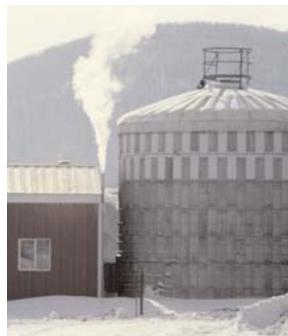


Anaerobic Digester Systems for Mid-Sized Dairy Farms



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FOR RURAL AMERICA**

EXECUTIVE SUMMARY

Six options for anaerobic digestion of animal manure on mid-sized dairy farms in Minnesota have been presented to provide dairy farm operators with information needed to make decisions about odor control and manure management technology.

Information for each option is presented with schematics of the system, an explanation of how the system functions, the environmental benefits and lessons learned from other similar digesters. Capital costs for the installation of the digesters and yearly costs are presented. The expected benefits from odor control and use of separated solids are presented for a 100-cow dairy. Scale up information for 200-cow and 300-cow dairies are included as a multiplier factor. There are also answers to the questions “who should consider a system like this?” and “why would a farmer install this digester?” Resources are provided with who to contact about similar digesters and additional references relevant to each design.

The generation of energy is discussed in a separate section. The six options applied to mid-sized farms do not produce excess energy beyond the energy needed to heat the digester during the winter months. Adding capacity and electrical generators would be an upgrade to the digester after experience was gained with the digestion system.

Five options presented would be constructed on an individual farm. A sixth option proposes that three to four neighbors within a two-mile radius construct and operate a community digester. This community digester includes both separation of solids for use as bedding and for off-farm sale to nurseries or as compost. An electrical generation system is included in this option because the size of this digester system is for 1000 cows.

Groups that work with dairy farmers or have dairy farmers as their members are excited about the potential that this reports holds. “Farmers have always recognized the value of manure. Anaerobic digestion of manure is another means of tapping into its value and Dr. Goodrich's work is key to expanding the utilization of this technology to more farmers. This is beneficial to the farmer and the non-farmer alike because anaerobic digestion improves the sustainable dairy ecosystem,” Bob Lefebvre, Executive Director, Minnesota Milk Producers.

“Because 96% of Minnesota's dairy farms have 200 or fewer cows, this report is very important. It shows how the majority of dairy farmers could provide and use another form of renewable energy,” Doug Peterson, President Minnesota Farmers Union.

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Funding for this report provided by:



ACKNOWLEDGEMENTS

The Minnesota Project would like to thank AgStar Fund for Rural America for providing the grant to complete this report. Also a special thanks to Philip Goodrich for utilizing his 30 years of experience in the field of anaerobic digestion to compile this report.

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Disclaimers

DISCLAIMER NUMBER 1: The author has more than 30 years of experience conducting research and development of digesters at the University of Minnesota Department of Biosystems and Agricultural Engineering. During that time the author has acquired some guide points (biases?) that may be reflected in this report. They are in no particular order:

1. The understanding that anaerobic digestion process is a very efficient method of degrading animal manures.
2. The anaerobic digester process is very good at reducing the odor normally associated with large liquid manure collection and storage systems.
3. Pollution control agencies have increasingly mandated longer storage period and larger storage structures, which means that there are more odors and more hazards of spills of liquid manure.
4. Open storage always means that there is additional manure to be disposed on fields because rainwater has fallen on the open storage.
5. Increased water use in the dairy facility means that the operator pays for the water 3 times, once to obtain the water from a well, or distribution system, again in the storage facility size and for a third time when the water must be hauled to the field for recycling to crops.
6. Hauling manure with tank wagons is inherently inefficient because the operator spends at least one half of the travel time pulling an empty tank.
7. A towed hose injector is a much more efficient system because the manure is pumped and injected more than 90% of the time that the tractor is operating.
8. The anaerobic digestion system is the only waste management system that is expected to make a profit and to pay off all of the investment in the system. In contrast, a liquid manure tank under a building or a lagoon is not expected to pay for the costs of installation and maintenance. This is an ingrained expectation that is difficult to understand, but it does exist whenever a digester system is discussed.
9. The anaerobic digestion system is the only waste treatment system that produces some energy; aerobic systems consume great amounts of energy to reduce odors.
10. Modular components for any manure treatment system are preferred to custom-built, non-modular components.
11. A reliable, local service organization that will place into service and maintain the anaerobic digestion system is necessary for continued success of the digester.
12. Most farm owners/operators already have used up most of their management time and talents applying them to the main focus of the farming operation that is raising animals and/or animal products for market. They do not have an abundance of time and management effort to apply to a new, somewhat complex biological digester system.
13. The use of heat exchangers within the digester vessel is problematic for long-term operation of the digester because crusting of manure occurs on surfaces. Deposition of calcite and corrosion materials may form on the surfaces and reduce the heat exchange rate necessitating corrective action. This usually means shutting down the digester to enter the hazardous space within the digester. External heat exchangers are much easier to clean, repair and/or replace.
14. In Minnesota, all plumbing must be installed so that the plumbing will not freeze under the worst imaginable conditions.

15. All digesters must have a bypass so that daily manure from the barn or other source is diverted around the digester when necessary.

16. The largest amount of heat energy needed for the digester is required to heat the inflow manure from ambient temperature to a temperature slightly higher than the required temperature in the digester. Insulation of the digester can easily minimize the loss of energy from the digester reaction vessel. Cold weather will mean that a large portion of the energy must be used to heat the influent.

DISCLAIMER NUMBER 2: The mention of any trade names or names of providers of services does not mean endorsement of the company or the products/ services provided by the entity. The names are for information only.

Anaerobic Digester Systems for Mid-Sized Dairy Farms

Introduction

Anaerobic digestion of animal manure is a manure treatment system that is gaining popularity as a means to protect the environment and to recycle materials efficiently into the farming systems. This manure treatment system has several advantages when contrasted to the simple storage of manure in our modern animal raising systems. The controlled anaerobic treatment of the manure degrades the organic material efficiently without releasing the many compounds that produce unpleasant odors to humans. The nutrients are conserved in the effluent material for recycling to the next crop. Fibrous material can be separated from the effluent and made into a soil amendment that has value to nurseries and vegetable gardens.

The anaerobic digestion process is carried out in an enclosed container at a temperature of about 100 degrees Fahrenheit to promote the growth of microorganisms that produce biogas containing about 60% methane. The methane can be burned for heat energy or converted to electricity in several ways. The twin benefits are reduction in odors from the manure during treatment and after treatment, coupled with the production of energy.

Because most of the development of anaerobic digesters for dairy producers has been for large dairies with cow numbers greater than 500 cows, this information will focus on the mid size farms with 100 to 300 milking cows. The large operations have focused on production of energy for sale off-farm. We will focus on the benefits of simpler systems that cost less and are simpler to build and operate. The main benefits will be a healthier environment for the farm operators and neighbors of the farm because of the reduction in odors. The operator will have more confidence that future production and expansion will be protected. The operator will also be in compliance with new emission regulations that are possible in the future.

Guiding Principles for this Analysis of Anaerobic Digesters for Smaller Dairy Farms in the Size Range of 100 to 300 Milking Cows

- The smaller number of cows in this analysis indicates that fewer individuals are potentially available to share the operation and maintenance of the digester system.
- The possibility of shared responsibility or purchased labor to run the digester is important.
- The digestion system may and probably should be built in stages to ease into the new system. Thus modularity is an important facet of the planned anaerobic digestion system.
- The system may need to be expanded when additional cows are added to the system.
- The operation may be limited in the capital that can be borrowed to purchase the system and therefore a simpler system may be better fit to the operation.
- Generation of product to sell off the farm (electricity, hydrogen, fiber, compost) is perhaps more limited.
- The generation of electricity and/or methane for sale and/or hydrogen for sale will be explained in a separate section so that modularity can be associated with each type of unit as an add on.

System #1. Upright Digester Treating Only Liquids after Solids Separation

Who Should Consider a System Like This?

- Farms that need odor control but do not want to initially generate electricity or other byproduct
- Farms where the collection of manure is easily accomplished
- Farms that want a digester and have limited space
- Farms that want to handle part of the material as a solid
- Farms with capital available for a separator building, digester and maintenance of the system
- Farms with the skills and technical interest for system operation and maintenance

Why Would a Farmer Install This Digester?

- To reduce odors from existing storage tanks or ponds
- To make use of fibers from manure for bedding, compost or other beneficial product
- To reduce the phosphorus in the liquid fraction, concentrating phosphorus into solids
- To allow the solids fraction to be moved to a more distant location
- To make use of irrigation as a means of applying the liquid fraction
- To have a system that can easily use modular parts to build and maintain
- To have the option to compost the solids and reuse as bedding in the barn

Digester System

System and Process Description

The digester system is composed of sub-systems. (See Figure 1.)

- Manure collection
- Digester and biogas production
- Boiler system and heat exchanger
- Manure separator system
- Liquid storage
- Composting

The digester design has an insulated 10.5 ft diameter (ID) x 16 ft high concrete tank. The tank is reinforced concrete precast in sections at a factory and transported to the farm in 5 sections. Erection on site is done using a crane. The factory making the sections should have extensive experience making septic tanks and underground vaults for electrical utilities. The bottom section has a flat bottom with a ring extending up from the base and rests on a gravel foundation of tamped gravel, 8 inches thick. The bottom has a preformed hole for pipes to enter the digester. The next three sections are rings and the top section is an inverted section like the bottom. The top section has two square entrances that can be sealed gas tight. The outside insulation is foamed in place polyurethane foam with a skim coat to protect against mechanical and sunlight damage. The plastered inside makes the system gas tight.

NOTE: A preformed double wall fiberglass vessel with a conical bottom would be preferred for structural simplicity, weight savings and the ability to complete the inlet and outlet flanges gas-tight at the factory. The added conical bottom would allow cleaning of the sludge from the vessel at scheduled intervals.

The hydraulic retention time is about 7 days in a digester of this type in New York State. The digester collects 2400 cubic ft/day (24 cubic ft/cow-day) of biogas (40% carbon dioxide, 60%

methane). A gutter cleaner collects about 1900 gallons of manure daily from the 100-cow tie stall barn. The gutter cleaner moves the manure into a reception pit with capacity to hold 2 days of manure and wash water. Milk house waste is added and some fresh water is added to make the slurry pumpable to the separator. A propeller agitator is used to mix up the manure slurry and a submersible pump pushes the slurry to the screw press type manure separator. About 2000 gallons of slurry are processed through the screw press manure separator producing 1620 gallons of liquid fraction and 140 cubic ft of solids. A short, wood-framed belt conveyor moves the solids to a small trailer located below the separator.

The separator is housed on the second floor of a wood framed building next to the digester. The separator and the controls are neatly kept warm in the insulated building. The solids are composted, sold off-farm or may be dried and used for bedding. The separated liquids are sent to a second tank. In the second tank is a grinder pump. The grinder pump grinds up any residual fiber to a size less than 0.24-inch diameter and feeds the digester every half hour so that there is a uniform application of material entering the digester throughout the day. The timing is set so that the total flow is put into the digester before the next day's material enters this tank.

Heat Generation

Biogas is used in a boiler to heat water that flows through a tube and shell heat exchanger through which digester fluid is pumped. A second boiler is connected in series and burns propane for startup and operates in tandem with biogas when the digester needs more heat than can be provided by the single biogas boiler.

Liquids and Solids Process Description

The manure is removed from the barn with a scraper system that empties into a manure mix tank. The milk house waste is added to this manure tank. Some additional water is added to make slurry that will separate using the FAN screw press separator system located in an elevated location in the digester control building. The tank is mixed by an agitator device and a chopper pump moves the slurry to the separator. The separator is controlled by a system that monitors and regulates the amperage flowing to the separator. The solids from the separator are conveyed a short distance on a wood framed conveyer to a wagon which collects the solids. The liquid effluent is conveyed by pipe to a second tank. In the second tank, a grinder pump is activated about every 30 minutes to pump the liquid to the digester. The liquids are resident in the digester for about 7 days and at that time, flow by gravity into the open-top, long-term storage tank. The residence time is an average because there is mixing within the digester so statistically the liquid resides in the digester. A valve allows the slurry to be shunted directly to the long-term storage tank in event of digester upset or some emergency such as a large water leak in the barn.

Biogas Handling and Use Description

Biogas is collected from the top of the digester. From there the biogas is routed to the biogas boiler where the biogas is combusted in the modified natural gas boiler. Water is heated by the boiler, passed through the heat exchanger, and then to a radiator outside for heat dumping when needed. Liquid from the digester is passed through the inside tubing of the heat exchanger and back to the digester to convey heat to the digester. This provides some mixing and heating of the digester. Clean water back flush is used to clean the pipes in the heat exchanger once daily to keep the smaller pipes from plugging. The fresh back flush water

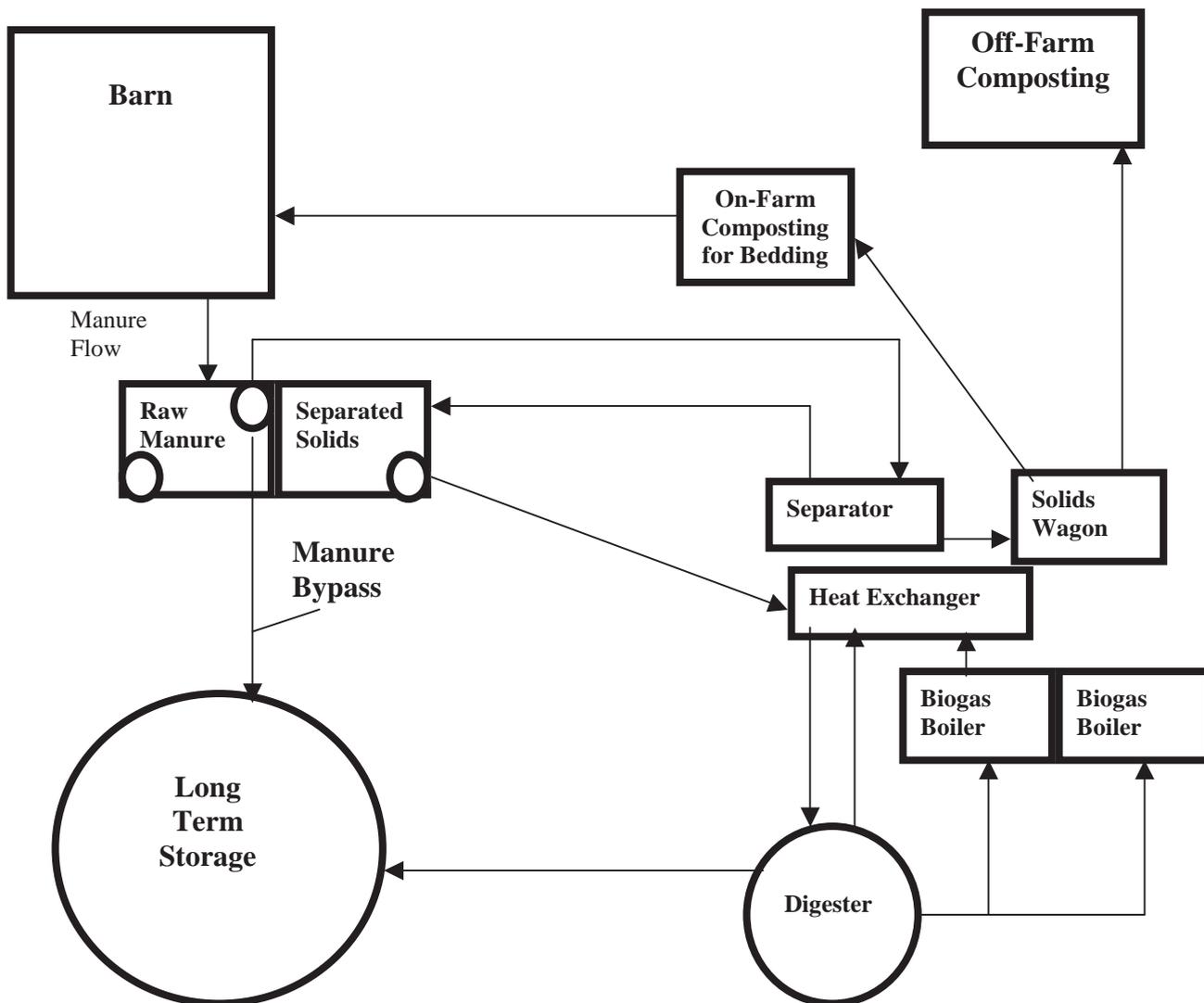


Figure 1
Schematic of low solids anaerobic digester system with separation prior to digester

becomes part of the liquid in the digester. Control of the digester temperature is controlled by one thermocouple in the digester. A small spray jet just below the biogas outlet pipe is used on a cycle of 15 minutes on and 15 minutes off to control foam in the digester. If serious foaming occurs, an antifoaming additive is inserted into the material being fed through the grinder pump into the digester. Excess gas would be piped to a safety flare located a safe distance from the digester.

Environmental Benefits

- Odors are reduced reducing complaints from neighbors and farm residents.
- Methane is captured in the digester and less methane is produced in the long-term storage tank.
- The solids are available for sale as soil amendments, which can be used to reduce soil erosion. The phosphorus that is contained in the solids is exported out of the watershed in the solids thus reducing the impact on water pollution.
- The nutrients are kept out of the streams when application of the liquid from the long-term storage is less in volume and can be efficiently hauled to cropland.
- Less energy is needed to agitate the storage tank for pumping out into spreader.

Table 1 Economic Information for 100-Cow Dairy Using System #1

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester tank and materials	\$47,000
	Partial building cost	\$5,000
	Boilers and heat exchangers	\$8,000
	Subtotal	\$60,000
	Solids and liquids separation	
	Separator	\$46,000
Composter and/or dryer	\$5,000	
Building and equipment	\$9,000	
Subtotal	\$60,000	
	Liquid storage (assumed in place)	
	Engineering design and other	\$40,000
	Total capital cost	\$160,000
	Annual capital cost	\$16,000
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$16,000
ANNUAL BENEFITS INCLUDING	Bedding material replacement, fertilizer savings, bedding savings, sales of solids	\$15,000
	Odor reduction benefit	\$15,000
	Subtotal	\$30,000
ANNUAL COST PER COW (\$/COW/YEAR)		\$20

NOTE: The costs shown above are approximate and will vary for each individual circumstance. The capital and operating costs for 200 and 300 cows would be approximately 1.4 and 1.6 times those shown for 100 cows.

Lessons Learned from Similar Digesters

- Use of large amount of calcite in the barn can cause problems of deposition in the piping within the system.
- Foaming is sometimes a problem that has to be monitored and some method planned to reduce the foam so that the foam does not enter the appliances using the biogas.
- Transporting large parts and erecting them takes special timing and coordination.

Who to Contact about Similar Digesters

Stanley A. Weeks, LLC, 4 Ashlor Drive, Middle Grove, NY 12850. Phone: 518-583-1914, Email: sweeks1997@aol.com

Manure Treatment Specialist, PRO-DAIRY, Cornell Cooperative Extension. Phone: 607-255-2803, Fax: 607-255-4080

Table 2 Advantages and Disadvantages of System #1

ADVANTAGES	DISADVANTAGES
Odor control	Medium capital cost
Pathogen reduction	High operating cost
Bedding savings	Need for daily management of digester system
Nutrient reduction	No reclaiming of excess energy

References with Information Relevant to this Design

Wright, P. and Ma J. 2003. *Fixed Film Digester at Farber Dairy Farm: Case Study*
[www.manuremanagement.cornell.edu/Docs/Farber%20Case%20Study%20draft%20\(6-11-04\).pdf](http://www.manuremanagement.cornell.edu/Docs/Farber%20Case%20Study%20draft%20(6-11-04).pdf)



Figure 2
Solids separation unit
manufactured by the
FAN Corporation

photo by Stan Weeks



Figure 3
Solids separation
building and digester

photo by Stan Weeks

System #2. Upright Mixed Digester Treating All the Manure from Herd

Who Should Consider A System Like This?

- Farms that need odor control but do not want to initially generate electricity or other byproduct
- Farms where the collection of manure is easily accomplished
- Farms that want a digester and have limited space
- Farms that want to handle all of the manure through the digester
- Farms with capital available the digester and maintenance of the system
- Farms with the skills and technical interest for system operation and maintenance
- Farms with an interest in recycling the solids for bedding

Why Would A Farmer Install This Digester?

- To reduce odors from existing storage tanks
- To have a system that can easily use modular parts to build and maintain the system
- To use a monolithic concrete structure for the digester

Digester System

System and Process Description

The digester system is composed of several sub-systems. (See Figure 4.)

- Manure collection
- Digester and biogas production
- Boiler system and heat exchanger
- Manure separator system
- Liquid storage

A digester with an upright tank that treats all of the manure from the herd will be bigger than one that treats only the liquids. The manure will be thicker because all of the solids will be fed to the digester. Mixing will be needed to make sure that the solids do not all sink to the bottom. A conical bottom will facilitate removing solids that do settle out. Insulation will be necessary so that the flow of heat from the sides and top of the digester are limited.

There are several different types of upright digesters, but only a single tank digester will be considered for simplicity and to keep the management of the system simple. The manure could be ground up using a grinder pump prior to introduction into the digester. Solids separation after digestion produces fiber that can be exported or can be used for bedding. For a simpler system, this portion may be added at a later time, or simply deleted entirely, saving the cost of the separation, but also deleting the beneficial impact of the recycling of bedding material and reducing the cost of purchased bedding.

Heat Generation

A biogas-fired boiler heats water for use in the heat exchanger system. An alternate fuel system of propane with its separate orifices is necessary when there is insufficient biogas and during the startup phase. A recirculation pump is necessary to move the hot water to the heat exchangers. A control system for the pumps and temperature control can be installed.

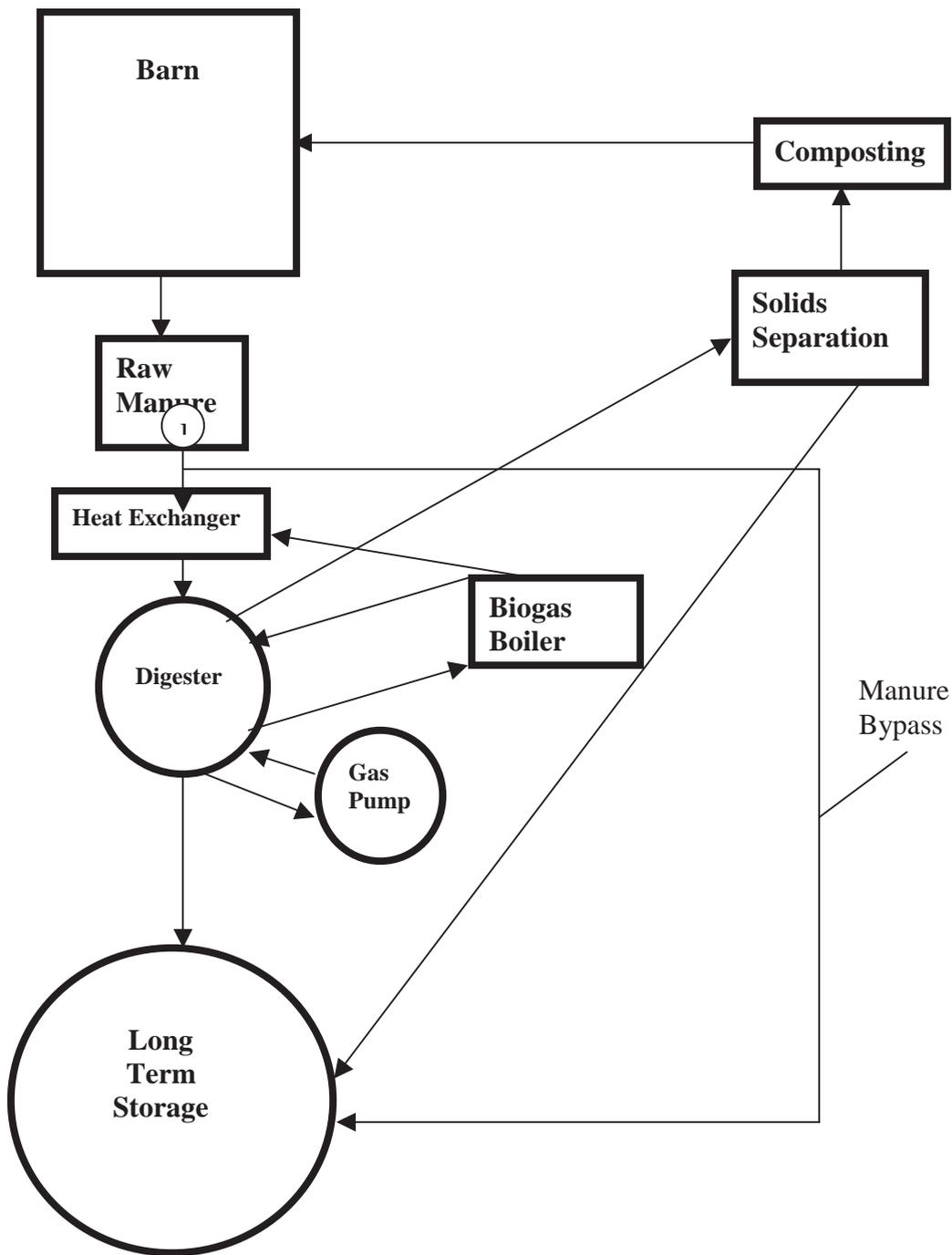


Figure 4
Schematic of completely mixed upright digester system

Liquids and Solids Process Description

The liquids and solids from the barn are scraped to a collection pit frequently. No frozen manure is put into this tank. A prop type mixer is used to agitate the manure prior to the time when the pump loads manure into the digester. The digester should be fed at least 6 times a day. The prop mixer and the loading pump should be sequenced using timed controls. A level control is needed to make sure that the pump is shut off if the bottom of the pit is reached during a pumping cycle.

The heat exchanger can be in line with the feed pump so that the manure is heated before reaching the digester. A second heat exchanger can be used to recirculate manure from the digester through this second heat exchanger to add additional heat as needed. Biogas is used in a biogas boiler to provide hot water to the heat exchangers at proper temperature.

Biogas Handling and Use Description

Biogas is collected at the top of the digester and used in the boiler to provide process heat. The process heat is used for heating the influent, for heating the digester if needed and for other heat needs on the farm. Examples of those needs are hot water, floor heating, warming drinking water, space heating and heating of the building housing the manure mixing pit, the boiler and the associated control systems and data management systems. Excess gas would be piped to a safety flare located a safe distance from the digester.

Environmental Benefits

- Odors are decreased from the manure handling and storage system.
- Odor and time will be reduced during agitation.
- Fewer odors will be generated when the manure is spread. However, if the manure is properly injected into the soil, odor will be minimized.
- Methane emissions from the storage facility will be significantly reduced thus reducing the greenhouse gasses placed into the atmosphere.

Table 3 Economic Information for 100-Cow Dairy Using System #2

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester tank and materials	\$66,000
	Partial building cost	\$20,000
	Boilers and heat exchangers	\$8,000
	Gas recirculation pump	\$4,000
	Subtotal	\$98,000
	Liquid storage (assumed in place)	
	Engineering design and other	\$40,000
	Total capital cost	\$138,000
	Annual capital cost	\$13,800
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$13,800
ANNUAL BENEFITS INCLUDING	Bedding material replacement, sales of solids	\$15,000
	Odor reduction benefit	\$15,000
	Subtotal	\$30,000
ANNUAL COST PER COW (\$/COW/YEAR)	NOTE: This is a net benefit for system	-\$24

NOTE: The costs shown above are approximate and will vary for each individual circumstance. The capital and operating costs for 200 and 300 cows would be approximately 1.4 and 1.6 times those shown for 100 cows.

Table 4 Advantages and Disadvantages of System #2

ADVANTAGES	DISADVANTAGES
Odor control	Higher capital cost
Pathogen reduction	Higher operating cost
Nutrient reduction	Need for daily management of digester system

Lessons Learned from Similar Digesters

- The digester must be mixed.
- A conical bottom will allow for the removal of solids that will build up in the digester over time.
- The heat exchanger tubes must be of sufficient size that they do not plug.
- A proper back flush system can be used.
- Mixing uses energy and a gas pump with sufficient capacity to inject gas at sufficient pressure to mix the material is required.

Who to Contact about Similar Digesters

Stanley A. Weeks, LLC, 4 Ashlor Drive, Middle Grove, NY 12850. Phone: 518-583-1914,
Email: sweeks1997@aol.com

Steve Dvorak www.ghdinc.net/products.aspx

References with Information Relevant to this Design

GHD Inc. www.ghdinc.net/products.aspx

Figure 5
Complete mix upright digester

photo by Stan Weeks



Figure 6
Biogas boilers to heat complete mix digester

photo by Stan Weeks



System #3. Conventional Plug Flow Digester with Flexible Cover

Who Should Consider a System Like This?

- Farms that need odor control but do not want to initially generate electricity or other byproduct
- Farms where the collection of manure is easily accomplished
- Farms that want a digester and have a long narrow space for the plug flow digester
- Farms with capital available for the digester and maintenance of the system
- Farms with the skills and technical interest for system operation and maintenance

Why Would a Farmer Install This Digester?

- To reduce odors from existing storage tanks
- To have a more flowable material to apply to the fields

Digester System

System and Process Description

The digester system is composed of sub-systems. (See Figure 7.)

- Manure collection
- Digester and biogas production
- Boiler system and heat exchanger

In this system the manure is collected from the barn and moved to a raw manure collection pit. A single pump is used to both agitate the manure and pump into the digester twice a day. If an external heat exchanger is used the heat exchanger is either in the pit or the manure is pumped through the heat exchanger on the way to the digester. The digester is a long and narrow tank usually with a flexible cover. Concrete walls and concrete bottom complete the digester. The manure is not mixed but moves through the digester like a plug moving through a sausage casing. The hydraulic detention time is approximately 30 days. A variation of the straight digester is a "U" shaped digester that loops back to the beginning end. With this variation, it is easier to reclaim heat from the effluent to heat the influent. The material exiting the digester is then moved to the long-term storage. A step to separate solids is sometimes done after digestion. With the plug flow digester, the manure has to be fairly high in solids and cannot tolerate much added water. Solids content of 12% is ideal.

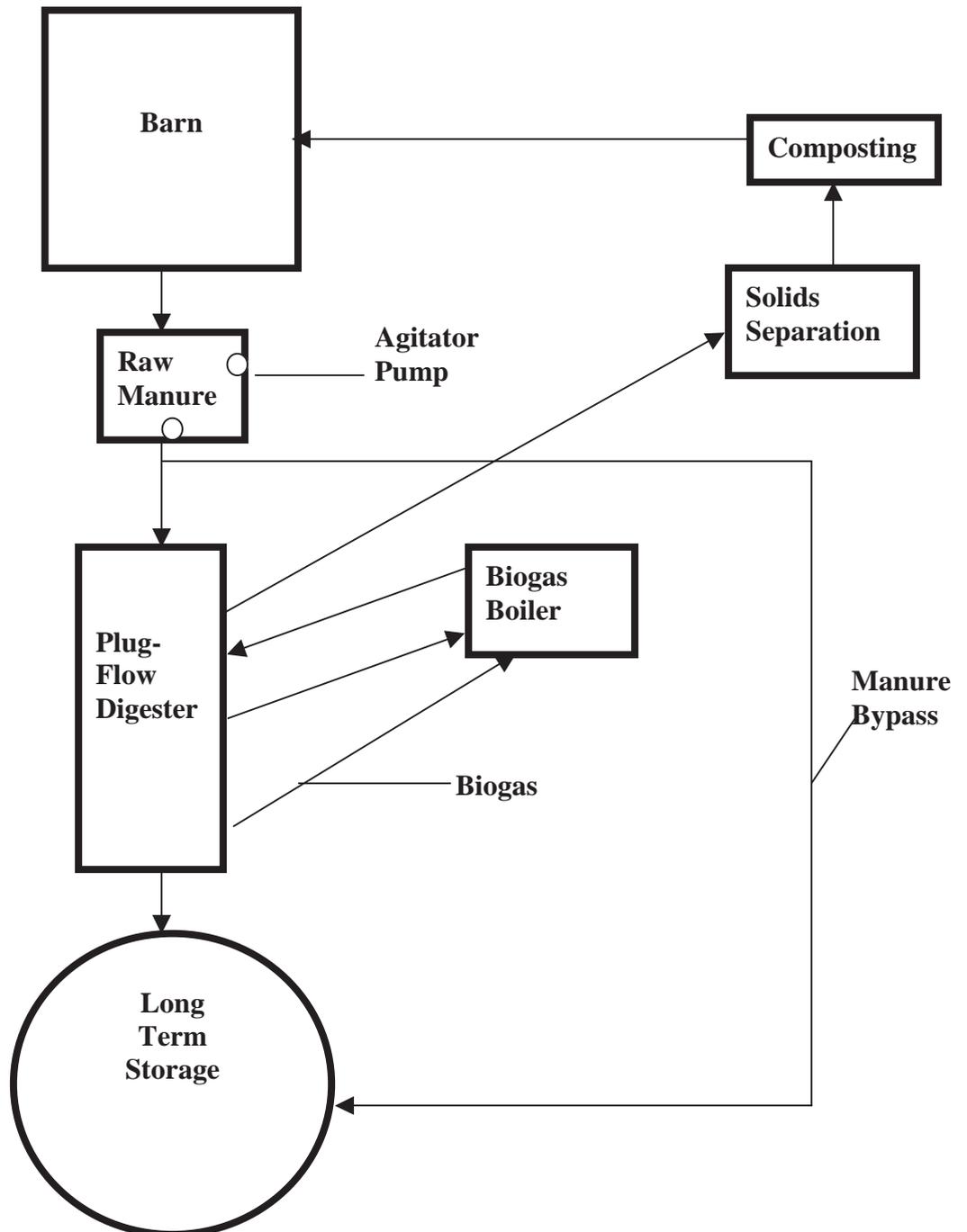
Heat Generation

A biogas-fired boiler is used to heat water for use in the heat exchanger system. An alternate fuel system of propane with its separate orifices is necessary to use when there is insufficient biogas and during the startup phase. A recirculation pump is necessary to move the hot water to the heat exchangers. A control system is also needed so that the proper temperatures are maintained in the digester. The heat exchanger can be external or internal to the digester vessel.

Liquids and Solids Process Description

The liquids and solids from the barn are scraped to a collection pit frequently. No frozen manure is put into this tank. A prop type mixer is used to agitate the manure prior to the time when the pump loads manure into the digester. The digester should be fed at least 2 times a day. The prop mixer and the loading pump should be sequenced. A level control is needed to make sure that the pump is shut off if the bottom of the pit is reached during a pumping cycle. The heat exchanger can be in line with the feed pump so that the manure is heated before reaching the digester. A second heat exchanger can be used to recirculation manure from the digester through this second heat exchanger to add additional heat as needed. Biogas is used in a biogas boiler to provide hot water to the heat exchangers at proper temperature.

Figure 7
Schematic of plug-flow anaerobic digester system with separation after digester



Biogas Handling and Use Description

Biogas is collected at the top of the digester and used in the boiler to provide process heat. The process heat is used for heating the influent, for heating the digester if needed and for other heat needs on the farm. Examples of those needs are hot water, floor heating, warming drinking water, space heating and heating of the building housing the manure mixing pit, the boiler and the associated control systems and data management systems. Excess gas would be piped to a safety flare located a safe distance from the digester.

Environmental Benefits

- Odors are reduced.
- Methane is captured in the digester and much less methane is produced in the long-term storage tank.
- The solids are available for sale as soil amendments, which can be used to reduce soil erosion. The phosphorus that is contained in the solids is exported out of the watershed in the solids thus reducing the impact on water pollution.

Table 5 Economic Information for 100-Cow Dairy Using System #3

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester tank and materials	\$46,000
	Partial building cost	\$10,000
	Boilers and heat exchangers	\$8,000
	Subtotal	\$64,000
	Solids and liquids separation	
	Separator	\$46,000
Composter and/or dryer	\$5,000	
Building and equipment	\$8,000	
Subtotal	\$59,000	
	Liquid storage (assumed in place)	
	Engineering design and other	\$40,000
	Total capital cost	\$163,000
	Annual capital cost	\$16,300
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$16,300
ANNUAL BENEFITS INCLUDING	Bedding material replacement, fertilizer savings, bedding savings, sales of solids	\$15,000
	Odor reduction benefit	\$15,000
	Subtotal	\$30,000
ANNUAL COST PER COW (\$/COW/YEAR)		\$26

NOTE: The costs shown above are approximate and will vary for each individual circumstance.

The capital and operating costs for 200 and 300 cows would be approximately 1.4 and 1.6 times those shown for 100 cows.

Table 6 Advantages and Disadvantages of System #3

ADVANTAGES	DISADVANTAGES
Odor control	High capital cost
Bedding savings	High operating cost
Nutrient reduction	Need for daily management of digester system

- The nutrients are kept out of the streams when application of the liquid from the long-term storage is less in volume and can be efficiently hauled to cropland.

Lessons Learned from Similar Digesters

- There are several designs for plug flow digesters.
- For a smaller digester, a single straight-line flow is usually best.
- A U shaped digester can be used if one wants to reclaim heat from the effluent to heat the influent.
- Care must be taken that if a flexible cover is used, there are no short circuits set up where manure can go directly from the influent to the effluent without passing through the rest of the tank.
- A flexible cover allows for storage of gas.
- It is very difficult to repair a flexible cover.
- The cover must be installed properly and protected from damage requiring repair.
- Salts do build up in this type of digester.
- There is no current method available to remove the solids without shutting down the digester and applying muscle to a very difficult, unpleasant and dangerous job.
- If a center beam is used on a single tank to support two halves of a cover, there can never be a time when the two covers are at different pressures or failure will occur.

Who to Contact about Similar Digesters

Mark A. Moser at Resource Conservation Management, Inc. A digester design and install company. contact@rcmdigesters.com

Richard Mattocks <http://waste2profits.com/htm>

References with Information Relevant to this Design

<http://64.225.36.90/publications/RCM.htm>



Figure 8
A horizontal plug-flow digester

photo by RCM Digesters

System #4. Covered Pond Digester with Insulated Sides and Cover

Who Should Consider a System Like This?

- Farms that need odor control but do not want to initially generate electricity or other byproduct
- Farms where the collection of manure is easily accomplished
- Farms that want a digester and only have space for long-term storage
- Farms that want to handle all of the material in one place and limit additional moisture
- Farms with very limited capital available for the system
- Farms with the skills and technical interest for simple system operation and maintenance
- Farms without a current storage pond, but where a pond can be permitted and the winters are not severe. Southern Minnesota is a possibility. Old ponds should not be retrofitted.
- Ground water cannot be close to the bottom of the planned pond

Why Would a Farmer Install This Digester?

- To reduce odors from existing storage
- To have a very inexpensive system with low inputs and low outputs
- To have a simple system that has few parts

Digester System

System and Process Description

The digester system is composed of sub-systems. (See Figure 9.)

- Manure collection
- Digester and Biogas production
- Boiler system and heat exchanger
- Liquid storage

This is perhaps the simplest digester system but the one that has the least energy output and has the most potential to not work very well. A basin is constructed in a well-drained soil and a layer of insulation put down. A liner is installed and a cover with a system of gas collection pipes is installed as the cover. A seal between the bottom and the top layer is made. Then manure is heated and placed in the "baggie." An insulated cover is needed if the digester is to work in cold weather. The biogas is collected from beneath the cover. The manure is digested for all the time that it is in the digester. The detention time is long, so more potential gas can be collected, but the control is much less than with other digester shapes and designs. This design is most likely to fail in Minnesota because of cold winters and moderate summers. The digester has to either be opened for agitation or a recycle system put in place so that some agitation can occur to remove solids. If fiber is removed before the manure enters the digester, the system will produce less gas, but will be relatively easy to pump out. A restart has to be completed if the digester is opened for the pumping. It is better if it can be pumped without opening the top. A system for pumping water off the top may be useful, however some experience has shown that this is not too critical. The gas collection system below the cover is critical to the success of the system. An alternative method may be to make two separate modules so that one can be cleaned while the other is kept operating. The first one is seeded before opening the second one for cleaning.

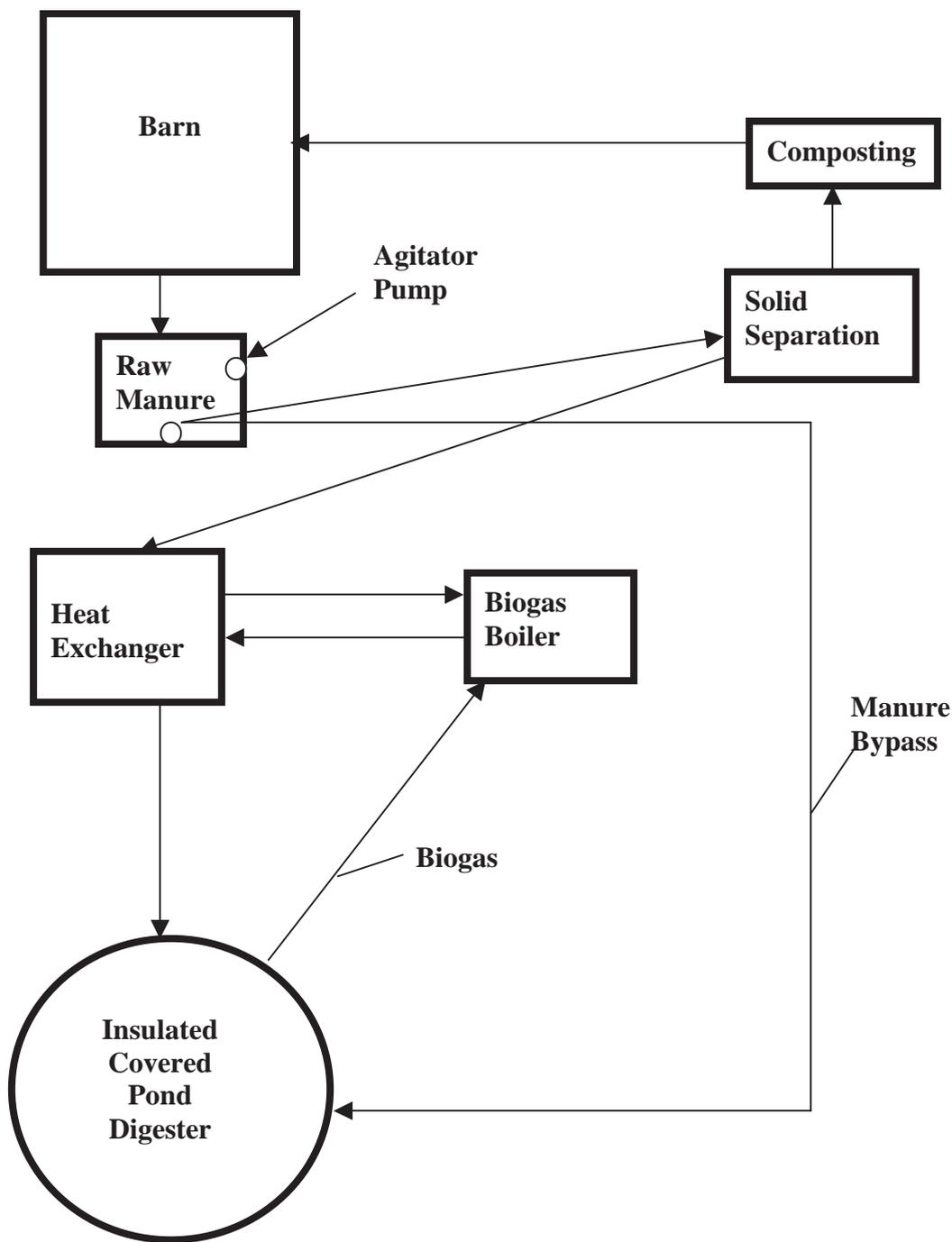


Figure 9
Schematic of covered pond anaerobic digester system with separation prior to digester

Heat Generation

Biogas is collected from a system of pipes under the cover. This system is connected to an underground pipe that extends to the building housing the boiler. The boiler burns biogas to generate heat that is transferred to the preheating tank. In the preheating tank, the manure slurry is heated before injecting the manure into the covered pond digester.

Liquids and Solids Process Description

The manure is removed from the barn with a scraper system that empties into a manure mix tank. The milk house waste is added to this manure. A heat exchanger heats the manure prior to addition to the digester. An agitator device mixes the tank. A chopper pump moves the

slurry to the separator, then to the heat exchanger and then on to the digester. If solids separation is not wanted, the manure goes directly to the heat exchanger and then to the digester. The liquids are resident in the digester for many days (up to 6 months) until the complete digester is emptied and the material spread on the land as fertilizer. The digester is restarted with new manure, some time for acclimation and restarting of the biogas production occurs. The residence time is not usually calculated in this type of digester.

Biogas Handling and Use Description

The biogas from this type of digester is not as predictable as with digesters of a fixed volume. Generally there is a startup period with limited biogas production and then the amount of biogas increases. This digester is more affected by outside temperature because of the large volume and area exposed to ambient temperatures. Biogas is used to heat the incoming manure and can be used as process heat in the dairy parlor. Planning for propane as supplemental fuel may be necessary or the digester can be shut down for very cold winter situations. A restart of the digester or just pumping out the material before the liquid becomes active in the spring is an alternative.

Environmental Benefits

- Odors are reduced.
- Less nitrogen is lost to the atmosphere because of the cover on the long-term storage.
- Methane is captured in the digester and in the long-term storage.
- The solids are available for sale as soil amendments, which can be used to reduce soil erosion. The phosphorus that is contained in the solids may be exported out of the watershed in the solids thus reducing the impact on water pollution.
- The nutrients are kept out of the streams when application of the liquid from the long-term storage is less in volume and can be efficiently hauled to cropland.
- Less rainwater is collected in this system and mixed with the manure.

Lessons Learned from Similar Digesters

- Not easy to capture the biogas from under the cover.
- Not easy to restart the digester after shut down.
- May build up salts that hinder digestion.
- Often hard to agitate under the cover to get the solids all out to spread on the fields.
- Insulation is a problem in colder climates.
- May need a water collection system to remove rainwater that falls on the top of the cover.
- Wind may affect the cover and cause humps of gas to collect in areas below the cover.

Who to Contact about Similar Digesters

Doug Williams wmsengr@thegrid.net

Richard Mattocks <http://waste2profits.com/htm>

References with Information Relevant to this Design

<http://rcmdigesters.com/Default.htm>

<http://www.valleyairsolutions.com/methanedigesters.htm>

<http://www.wurdco.com/News%20Clips/strausdairysantarosa.htm>

Table 7 Economic Information for 100-Cow Dairy Using Covered Pond System #4

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester liner, cover and insulation materials	\$46,000
	Pump and mixing tank	\$8,000
	Building cost	\$10,000
	Boilers and heat exchangers	\$5,000
	Subtotal	\$64,000
	Solids and liquids separation	
Separator	\$46,000	
Composter and/or dryer	\$5,000	
Building and equipment	\$9,000	
Subtotal	\$60,000	
	Liquid storage excavation costs	\$20,000
	Engineering design and other	\$40,000
	Total capital cost	\$184,000
	Annual capital cost	\$18,400
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$18,400
ANNUAL BENEFITS INCLUDING	Bedding material replacement savings, sales of solids	\$15,000
	Odor reduction benefit	\$15,000
	Subtotal	\$30,000
ANNUAL COST PER COW (\$/COW/YEAR)	NOTE: That this includes long-term storage	\$64

NOTE: The costs shown above are approximate and will vary for each individual circumstance. The capital and operating costs for 200 and 300 cows would be approximately 1.4 and 1.6 times those shown for 100 cows.

Table 8 Advantages and Disadvantages of Covered Pond System #4

ADVANTAGES	DISADVANTAGES
Odor control	Need for daily management of digester system
Pathogen reduction	May not work all year around
Nutrient reduction	Need to restart after emptying
Low capital cost	Need to remove some of cover to pump
High operating cost	

Figure 10
Overview of a floating
cover on a California
pond digester system

photo by Doug Williams



System #5. Low Cost Plug Flow Digester Utilizing a Plastic Liner Inside a Large Steel Culvert

Who Should Consider a System Like This?

- Farms that need odor control but do not want to initially generate electricity or byproduct
- Farms where the collection of manure is easily accomplished
- Farms that want a digester and have limited space
- Farms with limited capital and looking for a limited life digester
- Farms wanting to upgrade to a different digester in the future when have more capital
- Farms willing to try a new and untried design
- Farms with the skills and technical interest for system operation and maintenance

Why Would a Farmer Install This Digester?

- To reduce odors from existing storage tanks
- To use low cost modular parts to build and maintain the system
- To spend limited capital
- To minimize solids settling out in a plug flow digester
- To provide a protected flexible cover digester

Digester System

System and Process Description

The digester system is composed of sub-systems. (See Figure 12.)

- Manure collection
- Digester and biogas production
- Boiler system and steam injection
- Liquid storage

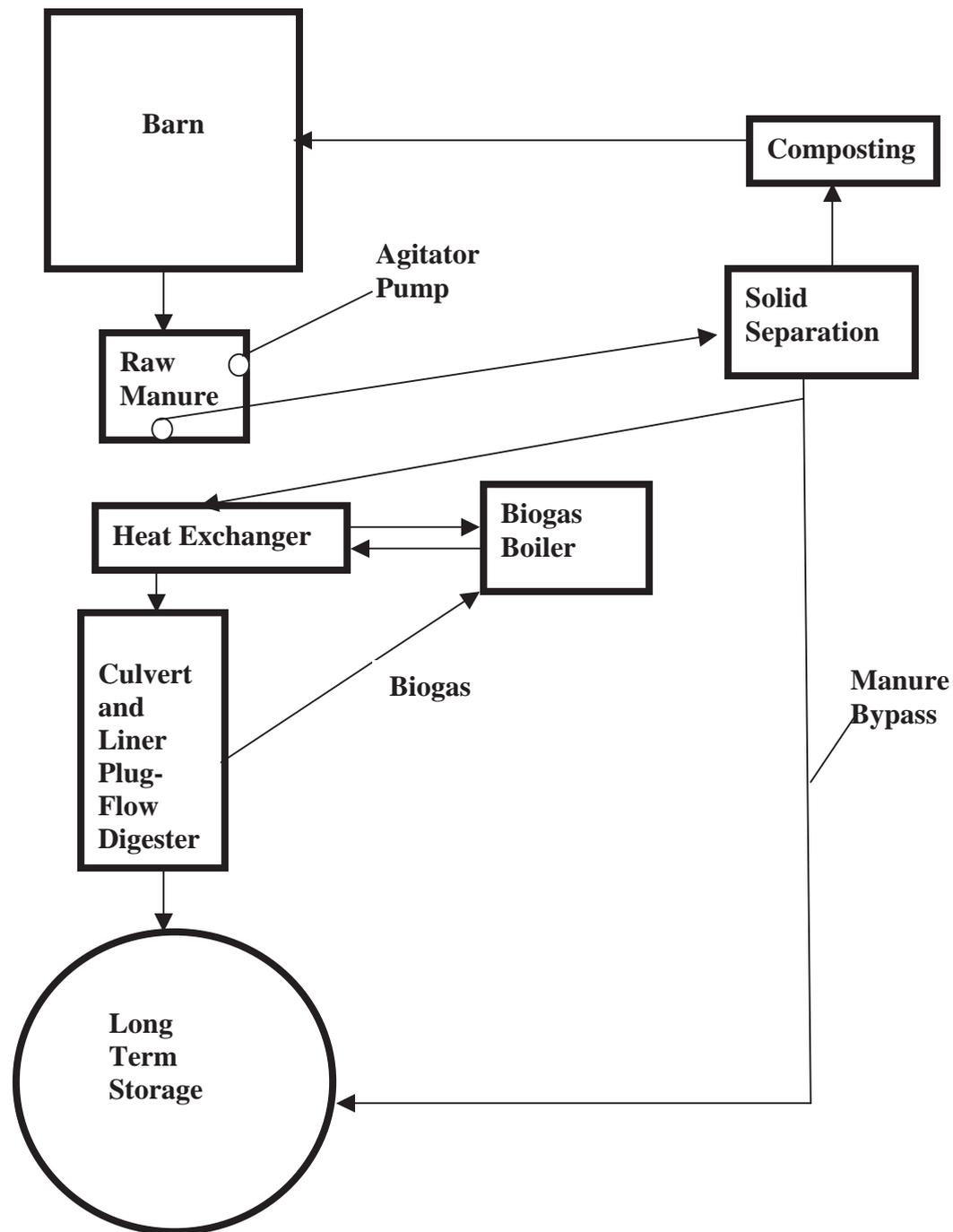
Heat Generation

The biogas would be fed to the low-pressure steam boiler to generate steam that would be injected into the manure in the mixing pit.

Liquids and Solids Process Description

Manure would be moved from the barn into the mix tank at least 6 times a day. The mixer would turn on and mix the material. Steam would be injected to heat the manure. A grinder pump would then grind the material and push manure into the digester at least 6 times per day to provide a more even feeding of the digester. This digester would be cleanable. The liner could be removed after about 5 years and replaced. The removable end caps would allow a scraper to be inserted and pulled with a cable to clean the settled solids out of the digester. Then a new liner would be installed and the end caps reinstalled. Since the digester is not much below ground level, the cleaning would be easily completed with adequate ventilation.

Figure 11
Schematic of plastic liner
in culvert digester system
with separation prior to
digester



Biogas Handling and Use Description

The biogas would be collected under the liner of the digester and conveyed to the boiler for burning to produce low-pressure steam. The steam would be injected into the mix tank when the mixer was being used to prepare the manure for placement into the digester. The manure would be heated to a temperature higher than the planned digester temperature to make up for the loss of heat through the walls of the digester.

Table 9 Economic Information for 100-Cow Dairy Using Culvert System #5

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester tank and materials	\$35,000
	Boilers and heat exchangers	\$10,000
	Building with mixing tank	\$10,000
	Subtotal	\$55,000
	Liquid storage (assumed in place)	
	Engineering design costs and other	\$40,000
ANNUAL OPERATING COSTS	Pumps, plumbing, electrical, and instruments	\$10,000
	Total capital cost	\$105,000
	Annual capital cost	\$10,500
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$10,500
ANNUAL BENEFITS INCLUDING	Odor control benefit	\$15,000
ANNUAL COST PER COW (\$/COW/YEAR)		\$60

NOTE: The costs shown above are approximate and will vary for each individual circumstance. The capital and operating costs for 200 and 300 cows would be approximately 1.4 and 1.6 times those shown for 100 cows.

Environmental Benefits

- Odors are reduced
- Methane is captured in the digester
- Less methane is produced in the long-term storage tank
- The material would be less viscous and would require less agitation before spreading

Lessons Learned from Similar Digesters

- None have been built with this exact design.
- A digester was built in Wisconsin in the 1970's with the conduit material and operated on dairy manure and turkey litter.
- Coating the inside of the digester to provide a gas seal was not a nice task.
- Heating with an engine generator set was problematic at best.

Who to Contact about Similar Digesters

Philip Goodrich goodrich@umn.edu

References with Information Relevant to this Design

None available in electronic format

Table 10 Advantages and Disadvantages of Culvert Linear System #5

ADVANTAGES	DISADVANTAGES
Odor control	Need for daily management of digester system
Pathogen reduction	No experience with this system
Nutrient reduction	Life of liner probably limited to 5 years, maximum
Low capital cost	May need to recycle some material from the effluent to keep active microorganism count high at the inlet
Low operating cost	The steam may kill some methane formers that are shed by the cows
Easy to clean out digester	The ground up manure may cause more foaming in the digester
Located at ground level and uses soil for insulation	
Protected from weather and vandals	
The grinding may release more gas in the digester	
The crusting of the outside storage may be reduced	



Figure 12
Construction of culvert based digester system

photo by Phil Goodrich



Figure 13
Finished construction of culvert based digester system

photo by Phil Goodrich

System #6. Community Digester Owned and Operated by 3-4 Farms

[Located No More Than 2 Miles from the Site Chosen for the Digester.

Total Cows on the 3-4 Farms is 1000-1200.]

Who Should Consider a System Like This?

- Farms that need odor control but do not want to have the responsibility and risk of a digester on their farm
- Farms where the collection of manure is easily accomplished
- Farms that already have a long-term storage facility and have space to build a short time storage space for the raw manure from the barn
- Farms that will stay in business at least 10 years so can form a business venture for the digestion
- Farms that have a working and business relationship with at least 3 neighbors to build and operate a common digester
- Farms that lack skills and technical interest for system operation and maintenance
- Farms that can either transport the manure to the central digester or are willing to have the effluent delivered back to the farm without concern about biosecurity issues.
- Farms where an end product such as energy would not be used on the farm

Why Would a Farmer Install This Digester?

- To reduce odors from existing storage tanks and reduce the odor from spread manure
- To make use of fibers from manure for bedding, compost or other beneficial product
- To remove part of the phosphorus in the liquid fraction
- To allow the solids fraction to be moved to a more distant location
- To make use of irrigation as a means of applying the liquid fraction
- To run a system as a separate enterprise by a specialist
- To make use of energy generated on a central site

Digester System

System and Process Description

The digester system is composed of sub-systems. (See Figure 15)

- Manure collection
- Digester and biogas production
- Boiler system and heat exchanger
- Manure separator system
- Liquid storage
- Composting
- Electrical Generation

Heat Generation

A propane or natural gas-fired boiler is used to heat water for use in the heat exchanger system during startup and for emergencies when the generator motor is not working. The risk of not having heat for the digester is large. Normally the heat for the digester is reclaimed from the cooling and exhaust system of the motor driving the induction generator, which is

feeding either one of the farms and/or the grid. A recirculation pump is necessary to move the hot water to the heat exchangers. A control system is also needed so that the proper temperatures are maintained in the digester.

Liquids and Solids Process Description

Each farm has a short-term storage pit where manure is collected from the barn. The minimum volume should be one-week storage. A second long-term storage facility for digested material should be located either at the barn or may be located close to where the manure will be spread. Both storages should be located so that access by large truck with a vacuum intake is easy in all kinds of weather and in all weeks of the year. Road restrictions should be understood and properly handled. A tanker hired by the central digester management will transport the manure to the central digester. The tanker stops at a farm and fills the tanker, drives to the central digester and off loads the manure to a mix tank at the digester. A tank load of digested material is put into the tanker and the tanker returns to the same farm. The digested material is off loaded into the long-term storage. The tanker reloads with manure and repeats the cycle until a full tanker is no longer available in the pit. Then the tanker moves on to the next farm and repeats the cycle. A schedule of farms and the amounts to be taken to the digester and amount to be returned to the farm has to be constructed. This will make sure that all the short-term storages are emptied and there is room for deposit of material generated each day. Optimization of the route and balancing of the input material and the material returned is necessary. Farmers want the manure to go to the digester; they are not as enthusiastic about the digested manure that is returning that they have to spread onto the farm.

At the central digester, accounting and planning are necessary for feeding the digester on a proper schedule and making sure that the short-term storage is used properly.

A solids separator is used on the effluent to remove fibers. This fiber is then marketed either for composting or composting is done onsite or an upgraded product is provided for sale in bulk or in bags.

The cost of hauling manure is important to the success of this digester and may be calculated using a distance of 0.5 miles from each of 2 farms to the central digester and back. Manure at the site is not hauled but drained to store on that site at nominal cost. Cost of long-term storage is not included in this analysis. A cost of \$10 per 1000 gallons of manure hauled for the two way trip was used assuming the half mile trip can use tractor hauled vacuum tanker holding 4000 gallons per load. An individual farmer provides agitation at the on farm storage location.

Biogas Handling and Use Description

Biogas from the digester is fed to the engine generator set on a continuous basis. The gas is burned in the engine generator set to make alternating current electricity for use at the digester. Electricity is produced for at least one local farm and for sale to the grid. If there is excess biogas, the biogas may be used on the farm for heating water, drying grain or used at the digester to dry the separated solids after composting.

Environmental Benefits

- Odors are reduced at all locations.
- Methane is captured in the digester and less methane is produced in the long-term storage tanks.
- Solids are more available for sale as soil amendments, which can be used to reduce soil erosion.

Figure 14
Schematic of community digester system with separation after digester

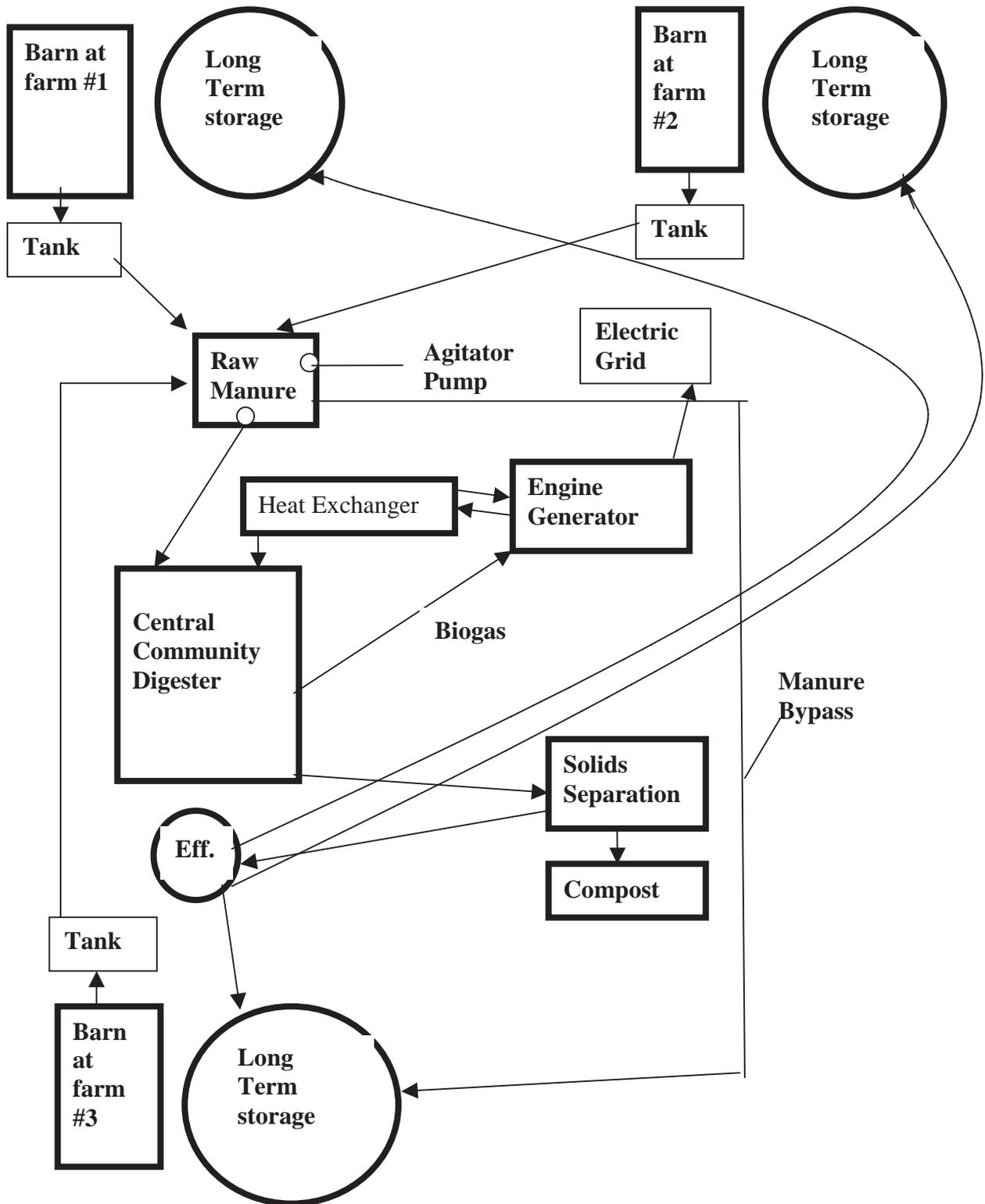


Table 11 Economic Information for 1000-Cow Community Digester System #6

	ITEMS	COSTS/BENEFITS
CAPITAL COSTS	Digester	
	Digester tank and materials	\$100,000
	Partial building cost	\$30,000
	Backup boilers	\$10,000
	Mixing Tanks	\$30,000
	Subtotal	\$170,000
	Solids and liquids separation	
Separators (2)	\$90,000	
Composter and/or dryer	\$30,000	
Building and equipment	\$30,000	
Subtotal	\$150,000	
	Liquid storage (not included)	\$0
	Engine generator (150kW)	\$150,000
	Electrical switch gear	\$20,000
	Engineering design and other	\$60,000
	Subtotal	\$230,000
	Total capital cost	\$550,000
	Annual capital cost	\$55,000
ANNUAL OPERATING COSTS	Maintenance, repairs, labor, fuel, insurance, reports, etc.	\$51,000
	Hauling manure to/from digester	\$49,000
	Subtotal	\$100,000
ANNUAL BENEFITS INCLUDING	Bedding material replacement, sales of solids	\$90,000
	Electricity generated and sold to local farm and to grid	\$58,000
	Reduction of odor benefit for 3 farms	\$45,000
	Subtotal	\$193,000
ANNUAL COST PER COW (\$/COW/YEAR)	NOTE: This is a net benefit to the system	-\$38

NOTE: The costs shown above are approximate and will vary for each individual circumstance.

The capital and operating costs for 1000 cows on 3 (or more) farms located no more than 0.5 miles from the digester located at one of the dairy barn sites.

- The phosphorus that is contained in the solids can be exported out of the watershed in the solids thus reducing the impact on water pollution.
- The nutrients are kept out of the streams when application of the liquid from the long-term storage is less in volume and can be efficiently hauled to cropland.
- If the solids are used as bedding replacement, then less bedding has to be imported using fossil fuels for transport and handling.

Table 12 Advantages and Disadvantages of Community Digester System #6

ADVANTAGES	DISADVANTAGES
Odor control	Higher capital cost
Pathogen reduction	Higher operating cost
Bedding savings	Need for daily management of digester system
Nutrient reduction	Need for hauling
Less risk for each farm	Have to have cooperation to make work
Central person running digester	Possible disagreements
Economies of scale	Requires farms to be close and cooperative
Can be run as a separate business	for hauling to be minimal
Marketing of the solids is more probable than from an individual	Farmers prefer getting less manure back to farm
Possible to scale up and add other materials to the input stream	

Lessons Learned from Similar Digesters

- Hauling can be very costly if done by a contract carrier.
- Hauling is difficult to schedule.
- Environmental regulations may be more stringent on central digester.
- A well-trained, capable enthusiastic operator is needed with a trained backup available.
- A plan must be in place to address what happens if a partner ceases farming.

Who to Contact about Similar Digesters

Port of Tillamook Bay MEAD project. www.potb.org/methane-energy.htm

References with Information Relevant to this Design

www.potb.org/methane-energy.htm



Figure 15
Tanker delivering
manure to a community
digester system

photo by MEAD Project



Figure 16
Multiple digester cells at
a community digester

photo by MEAD Project

Energy Conversion Systems

The topic of energy conversion systems is being addressed separately from the digester systems. Smaller digesters do not produce large amounts of energy that can be converted into forms other than heat for the digester or for hot water. The complexity of adding the energy conversion system to a small digester system may be better handled as an add-on at a later time. Options for adding generators for electrical conversion are handled here and not considered in the planning for the digester. Several other possible options for use of the energy are explored because the option for connecting to the grid has become difficult due to the lack of enthusiasm by the power companies in Minnesota to purchase power from small operators at a reasonable price. Legislation has not kept up with legislation in some other states where the net metering is required. Different types of conversions options to make electrical energy from the biogas are explored first.

Engine Generators

An engine generator set (genset) connected to an induction generator can be interfaced to the power grid. The heavy-duty gas fired engines are not normally made in small sizes that match the output of the small digesters serving 100 cows. But for 300 cows, this is more reasonable. An engine generator set will cost approximately \$100,000 including installation. These can be obtained from suppliers who also sell backup power systems.

The normal backup generators are not able to perform this function because the digester produces dirty gas and they will not run continuously on dirty gas. They are also self-excited and cannot be connected to the grid.

Figure 17
Engine generator set that could be used to convert biogas to electricity

photo by Phil Goodrich





Figure 18
A microturbine and compressor that could be used to convert biogas to electricity

Microturbines

A micro turbine generator coupled to induction generator can be connected to the grid. These are available in 30kW sizes and will match to a digester serving about 200 cows. A ratio of 5-8 cows per kW is reasonable to use in sizing a micro turbine or a generator system.

A microturbine must have a compressor to raise the pressure of the biogas for the intake. Compressors have serious problems with wet gas so a filter to remove water must be placed ahead of the compressor. Early adopters of micro turbines have had severe problems with compressor failure and problems with heat exchangers to reclaim energy from the exhaust on the micro turbine. Care must be exercised to evaluate the provider of the micro turbine and the compressor system to make sure that it will work. Purchasing an older model of either a compressor or a microturbine is purchasing problems that have not been fixed. A microturbine with compressor and heat recovery unit will cost about \$75,000 plus installation.

Natural Gas for Off Farm Sale

Cleanup systems can produce compressed natural gas that is piped to a user normally buying from a natural gas pipeline supply. This method of exporting the energy fits best when the potential user (purchaser) is located close to the digester. Potential purchasers may include greenhouse operators, cheese plants and industries using heat in their processes. The cleanup process is not simple if the carbon dioxide has to be removed in addition to the hydrogen sulfide that is usually present in biogas from digesters.

Fuel Cell

Another possible means of energy conversion is a cleanup system producing high purity methane fed to a fuel cell that produces electricity for the grid. This is a highly experimental system and not one that should be contemplated at this time.

Hydrogen Gas for On-farm Use

Another system would be a cleanup system producing high purity methane that is converted to hydrogen for sale to hydrogen users such as power plants, biorefineries, chemical plants, or motive hydrogen consumers. Again this system does not fit well with a smaller digester system because of the complexity of the filters needed.

Figure 19
A 5 kW fuel cell for
conversion of natural
gas to electricity for
the grid

photo by Phil Goodrich



Conclusion

Although this report is a good first step in exploring options for anaerobic digesters on average sized farms, it is by no means the final or last step in determining appropriate models. Anaerobic digester projects are rapidly developing across the country. Technology is also developing to accommodate the agriculture interest in installing digesters on farms in the U.S. It is expected that new technologies will be available in the future that would be best suited for average sized farms. The Minnesota Project will continue to be involved in this field gathering and disseminating information for greater Minnesota.

The next step for the Minnesota Project as a result of this report is to install and study a pilot project using one of the systems identified in this report at a dairy farm in Minnesota. The pilot project will be partially funded by the Environment and Natural Resources Trust Fund, recommended by the Legislative Commission on Minnesota's Resources. If you are a dairy farmer with 300 cows or less and are interested in participating in a pilot project, please contact Amanda Bilek at 651-645-6159 x. 5

Additional References

Agricultural Biogas Casebook 2004: www.cglg.org/biomass/AgriculturalBiogasCasebook.pdf

AGSTAR program EPA and USDA joint program for encouraging methane recovery. Includes lists of experts, assistance programs and tools. www.epa.gov/agstar/index.html

AURI website: www.auri.org/research/digester/digfull.pdf

Canadian manure site: http://res2.agr.ca/initiatives/manurenet/en/man_digesters.html

Cornell Manure Management site: www.manuremanagement.cornell.edu/

Global Energy www.globalmicroturbine.com/biogas.htm

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