency to methane (two H_2 molecules to every one CO_2 molecule will form CH_4) then one could expect one half of 22,040 ft^3 of H_2, or 11,020 ft^3 of CH_4/day. Depending on the size of the digester this could add a significant volume of gas. However, this would only be significant if large amounts of energy are not used to produce the hydrogen. For the same biomass production rate from blue-green algae, several times this amount of hydrogen might be expected.

Total Systems Design

At the present time we have conceptualized two basic schemes for the coupling of anaerobic digestion with algal-hydrogen producing systems. System I is diagramed below.

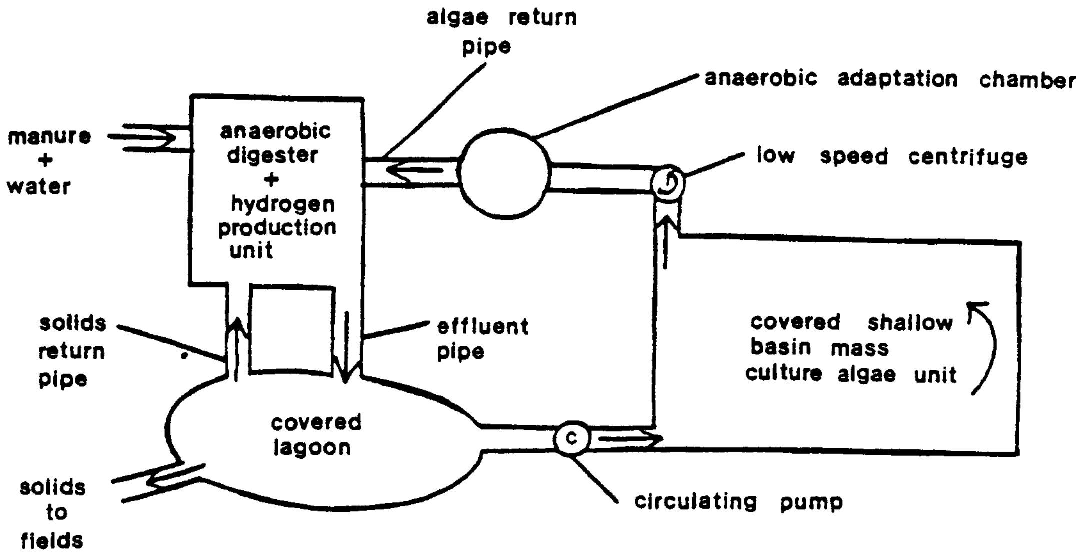


Figure D10: Total algal-digester system design with algae introduced directly into digester.

Description of System I

Cow manure is first introduced into the anaerobic digester. Digested effluent is then pumped from the digester into the covered lagoon. The lagoon is covered to prevent any NH_4^+ - NH_3 losses. In the lagoon, manure solids settle to the bottom and are either pumped back into the digester for redigestion, or hauled out to the fields. The top few feet of the lagoon is composed of a low solid algal growth sustaining liquid. This liquid will be referred to as the supernatant liquid. Algae will grow on the surface of the lagoon until sufficient population density, for mass culture, is reached. Once adequate numbers are reached the supernatant liquid is pumped into a shallow, covered, mass culture unit. During this stage of operation algae population density will reach its maximum. Algae will then be centrifuged to a liquid-paste consistency, with a low speed centrifuge, and then pumped to an anaerobic chamber to incubate. Once adapted, algae will be introduced directly into digester for hydrogen production and subsequent digestion.

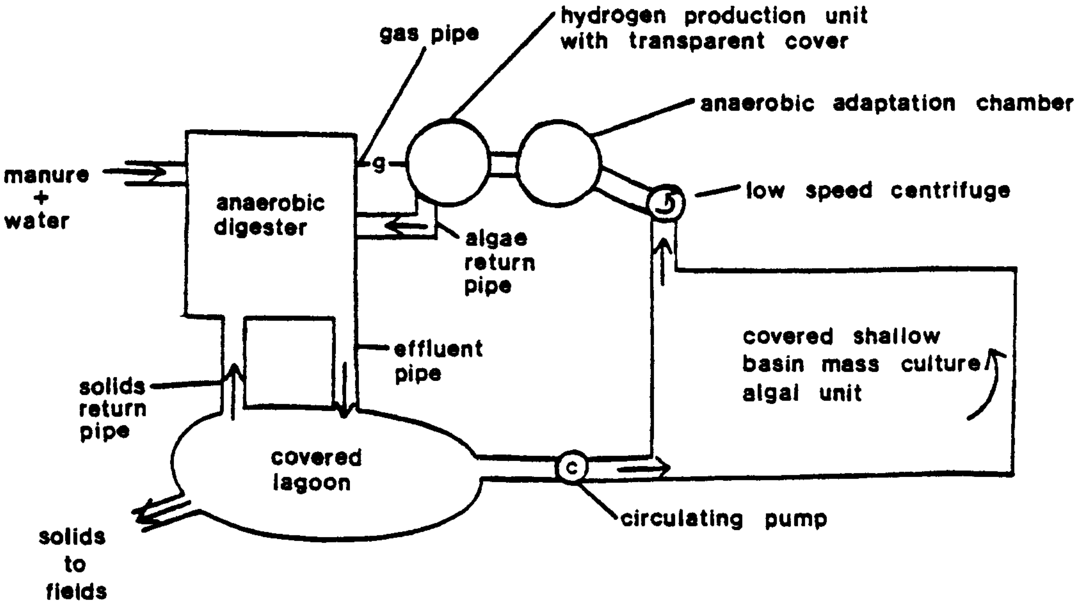


Figure D11: Total system design using separate hydrogen producing chamber.

Description of System II

This system is essentially the same as system I until we get to the hydrogen production unit. In this system algae are introduced into a separate chamber outside the anaerobic digester. In this system algae are subjected to an optimum hydrogen-producing environment. Hydrogen gas is then piped into the digester and through the digesting medium. Once algae have surpassed optimum hydrogen production levels, they are pumped into the digester to undergo anaerobic digestion.

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APPENDIX E

TABLE E1. ASSUMPTIONS USED IN ECONOMIC EVALUATIONS ANAEROBIC DIGESTERS

To show returns on energy production alone, it was assumed that:

1. A covered anaerobic lagoon exists. This was chosen as the best possible manure handling system in terms of organic nitrogen conservation. The anaerobic digester is an additional investment to the lagoon.

2. Annual capital costs are based on 9½ percent interest rates on loans to farmers.

3. Equipment maintenance and repair for equipment other than engine generators is 2 percent of the capital invested. The engine generator maintenance figures are based on manufacturers recommendations for annual maintenance and overhauls every six years.

4. Labor to operate and maintain the digester is an additional four hours per week at $3 per hour.

5. Taxes and insurance are based on 3 percent of the capital equipment costs.

6. Tax deductions from interest paid and straight line depreciation are based on amount allowable for a 30 percent tax bracket.

7. One hundred percent of the biogas is used to produce electricity or is combusted directly.

8. Annual operating costs are constant for the first 10 years, after which they rise at 3 percent per year.

TABLE E2 COSTS OF INSTALLED COMPONENTS USED IN ANAEROBIC DIGESTER SYSTEM

Fermentation Tank (25,000 gal.)	$ 5,000 - 7,000
Pumps (2 diaphragm)	1,500
Controls	1,500
Piping	1,500
Hydraulics	2,500
Building to house equipment	3,600
High pressure storage	2,000
Electrical tie in	1,500
Well	600
Boiler and heat exchanger	1,300
Gas engine-generator (12 kw)	12,000
Diesel-generator (12 kw)	15,000
Heat recovery equipment	5,000
Miscellaneous	15%
Engineering	15%

TABLE E3: ANNUAL COSTS OF DIGESTER WITH HEAT RECOVERY USING DEISEL POWERED GENERATOR

		5 YR.	10 yr.	20 yr.
Initial Investment				
Annual Capital Costs		$12,774.00	$ 7,716.00	$ 5,556.00
Operating Costs		3,245.00	3,245.00	3,245.00
Equipment Maintenance and repair	$1,174			
Labor	624			
Taxes & Insurance	1,161			
Diesel Fuel	286			
TOTAL ANNUAL COSTS		16,019.00	11,061.00	8,811.00
Annual cost per cow normalized over 20 years		67.32	74.46	91.74

TABLE E4: COSTS OF INSTALLED COMPONENTS FOR DIGESTER SYSTEM WITH DIRECT COMBUSTION OF BIOGAS ON FARM

Digester Tank		$ 5,000
Pumps		1,500
Controls		1,500
Piping		1,000
Boiler and heat exchange		1,300
Building		3,600
Miscellaneous (15%)		2,085
Engineering (15%)		2,400
	TOTAL INVESTMENT	18,385

TAB1E E5: ANNUAL COSTS OF DIRECT COMBUSTION DIGESTER

		5 year	10 year
Annual Capital Costs		$ 4,788.00	$ 2,929.00
Operating Costs		1,268.00	1,269.00
Equipment	$ 320.00		
Labor	468.00		
Tax & Insurance	480.00		
TOTAL ANNUAL COSTS		6,056.00	4,196.00
Annual Cost per cow averaged over 10 years		36.62	41.96

TABLE E6: HEAT LOSS FROM RICE LAKE FERMENTATION TANK

ASSUMPTIONS:

1) Tank temperature kept at 95 F 24 hours per day, 365 days per year.

2) Ground temperature around tank is constant 50 F year round.

3) Area of the fermentation tank is 2,036 square feet.

4) Effective U value of tank and insulation is .2 Btu/ft^2/F.

Heat loss calculation:

45 T x .2 x 24 x 365 x 2036 = 160.52 x 10^6 Btu/yr.

TABLE E7: THEORETICAL DAILY BIOGAS PRODUCTION USING DAIRY - MSW MIX*

	LBS.
Manure - MSW	9.56 x 10^3
Total Solids	1.69 x 10^3
Volatile Solids	1.29 x 10^3
Biogas production	
100% capacity	5.61 x 10^3 cf
85% capacity	4.77 x 10^3 cf
Btu output per day	2.767 x 10^6 Btu/day

100 Animal Units
85 lbs. manure/day
63% total solids -Manure
37% total solids -MSW

68% volatile solids -Manure
32% volatile solids -MSW
4.35 ch biogas/lb VS_A

*Based on 63% dairy and 37% MSW

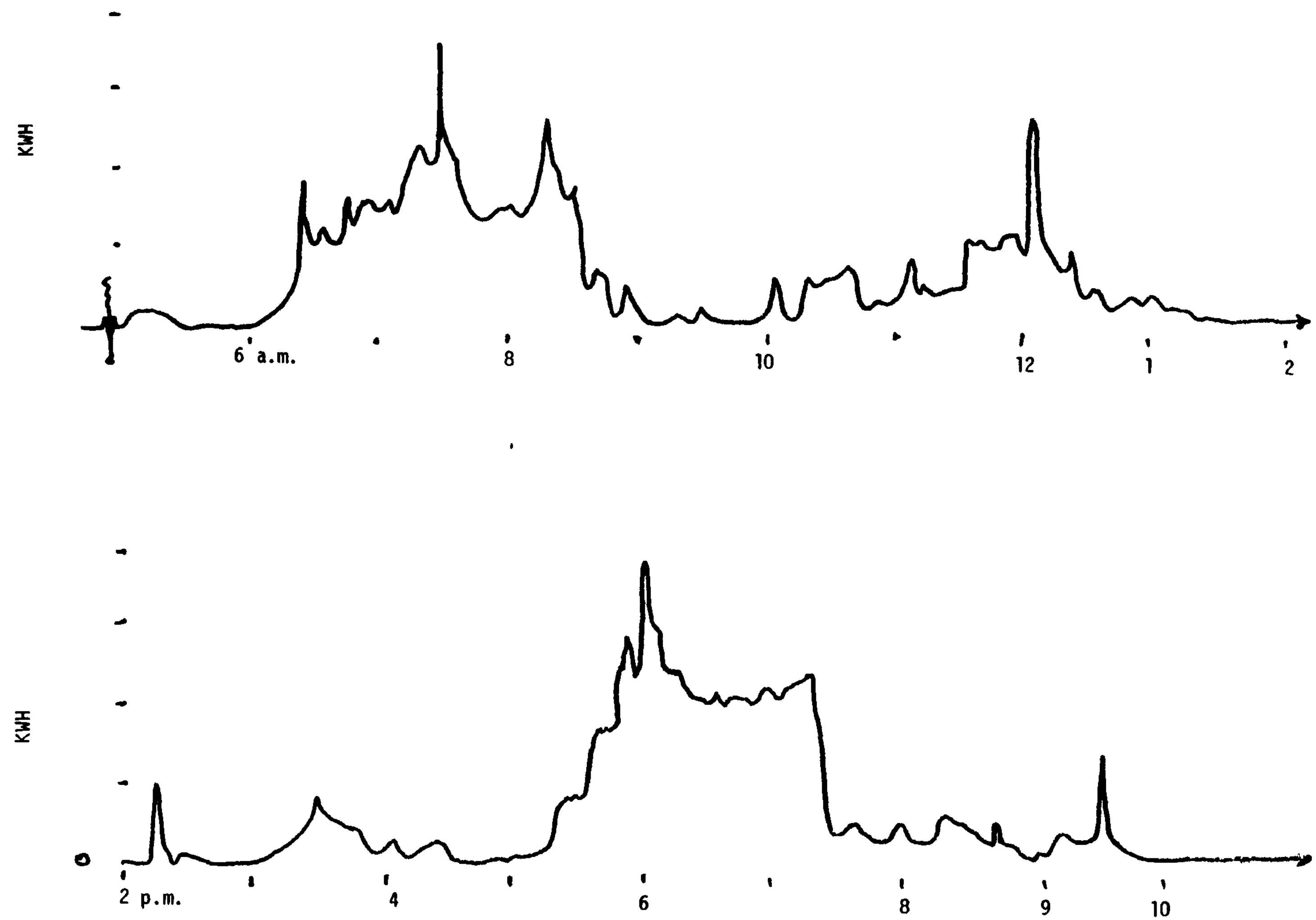

FIGURE E1. DAILY ELECTRICAL LOAD PROFILE, RICE LAKE FARM

APPENDIX F

FACTORS UNDERLYING THE ADOPTION OF AGRICULTURAL INNOVATIONS

(Factor)	(Relative importance/comment)
Cost	
1. Initial cost	Not an important deterrent
2. Continuing (operating) costs	Minor significance
Returns	
3. Rate of cost recovery	Minor significance
4. Monetary payoff	Significant
Profitability	
5. Extent of economic advantage over alternatives	Significant
6. Replacement status (condition) of existing equipment	Significant
"Efficiency"	
7. Saving of time	Minor significance
8. Saving of discomfort	Minor significance
Risk and Uncertainty	
9. Regularity of reward (Shows results every time)	Significant
10. Divisibility for trial (How easy to try; first, on a small scale)	Significant
Congruence	
11. Association with main enterprise (dairying)	Significant
12. Advantage (overall significance of the practice for the entire farm program)	Significant

13. Pervasiveness (of consequences of adoption; leads to other changes or practices)	Not an important deterrent
Communicibility	
14. Complexity (of understanding and use)	Minor Significance
15. Clarity of results (How clearly do results show?)	Minor significance
Farm Characteristics	
16. Farm size (total acreage, dairy herd size)	Significant
17. Location of farmstead (proximity to others; coop unit possibilities)	Significant
Farm Financial Position	
18. Capital (Curvilinear effect; Proxies-estimated value of land, buildings, equipment, and livestock)	Significant
19. Current income (proxies-gross farm sales, milk receipts)	Significant
Farmer Characteristics	
20. Age	Significant
21. Education	Significant
22. Tenure (owner/renter)	Significant
23. Years farmed	Significant predicator of adopting environmental measures.
24. Attitudes and values (proxies-affiliation with farm organizations, activity with social groups, contact with "science" via reading magazines and extension bulletins)	Significant
Regualtory and Legal	
25. Pollution control (manure handling rules and policy)	Significant
26. Safety requirements	Precondition
27. Zoning and land use regulations	Precondition
Institutional and Infrastructure	

28.	Availability of technical support (engineering firms, university extension)	Condition for widespread adoption
29.	Convenience of repair and maintenance services	Condition for widespread adoption
30.	Supportive (and familiarity with the innovation) farm finance and insurance sector	Condition for widespread adoption
31.	Information sources (mass media-radio, TV, newspapers and magazines; friends and neighbors-mostly other farmers; agricultural agancies-univ. ex., SCS, farm credit agencies and the like; vendors and potential suppliers)	Significant for diffusion

The factors listed above were adopted, with modifications and expansion from:

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APPENDIX G

EXISTING OR PLANNED DIGESTER OPERATIONS IN USA

LOCATION	TYPE OF INFL	TYPE	TYPE OF DIG.	OPERATION	IS GAS BEING USED	WHO BUILT THE SYSTEM
Guymon, OK (no.1)	Cattle	Full Scale 50,000 gal.	Continuous feed Complete mix, Mesophilic	yes	In-house purposes (sold to pipeline)	Thermonetics Calorific Recovery
Guymon, OK (no.2)	Cattle	Full Scale 50,000 gal.	Continuous feed, Complete mix, Mesophilic	yes	In-house purposes (sold to pipeline)	Thermonetics Calorific Recovery
Ripon, WI	Poultry	Full Scale 50,000 gal.	Continuous feed, complete mix, Mesophilic	yes	Heat House	Wayne Gibbons
Mt. Pleasant, IA McCabe Farm	Swine	Full Scale 50,000 gal.	Gas mixing	yes	No, boiler	Harold McCabe
Ames, IA State Univ.	Beef		Complete mix Mesophilic	No	No	University of Iowa
Edwall, WA	Cattle	Pilot Scale 1800 gal.	Continuous feed	No	Experimentally	Earth Cyclers
Aurora, OR	All types	Pilot Scale	Modular	No	No	David House
Hartford, NY	Cattle	Pilot scale	Plug-flow	yes	yes	Bill Jewell, Cornell
Hartford, NY	Cattle	Designed for 65 Cattle Mis	Conventional	No, in building stage	No-space heat	Bill Jewell, Cornell

APPENDIX G

PART II

LOCATION	TYPE OF INFL.	TYPE	TYPE OF DIG.	OPERATION	IS GAS BEING USED	WHO BUILT THE SYSTEM
Hartford, NY	Cattle	Designed for 65 Cattle	Plug-flow "Bage type"	no (in building stage)	No (space heating)	Bill Jewell Cornell
Dewey, IL	Poultry	Full Scale 25,000 chickens ($5x10^6$ Btu/day)	Plug-flow	no (in building stage)	No (eventually) run engine	Bill Jewell Cornell
Lancaster, PA	Poultry	Full Scale 75,000 chickens ($15x10^6$ Btu/day)	Plug-flow	no (in building stage)	Electric generator and crop dryer	Energy Recovery
Wyoming, MN Verlo Larson	Swine	Full Scale 10,000 gal	Continuous feed completely mixed	yes	Heating digester	Phil Goodrich Univ. of MN
Jefferson, WI Habeck Farm	Dairy Cattle	Full Scale 32,000 gal.	Batch load completely mixed vertical tank	no, not since 1976	Heating digester	A.O Smith Corp.
NorthGlenn, Co. Karl's Dairy Farm (owned by city of NorthGlenn)	Dairy Cattle	Full Scale 400 cows	Plug flow	no, (in design stages)	Will run generator 52 KW	Energy Harvest Schaeffer & Roland, Chicago
Monfort, CO Monfort feedlot	Dirt lot Waste	Pilot plant 110 lbs/day	continuous feed, completely mixed	yes	yes	Hamilton Standard
Bartow, FL Kaplan Feedlot	Cattle (feed lot waste)	Full Scale 570,000 gal.	Continuous or semi-continuous feed-completely mixed, thermophilic	no (in building) (in building stage)	no	Hamilton Standard

APPENDIX G

PART III

LOCATION	TYPE OF INFL.	TYPE	TYPE OF DIG.	OPERATION	IS GAS BEING USED	WHO BUILT THE SYSTEM
Arvada, CO	Cattle (feed lot)	Pilot plant 200 gal.	Plug-flow Mesophilic	yes	no	Biogas of Colorado
Lamar, CO	Cattle (feed lot manure)	Full scale 6,000 gal.	Plug-flow Mobile unit Mesophilic	yes	yes-to heat digester	Biogas of Colorado
West Union, IA Sunny Times Farm	Chicken	Full Scale 160,000 layers	Gas mixed Mesophilic	yes	yes-to heat digester and engine generator	Haeying Enterprises
Greeley, CO Miller Feed lot	Beef	Full Scale (2½ x 10^6 Btu/day)	Plug-flow	yes	heating building and hot water	Energy Recovery Inc., Aravada
Henderson, MN No. 1	Hog	Full Scale (5 x 10^6 Btu/day)	Plug flow	yes (mid April,'78)	Electric Generator	Energy Recovery Inc., Aravada
Drury, MO New Life farm	Hay/Sludge 4,000 gal.	Full Scale	Plug-flow	yes	no	Ted Landers
Custer, MI Jim Allison farm	Cattle	Full Scale 350 cattle	Plug-flow bag type	yes	yes-running 30 KW generator	Energy Harvest Shaeffer & Roland
Rice Lake, WI Schieffer Farm	Dairy Cow	Farm Scale 110 cows	Plug-flow	yes	yes-running 12 KW generator	Energy Harvest Shaeffer & Roland
Monroe, WA Monroe State Dairy Farms	Dairy cow	Full Scale designed for 350 but uses more	Complete mix system, gas recirculation	yes	yes-running generator	Ecotope Group

APPENDIX G

END

LOCATION	TYPE OF INFL.	TYPE	TYPE OF DIG.	OPERATION	IS GAS BEING USED	WHO BUILT THE SYSTEM
Clay Center, NE USDA Animal Meet Research Center	Cattle	Pilot Scale	Semi-continuous	yes	no (mainly interested in refeed	Hamilton Standard
Hastings, NE	Cattle	Lab Scale	Semi-continuous	yes	no	Dr. Andy Hashimoto
University of MO Columbia, MO	Swine	40 sow herd	concrete stave silo	yes	yes, some being used for heating	Ag. Engineering Dept of MO
University of IL Champaign-Urbana	Beef	Pilot Scale 140 gals.	completely mixed stainless steel tanks, thermophilic	yes	no	Civil Engineering
University Park PA	Dairy	100 m^3	Mixed 2 chamber mesophilic	yes	Heating digester	Penn. State University
Stillwater, MN	Poultry Human Vegetable	Homestead size	Plug-flow mesophilic	yes	cooking and heating	Rutan Research, Al, Rutan
Cardiff, CA	Sewage Sludge and water hyacinth	Pilot 200 gal	Plug-flow	yes	no	County owned water treatment facility