Biogas Production from Animal Manures: What Is the Potential?

by

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Abstract: Livestock producers who operate large-scale confinement operations, such as dairies and hog farms, are looking for ways to handle and dispose of animal wastes that are cost effective and meet odor and pollution regulations. Farm-level production of biogas (using anaerobic digesters) is one solution for livestock producers that also will help control methane emissions into the atmosphere. Methane is a greenhouse gas that contributes to potential global warming. Biogas is 60- to 65-percent methane; carbon dioxide and trace amounts of water and other gases, such as hydrogen sulfide, account for the remaining 35 to 40 percent. It is a medium-Btu fuel that can be used to generate electricity or burned in natural-gas or propane boilers and space heaters. Heat, fertilizer, and soil amendments are coproducts of the digestion process that contribute to its economic viability.

In general, with current technologies, anaerobic digesters require warm climates, large volumes of manure, high local electricity rates, and daily maintenance and management to be profitable. The Federal government, through the AgSTAR Program, is promoting biogas production as a way of generating extra income for farmers, reducing greenhouse gasses, and improving water quality. Four case studies demonstrate that farm-level production of biogas is feasible under local conditions.

Keywords: livestock manure, methane, anaerobic digesters, biogas.

Methane-recovery systems and anaerobic digesters first gained popularity in the United States during the 1970's. At the time, alternative energy sources were promoted due to the rising costs of petroleum-based energy. Both state and Federal agencies provided financial assistance to help construct farm-level, methane-recovery systems. However, many systems were overdesigned and difficult to maintain. Subsequent failure and/or poor performance of a number of anaerobic digesters reduced confidence in these systems. Since then, improved technology and increased concern for the environment have renewed interest in the feasibility and use of methane-recovery systems.

Managing Animal Wastes To Minimize Pollution

The major problems associated with livestock and poultry manure include: surface water and groundwater contamination from nitrogen and fecal bacteria; methane emissions from anaerobic digestion of manure; and air pollution resulting from the formation of odor, dust, volatile organic acids, and ammonia.

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The first comprehensive Federal efforts to improve water quality were implemented in the early 1970's with the passage of the Clean Water Act (CWA). The initial focus of the CWA was on regulating point sources of pollution, primarily municipal sewers and industrial plants. Subsequently, agricultural point sources were targeted, including livestock production systems that use manmade structures, such as feed pens, confinement buildings, slurry tanks, pipes or culverts, holding ponds, lagoons, irrigation systems, and dead-animal disposal facilities.

Concentrated animal feeding operations (CAFO's) are considered point-source polluters. Livestock production is included under the CAFO definition if:

- Animals are stabled or confined and fed for 45 days or more in a 12-month period;
- Vegetation is not sustained during the normal growing season in any portion of the lot or facility;
- The feedlot must have either 1,000 animal units and discharge pollutants, or between 301 and 1,000 animal units if pollutants are discharged into navigable waters through a manmade conveyance or into navigable waters that originate outside of, but come into contact with, the area used by the operation;

- Pollutants are discharged in absence of a 25-year-frequency, 24-hour-duration rain storm (a theoretical "super storm" as defined for each specific state and region).

Smaller facilities with less than 300 animal units may be designated as point-source polluters if they present a significant risk to water quality by discharging directly into navigable waters through the facility or through a manmade conveyance. These facilities are evaluated on a case-by-case basis, but most are classified as nonpoint sources of pollution and face a different set of regulations.

Livestock production facilities that are considered point-source polluters must obtain a National Pollutant Discharge Elimination System permit as mandated by Section 402 of the CWA. Livestock point sources are regulated by the U.S. Environmental Protection Agency (EPA) or state environmental agencies acting on its behalf.

The CWA also created a program to control nonpoint sources (NPS) of pollution and to protect groundwater. Section 319 of the act requires each state to submit an assessment of state waters not expected to meet water quality standards because of nonpoint-source pollution and submit a management program for controlling such pollution. The NPS program has evolved more slowly than efforts to control point-source pollution because the latter was easier to regulate and more cost-effective to implement. More recently, NPS pollution has received additional attention, and controlling it has typically involved implementing best management practices (BMP) rather than enforcing specific regulations. Most BMP's include educational, technical, and financial incentives designed to encourage better land- and resource-management practices, plus more prudent use of pesticides and fertilizers.

In response to these water-pollution regulations, livestock producers have built containment facilities--such as lagoons, ponds, and other types of storage devices--to prevent runoff and leaching of nutrients from animal manure. While the actions have helped to reduce water pollution, they have actually increased methane emissions. Under the anaerobic (oxygen-free) conditions that exist in the containment facilities, bacteria convert the organic matter in manure to methane.

Methane released into the atmosphere is a large contributor to potential global warming, second only to carbon dioxide. Methane is 60 times more effective at trapping heat in the atmosphere than carbon dioxide over a 20 year period. Methane concentrations in the atmosphere have more than doubled over the last two centuries and continue to rise annually. Because methane has a short lifespan in the atmosphere (11 years compared with 120 years for carbon dioxide), controlling emissions will have a rapid impact on mitigating potential climate change (1).

The Federal government does not have formal rules or regulations regarding methane emissions from agriculture. However, the AgSTAR program, initiated by EPA's Global Change Division, is currently assessing the technical and economic feasibility of capturing methane for conversion into energy sources for farm use.

Several states account for most of the methane emissions from animals. An EPA study estimated that in 1990 methane emissions from dairy and hog production in the United States were 734,000 metric tons and 1.1 million metric tons, respectively (table A-1). Emissions from dairy farms were highest in California, while hog farm emissions were high in Missouri, Iowa, Illinois, North Carolina, and Indiana.

Converting Manure into Biogas?

Anaerobic digesters use bacteria to convert manure into biogas, which is a combination of 60- to 65-percent methane (CH_4), carbon dioxide that accounts for most of the remaining 35 to 40 percent, and trace amounts of other gases, such as hydrogen sulfide and ammonia. These digesters operate under anaerobic conditions and within certain temperature ranges. The methane in biogas can serve as a replacement for natural gas to produce heat or electricity. In addition, anaerobic digesters stabilize the remaining manure solids into a nearly odorless product that can be used as a soil amendment and fertilizer.

The potential for anaerobic digestion of animal manure in the United States depends on the manure handling practices used by producers and the size of their operation. Methods of manure disposal vary widely depending on the type of animal (table A-2). Some practices are more amenable to biogas production than others. For instance, manure left by beef cattle on range or pasture is not economically collectable for anaerobic digestion or other

Table A-1--Methane emissions from dairy and hog facilities in selected states, 1990

State	Emissions
	Metric tons/year
Dairy	
California	174,978
Texas	63,708
Missouri	54,522
Washington	44,031
Wisconsin	22,335
Other states	374,062
Total	733,636
Hog	
Missouri	127,050
Iowa	117,518
Illinois	113,213
North Carolina	103,261
Indiana	90,224
Other states	572,011
Total	1,123,277

Source: (6).

uses. An estimated 90 percent of poultry manure is collected using solid disposal systems. While most of this manure is economically collectable, feathers and certain types of poultry litter can clog anaerobic digesters.

Manure production from a 1,250-pound Holstein milk cow is estimated at 1.75 cubic feet per day (table A-3). Also, a sow unit (sow and pigs) is expected to produce a similar volume of manure on a daily basis. Biogas production from a properly functioning anaerobic digester using these sources is estimated to range from 54 to 56 cubic feet per animal per day. The actual volume of biogas will vary depending on the type of manure-collection system. For instance, one farmer estimated that, using a flush manure-handling system on his farm, manure from one dairy cow will produce 60 cubic feet of biogas per day, while a scrape system will yield up to 85 cubic feet per day.

Over 20 private methane-recovery systems are in operation across the United States. An additional six experimental systems are housed at various universities (6). Although there are many different types of digesters that could be used by livestock producers, only covered lagoons, plug-flow digesters, and complete-mix digesters are used on livestock farms due to capital investment and management requirements.

The simplest anaerobic digester is the lagoon. Manure progresses naturally through all three chemical stages of methane formation. Significant quantities of biogas can be produced from a covered lagoon system that is properly designed and in which the manure is held over 60 days (6). A floating cover is placed over the lagoon and biogas is collected underneath the cover. Maximum biogas generation occurs in the summer, while the rate of gas production decreases with colder temperatures. Some gas can be stored under the cover and used later; however, long-term storage is not economical.

Plug-flow digesters are designed to accept a daily plug of new manure. As a new plug is added, an equal amount of effluent is discharged from the opposite end of the digester. The retention time for most plug-flow digesters is between 20 and 30 days. Most plug-flow systems are designed to move manure and effluent by gravity, thus eliminating the need for pumps. In addition, plug-flow digesters must be designed to prevent the passage of air into the digester when manure is added, as well as when effluent is discharged.

Complete-mix digesters are usually constructed for livestock operations that generate large amounts of low-solids manure (6). The basic concept is similar to the

Table A-2--How manure is handled in the United States 1/

Livestock and poultry type	Liquid disposal			Solid disposal		
	Anaerobic lagoons	Liquid slurry and pit storage	Daily spread	Solid storage and drylot	Pasture, range, and paddock	Litter, deep pit, and others
	Percent					
Dairy cattle	10	23	37	23	0	7
Nondairy cattle	0	1	0	14	84	1
Poultry 2/	5	4	0	0	1	90
Sheep	0	0	0	2	88	10
Swine	25	50	0	18	0	6
Other 3/	0	0	0	0	92	8

1/ Totals may not add due to rounding. 2/ Includes chickens, turkeys, and ducks. 3/ Includes goats, horses, mules, and donkeys.
Source: (5, 6).

Table A-3--Manure production from various livestock, and biogas yield from a properly functioning anaerobic digester

Animal	Average animal weight	Manure production 1/	Expected biogas yield	Recommended retention time	Electricity production 2/
	Pounds	Cubic feet/day	Cubic feet/animal/day	Days	kW hours/day/animal
Holstein milking cow 3/	1,250	1.75	54.00	20	2.00
Beef feeder steer	800	1.00	25.00	15	1.00
Feeder pig	130	0.16	5.60	15	0.20
Sow and litter 4/	1,300	1.75	56.00	15	2.00

1/ Solids, liquids, and 15 percent extra volume from waterers and wash water. 2/ Assumes biogas has an energy value of 600 Btu per cubic foot and the generator operates at 21 percent overall efficiency. 3/ Increase digester volume by 50 percent if manure from dry cows and replacement stock is added. 4/ The average weight of a productive sow and pigs at any time from farrow to finish. A sow produces an average of 16 pigs annually.
Source: (3).

plug-flow digester. Animal manure is collected in a mixing tank and then transferred to the digester. Because the manure is mixed, it creates a good environment for biogas production. The system does not have a fixed retention time due to the way the manure is added and mixed.

In order to protect the digester and to maintain the necessary temperatures for biogas production, some producers enclose their systems in greenhouses or build wind fences around them, while others recycle generator heat back to the digester. Greenhouses also can be built near digesters to use excess heat when needed and carbon dioxide to stimulate plant growth.

Actual purchase and installation costs for anaerobic digesters vary widely. However, costs developed for a 1,000-cow dairy operation in a warm climate give an indication of investment required. The estimates--$145,000 for a covered lagoon, $154,000 for a plug-flow digester, and $213,000 for a complete-mix system--include the purchase of an engine generator to use the biogas and the assumption that 55 percent of the dairy manure will be collected and processed. The life expectancy of the complete-mix digester is estimated to be 20 years, while the others are 15 (2).

Of the three types of systems, covered lagoons appear to be an economical choice for swine and dairy farms in the Southeast and West that use hydraulic flushing for manure collection and a lagoon system for their waste handling system (2). Lagoon systems as far north as North Carolina have proven successful in economically producing biogas for most of the year. A plug-flow-digester system is more expensive than a covered lagoon, but it still can be economically viable option under certain climatic conditions, depending on the value received for the coproducts of the process (heat, carbon dioxide, and fertilizer/soil amendments).

Complete-mix systems have higher capital, operating, and maintenance costs than lagoon or plug-flow digesters (table A-4). Therefore, the complete-mix system is probably best suited for large livestock operations that are in climates too cold for covered lagoons or those that handle manures with low solids content (2).

Table A-4--Characteristics of selected types of anaerobic digesters

Digester process	Process complexity	Operational complexity	Capital costs	Operating costs
Covered lagoon	low	low	low	low
Plug flow	low	low	low	low
Complete mix	medium	medium	medium	medium

Source: (7).

Using Biogas on the Farm

Biogas produced from farm-level, methane-recovery systems is a medium-Btu-content fuel. Technologies exist to remove impurities to produce a higher quality fuel. The amount of clean-up that is necessary depends on the composition of the biogas and its intended use. Primary objectives of clean-up processes are usually either to remove the corrosive elements (hydrogen sulfide and water vapor) or to remove both the corrosive elements and those elements that dilute the methane level in the biogas and its heating value (carbon dioxide and nitrogen). Although the removal of sulfur is sometimes recommended to avoid excessive engine wear, some methane-recovery systems have been very successful without cleaning the biogas before is it used to fuel an engine generator. High-quality oil changed at regular intervals is cheaper and as effective as sulfur-removing mechanisms.

Fueling engine generators, boilers, and space heaters are the most common farm uses of biogas. Most livestock producers that install an anaerobic-digestion system to dispose of animal waste will burn the biogas in an engine generator to meet the farm's electrical demands, produce heat and fertilizer, and sell any excess electricity to a local utility company.

Small engine generators usually convert only 20 to 25 percent of their fuel, such as biogas, into electricity (3). A majority of biogas energy is actually converted into heat. In order to utilize this energy, heat exchangers for the exhaust system and engine coolant are used to recover 40 to 50 percent of the energy. This heat can be used to maintain the correct temperatures for anaerobic digestion and other purposes, such as heating water for cleaning equipment and facilities.

Selling the excess electricity to the local utility company may involve installing an automatic interrupting device, which can isolate the farm generator from the utility lines when there is a loss of power by the utility or a fault in the generator's circuitry.

Natural-gas and liquid-propane-gas appliances (boilers and space heaters) will operate on biogas. However, the lower energy density of the biogas results in reduced heat output (3). In order to maintain necessary levels of heat generation, relatively inexpensive modifications are sometimes necessary. This is usually done by enlarging the size of the orifice to allow more gas to pass through to the appliance. Assuming a 65-percent methane content, biogas would require an orifice 1.39 times larger than the one for natural gas or 1.72 times larger than the one for propane to maintain a constant temperature.

Barriers to Using Methane-Recovery Systems

There are informational, managerial, and financial barriers to widespread use of methane-recovery systems. Many digesters built during the 1970's failed because of poor design, improper maintenance, or low local electricity prices (6). While the technical problems have been mostly resolved for commercial-sized livestock operations, more demonstrations of successful systems are necessary to verify operation on a continuing, dependable, and economical basis.

Careful management is essential to maintaining optimum digester conditions and output. Although most managers of large livestock operations have little time to devote to other activities, anaerobic digestion and electricity generation is an additional enterprise that must be looked after on a regular basis. Unlike the 1970's, however, today's technologies require less management. The problems that must be dealt with include variable quantities and qualities of manure, inadequate heat maintenance, and buildup of nondegradable materials in digesters.

The main financial barriers that exist for livestock producers interested in methane-recovery systems are initial design and installation costs, limited access to capital, and low buy-back rates for the electricity from local utilities.

AgSTAR Promotes Use of Digesters

The goal of the AgSTAR program is to help livestock and dairy producers lower capital, operational, and maintenance costs; control odor and methane emissions; maintain water quality; and utilize a renewable domestic energy source--by encouraging more widespread use of methane-recovery systems. In addition to EPA, USDA and the U.S. Department of Energy are also involved in the program. AgSTAR is considered a key component of President Clinton's Climate Change Action Plan, which promotes U.S. ingenuity and efficiency as solutions to global warming.

AgSTAR, a voluntary program, was designed to help producers overcome obstacles to adoption. Once fully operational, it will have three components: the Partner Program, the Ally Program, and the Utility Program (4). The Ally and Utility Programs are aimed at people who design, promote, build, sell, and install manure digesters. EPA will work with utilities, universities, private firms, and others to promote reliable methane-recovery systems, provide information, and develop financing mechanisms.

The Partner Program encourages livestock producers to investigate the viability of constructing and implementing a methane-recovery system. To become an AgSTAR partner, a producer signs a Memorandum of Understanding with EPA. The producer agrees to survey his/her facilities, install AgSTAR-selected technology where profitable, and appoint a manager to oversee participation in the program.

In return, EPA provides technical support. For example, producers receive a methane-recovery handbook and reference guide for specific livestock-rearing methods and manure-management strategies. Included in the manual are topics such as odor control, technical design, energy applications, economics, case studies, financing options, manure-management principles, and nutrient-management strategies. Producers who enroll also have access to a computer software package that enables them to survey their facilities, assess energy options and applications, and select the most profitable digester. The software will generate financial reports that allow managers to compare the economics of a present waste-management system with a methane-recovery system. AgSTAR will also manage high-visibility demonstration projects and provide a directory of participants.

What Are the Economics?

Livestock producers and dairy farmers must deal with disposing of animal waste products, including manure. Anaerobic digestion of animal manures can make economic sense for farmers in some cases when they are used to generate electricity, heat, fertilizers, and soil amendments for farm use. Using digesters to produce methane to sell off-farm does not make sense because the gas is not pure enough for natural gas companies and there is no pipeline collection system in place. Electricity generated in excess of a farm's needs often can be sold into the local electric power grid. Prices received vary from a low of 3 cents per kilowatt hour to a high of 15 cents. The variation is due to different local rates, the need for additional electricity in the region, the need for enhanced environmental quality, and other factors.

Producing biogas solely for electricity generation requires rates greater than 6.5 cents per kilowatt hour. Values associated with coproducts enhance the economic feasibility of any system, especially when rates are below 6.5 cents. Society must also recognize the importance of reducing methane emissions, controlling odor, improving water quality, and generating rural economic activity.

A recent study evaluated covered lagoons, plug-flow digesters, and complete-mix systems using three investment strategies: net present value, internal rate of return, and simple payback period (2). In many cases, covered lagoons were found to have an economic advantage due to lower capital, operating, and maintenance costs. However, lagoons are usually limited to relatively warm regions. Moreover, the results are sensitive to local electricity prices and coproduct values.

Most analyses suggest that only larger livestock operations would be able to economically justify a methane-recovery system. Most dairies require at least 500 head of milking cows and most swine operations require at least 2,000 to

3,000 head for a methane-recovery system to be economically viable (based on 1993 electricity prices, an average milking cow weight of 1,400 pounds, and an average hog weight of 138 pounds) (6).

Although a major portion of U.S. milk production originates in the northern Midwest, the dairies there have relatively small herds. Combined with the cold climate, these operations are generally not the best candidates for manure digesters. Opportunities exist, however, for large dairies in California, Arizona, Texas, and Florida and emerging large-scale operations in New Mexico and Kansas.

Similar circumstances exist for swine herds. A majority of hogs in the United States are raised in Iowa, Illinois, Indiana, Missouri, and North Carolina. Most of the hogs raised in Iowa, Missouri, and Indiana come from small herds. However, large increases in hog numbers by a few vertically integrated hog producers in North Carolina, Arkansas, and Missouri are rapidly changing the structure of the hog industry, which could make anaerobic digestion more feasible.

Case Studies Show Methane-Recovery Systems Can Be Profitable

While the technical and economic feasibility of biogas production is site specific and highly dependent on system management, the following case studies provide information on several livestock operations that have been successfully producing biogas.

Mason Dixon Farms, Gettysburg, PA, is a 2,700-head dairy cow operation. The owner built his first anaerobic digester in 1979 when the operation had 600 cows. As the herd expanded, a second and third digester were added to the biogas system. All three digesters are located underground, which allows for a relative constant digester temperature through the year, thus minimizing weather-related problems. The owner expanded the digestion system because he found that anaerobic digestion was a profitable way to handle animal waste.

In addition to generating electricity, odor reduction is a very important characteristic of the digesters because the farm is located near populated areas. The nitrogen in manure is in the form of ammonia, which is very volatile. During the digestion process, the ammonia changes to ammonium nitrate, which is more stable. The owner also uses the system's liquid effluent as a fertilizer for cropland and sells the remaining solids to area nurseries as a soil amendment. The pH level of this farm's manure is around 4.5, but the digested effluent has a pH level of 7.3 to 7.5. Therefore, liming the cropland is no longer necessary.

The owner has invested $250,000 (1991 dollars) in the system. After considering maintenance costs, the value of generated electricity, and the effluent, the net annual income from the system is around $90,000 per year. He emphasized the importance of maintaining the specific herd population for which the digesters were designed. He does not clean his biogas prior to use, and the three engine generators have operated for several years with normal wear and no unexpected operational problems.

Langerwerf Dairy, Durham, CA, is a family-owned operation with a 500-head dairy cow herd and 300 acres of cropland. In 1982, they installed a plug-flow digester to produce electricity, hot water, composted solids, and liquid fertilizer. The decision was based on the rising costs of energy and the problems and costs associated with manure disposal. The annual cleanout of the existing manure lagoon was costing from $10,000 to $15,000.

Manure is scraped from the dairy barns daily and deposited into a 20,000-gallon mix/holding tank. The mixed manure is pumped from the tank to the anaerobic digester, which holds 225,000 gallons. The collection bag can store about one-third of a day's biogas production. They now have a greenhouse over the digester to protect the top from weather and wind damage.

The biogas is piped through a filter before reaching the engine generator set. The filter removes most of the water and hydrogen sulfide. The engine/generator set is a 85-kilowatt (kW), induction-type generator powered by a six-cylinder Caterpillar 3306 natural-gas engine. The engine was modified to run on lower Btu biogas. The generator produces, on average, 40 kW of electricity per day. The dairy uses about 35 kW and the excess is sold to the local utility. Waste heat from the engine's cooling system and exhaust are used to provide hot water for the dairy and help maintain the temperature of the digester.

The effluent is pumped to a vibrating screen that separates the solids and liquids. The solids are sold to landscaping businesses, used as a soil amendment, or spread as a bedding material for dairy cows in the freestall barn. Liquids are applied to cropland as a source of fertilizer. The liquid effluent remaining after the anaerobic process has very little smell, which reduces the potential for odor problems in a densely populated area.

The system requires about a half an hour of labor each day. The Langerwerfs experienced premature engine problems when they first started their system and had to rebuild the engine after 5,000 hours of operation, well short of the normal 24,000 hours. Since then, they have changed the type of engine lube oil. Testing after 6,000 hours showed engine wear to be within normal limits.

The total installed cost, including site improvements and repair costs in the first couple of years, was $203,800. An 8-year economic analysis of this system shows a total cost for capital, interest, labor, and maintenance to be $324,968. Some of the credit was obtained on preferential terms. Total income for those 8 years was estimated to be $692,900. The annual return on investment without considering tax credits is almost 30 percent and over 50 percent when tax credits are included.

Royal Farms, Tulare, CA, is an 8,000-head, farrow-to-finish hog farm. About 2.5 tons of manure solids are removed from the barns each day by flushing the confinement houses with water. The water-flush system uses 50-percent new water and 50-percent recycled water. The manure slurry is pumped into an anaerobic lagoon system. The biogas that is produced fuels a 75-kW engine generator. The electricity produced is used on the farm, with the excess sold to the Southern California Edison Company.

The initial capital investment was $89,000. First-year revenue from the electricity was about $36,000. The payback period for the system was about 3 years.

Harlan Keener, Lancaster, PA, owns a sow farrow-to-finish operation. He added a manure digester in 1984 when he expanded from 600 sows to the current 990. Potential problems with the laws regulating odor emitted from his confinement system prompted Mr. Keener to construct an anaerobic digester for his operation.

Manure is moved by a sump pump from the confinement houses to two mixing pits, each of which can hold up to 25,000 gallons of animal waste. Twice a day, the manure slurry is pumped into the digester. The digestion process takes 18 to 23 days, depending on conditions. A heavy rubberized tarp that covers the 350,000-gallon digester collects the biogas, which is then piped into the generator. Keener's system produces an average of 125 kW on a continuous basis and can be used to supply the farm's electrical needs or sold to the local utility company. The effluent contains 1-percent solids and is stored in a concrete holding tank or two holding ponds until it is used by area farmers as fertilizer for their cropland.

Conclusions

The production of biogas by anaerobic digestion of manure will reduce methane emissions into the atmosphere if the gas is collected and used for heating or to generate electricity. While technical barriers that occurred during the 1970's have largely been overcome, economic viability of farm-level methane-recovery systems depends on the size of livestock operation, management capabilities, and the value of the biogas products. Livestock producers across the United States have profitably used all three types of digestion systems--covered lagoon, plug flow, and complete mix. While the case studies have been successful and generated high rates of return, other systems have failed because of poor design and inadequate management.

Much of the current interest in anaerobic digesters is from large operations in milder climates. However, as the Mason-Dixon-Farms case study proves, cold-weather operations are both possible and profitable. In the case studies, producers were able to recoup their initial investment in equipment and facilities in about 3 years. While this is an excellent return on investment for agricultural enterprises, such a rate should not be expected for all installations.

After a system has been properly designed and installed, management of the enterprise is the key to success. Producers must be willing to devote to the system the time and effort required to assure continued profitable operation.

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