ANAEROBIC DIGESTERS ON WISCONSIN FARMS

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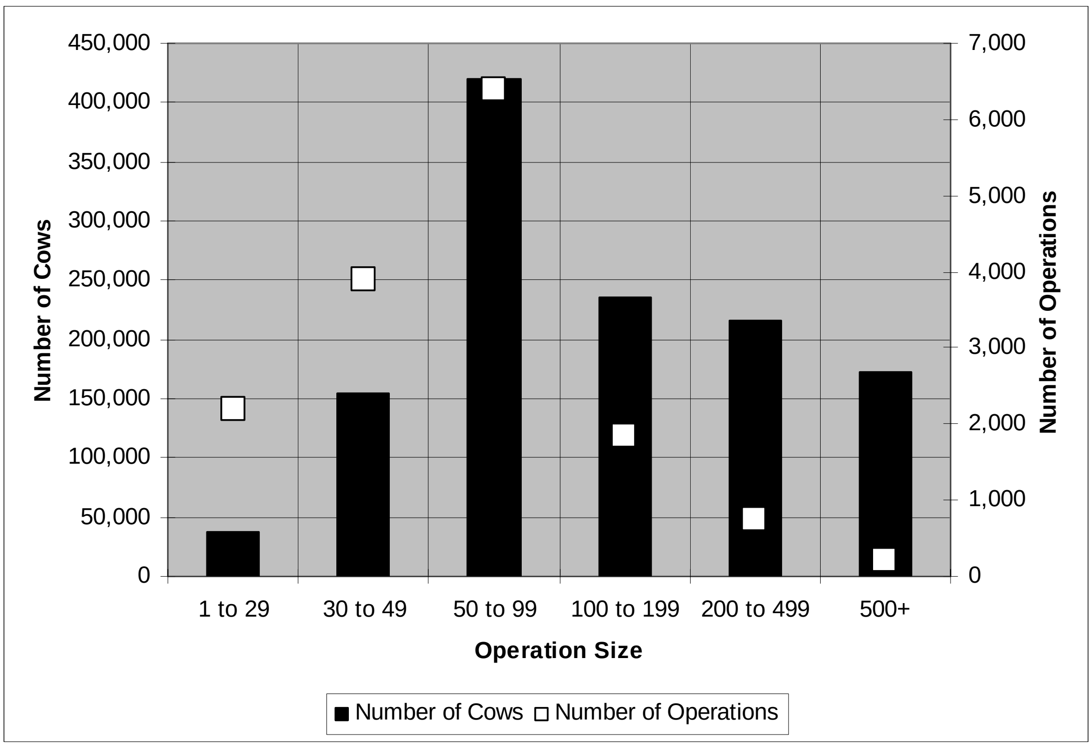
Introduction

It is difficult to understate the dairy industry's significance to Wisconsin. It has been estimated by the University of Wisconsin that the dairy industry contributes approximately $20 billion annually to the state's economy and is a key component to the economic well-being of rural communities. As shown in Figure 1, most of Wisconsin's 1.2 million head of dairy cattle reside on operations with a herd size between 50 and 99 head, with the average herd size for Wisconsin dairy farms being just over 80.

Figure 1: Number of dairy farms and dairy cows in Wisconsin by operation size (Source: Wisconsin 2006 Agricultural Statistics, 2005 Numbers).



It can also be seen in Figure 1 that there were at least 200 herds with more than 500 dairy cows operating in the state in 2005, accounting for approximately 173,000 head. These large dairy operations are different from the more traditional smaller farms in many regards. Most notably, they are more capital intensive and tend to concentrate the environmental problems associated with manure management, which often results in increased environmental scrutiny from neighbors and environmental groups regarding issues such as manure storage, odor and land application.

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Anaerobic digestion systems have been increasingly viewed as an attractive option for larger dairy operations, in part because they mitigate some of the previously mentioned environmental issues, such as odor, and also have the potential to provide economic benefits to the farm from electrical generation, the use of digested solids as animal bedding, and other more long-term benefits such as a reduction in greenhouse gases. The capital intensive nature of these larger dairy farms provides a context in which the considerable investment required for an anaerobic digester may be justified, particularly if the digester significantly offsets operating costs or, even better, provides an additional and diversifying new revenue stream. Nationally, the number of digesters has more than doubled over the past two years due to a diverse array of national, state, and local activities to market, cost share and reliably develop operational systems (AgSTAR, 2006). This paper presents a basic overview of anaerobic digestion system technologies and how these technologies have been utilized by Wisconsin dairy farms, as well as potential costs and benefits associated with these systems.

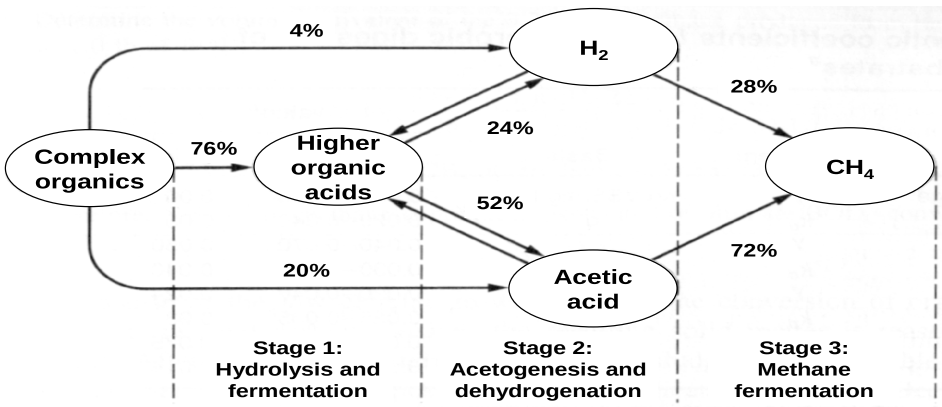
The Anaerobic Digestion Process

Anaerobic digestion can be defined as the biological utilization of organic matter by microbes in an environment in which there is no molecular oxygen. The anaerobic digestion process is thought to occur in three steps, as shown in Figure 2. The first step in the process (hydrolysis) involves the enzyme-mediated transformation of higher molecular-mass compounds into compounds suitable for use as a source of energy and cell carbon. The second step (acetogenesis) involves bacterial conversion of the compounds resulting from the first step into identifiable lower molecular-mass intermediate compounds (like volatile fatty acids). The third step (methanogenesis) involves the bacterial conversion of the intermediate compounds into simpler end products in the form of biogas (Metcalf and Eddy, 1991). The biogas produced during the anaerobic digestion process is typically made up of 55 to 65% methane (CH_4), 35 to 45% carbon dioxide (CO_2), and traces of ammonia (NH_3) and hydrogen sulfide (H_2S). Pure methane is a highly combustible gas that has an approximate heating value of 994 BTU/ft^3 and can be burned in boilers to produce hot water or steam, in engines to power electrical generators, and in absorption coolers to produce refrigeration. Anaerobic digestion may occur at either mesophilic (90° to 105°F) or thermophilic (120° to 135°F) temperature ranges. Digestion at thermophilic temperatures may allow for a higher rate of degradation, which in turn allows for smaller reactors, lower associated capital costs, faster solid-liquid separation, and better control of bacterial and viral pathogens. However, thermophilic systems require more heat to be added to maintain digester operating temperature than mesophilic systems, which can be a significant issue in climates such as that found in Wisconsin.

Types of Anaerobic Digesters

The three most common types of anaerobic digestion systems available for use on dairy farms include covered lagoons, plug flow systems and complete mix systems. Covered lagoons are typically used for large volume, low solids manure and consist of a simple lagoon with an impermeable cover that traps gas generated during the anaerobic decomposition of the manure. Covered lagoons, which are by far the lowest cost systems, are capable of achieving odor reduction, but the amount of energy recovered is minimal and often not enough to justify the capital expenditure for the electrical generation equipment. Covered lagoons often require long detention times of 60 or more days and do not use mixing or temperature control, which makes them particularly sensitive to their local climate, which again would be a potential drawback in Wisconsin. Nationally, covered lagoons account for approximately 20% of all operating farm anaerobic digestion systems, which includes those in start-up and construction (AgSTAR, 2006).

Figure 2: Steps in the anaerobic digestion process (Source: Metcalf and Eddy, 1991).



The second type of digester is referred to as a plug flow digester. This type of system is for high solids manure, which moves through the system in what is considered to be a plug, with little mixing occurring in the system. Plug flow digesters generally operate at mesophilic temperatures (90° to 105°F) and employ a rigid or flexible cover to collect gas. They are temperature controlled with detention times of approximately 15 to 30 days. Solids deposition is a potential problem for plug flow systems if sand or grit get into the system or if the solids content of the manure changes substantially because of seasonal operational issues (e.g., use of summer sprinklers) and drops below approximately 12% solids. Nationally, plug flow anaerobic digestion systems account for approximately 50% of all operating farm anaerobic digestion systems (AgSTAR, 2006).

The final type of anaerobic digester is referred to as a complete mix system. Complete mix anaerobic digestion systems are typically utilized for manure with a solids content of 3 to 10%, which is below what would typically work in a plug flow system. The tanks used for complete mix systems may be installed either above ground or below ground and use temperature control and mixing. Complete mix systems can operate at either mesophilic (90° to 105°F) or thermophilic (120° to 135°F) temperature ranges and generally have detention times of between 15 and 20 days. However, due to their relative complexity, complete mix digesters also have higher capital costs than the other types of anaerobic digestion systems. Additionally, the operation of the mixers used in complete mix systems requires electrical energy which can reduce the net amount of electrical energy produced by the anaerobic digestion system. Nationally, complete mix systems account for approximately 30% of all operating farm anaerobic digestion systems (AgSTAR, 2006).

Although anaerobic digestion has been used successfully for many years by municipal wastewater treatment plants, primarily for stabilization of biosolids prior to land application, operating anaerobic digestion systems as a for-profit activity by other industries has proven to be more difficult. This is primarily related to the high capital costs required for system construction, as well as the relatively low price paid for electricity in many parts of the country, including Wisconsin. It should be noted that in some cases, anaerobic digestion systems can only be considered profitable when other revenue streams, such as using the digested solids for animal bedding and utilizing the engine heat, are included in the analysis. However, not all farmers are willing to use this type of bedding, as many prefer sand bedding or wood shavings, thereby eliminating the bedding as a potential source of revenue. However, it should also be noted that financial incentives available from Focus on Energy in the form of implementation grants for electrical generation and thermal energy recovery, as well as grants available from the U.S. Department of Agriculture, can substantially lower the first costs of these anaerobic digestion systems, which can change the profitability considerably, with some anaerobic digestion systems having a straight-line payback period in the range of 6 to 8 years.

Costs and Benefits

As noted previously, anaerobic digestion systems can be quite costly and are generally found only at larger farms. Capital costs typically account for approximately 90% of the overall anaerobic digestion system costs, with the remaining 10% for preliminary feasibility studies, design and engineering. Approximately 45% of the capital costs are for the electrical generation equipment, 35% for the digester vessel itself, and the remaining 10% for the equalization tank and manure collection systems. The total cost of installed anaerobic digestion systems vary widely and are not always available. This is due to the range of design options, manufacturers, and contractors involved. In Wisconsin, for those systems where data are available the cost is generally between $650 and $1000 per head, with $1000 per head being more common for recently constructed systems (Krom, 2006). As noted previously, a range of grants are available to help offset the initial capital costs of anaerobic digestion system projects.

Despite the relatively high costs associated with anaerobic digesters, a number of significant financial benefits may be realized from installing these systems. While not every project may necessarily take advantage of all of these, typical benefits include: reduction of odor, production of high-quality fertilizer (N, P, and K), reduction of surface and groundwater contamination, destruction of pathogens and weed seeds, reduction of atmospheric methane emissions, and on-farm energy production. Electrical sales and reduced bedding costs represent the two largest sources of revenue for anaerobic digestion systems, particularly as electric utilities implement green power programs or need to meet renewable portfolio standards that exist in many states including Wisconsin. For example, We Energies, Wisconsin's largest utility, received authorization from the Wisconsin Public Service Commission of Wisconsin (PSC) to significantly expand its renewable energy programs. As part of these expanded programs, the PSC approved a new "Biogas Buy-back Rate," which pays $0.08/kWh for on-peak energy and $0.049/kWh for off-peak energy to customers who generate electricity from anaerobic digester technology using waste from animal feeding operations, industrial food processing, or municipal wastewater treatment facilities (AgSTAR, 2006).

It can generally be assumed that a 1000-cow dairy will produce approximately 200 kW of generating capacity, which would be equivalent to approximately 1.5 million kWh/year or 4 kWh/cow/day at a capacity factor of 90% (Krom, 2006). Additionally, the continued implementation of anaerobic digestion systems coupled with cogeneration systems may also increase the potential financial benefits, with the heat used for digester heating, parlor heating, or the heating of other buildings such as greenhouses. The use of the digested solids as animal bedding also represents a significant financial opportunity, although it should be noted that a solid separation system will be required to capture the digested solids and achieve a moisture content that is suitable for use as animal bedding. The benefits of the digested solids used as animal bedding may vary widely, depending on the existing bedding system utilized at the farm, as well as how the bedding is managed. However, it can generally be estimated that bedding costs for a typical farm would be $40-50/cow/year, assuming approximately 3 cubic yards/cow/year, which would be offset by the use of the digested solids as bedding (Krom, 2006). Furthermore, there are also a number of other non-quantified benefits such as odor control that may help farms avoid lawsuits and continue to operate and site new and increasingly larger dairy farms (Kramer, 2005).

Anaerobic Digestion Systems on Wisconsin Farms

Several farm-based anaerobic digestion systems have been constructed in Wisconsin and documented in the *Agricultural Biogas Casebook* (Kramer, 2004), with many more becoming operational or currently under construction since the release of *Agricultural Biogas Casebook*. General information on these Wisconsin farm anaerobic digestion systems can be seen in Table 1.

Table 1: Anaerobic Digesters on Wisconsin Farms.
Sources: Agricultural Biogas Casebook – 2004 Update (Krom, 2006).

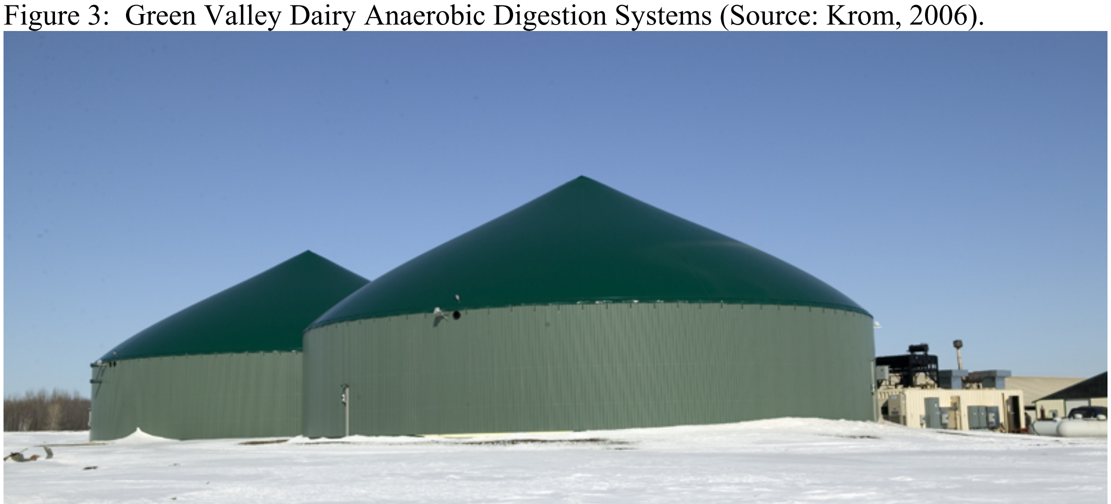
Farm name and location	Farm type head	Digester type	Biogas use	Heat application
Five Star Dairy Elk Mound	Dairy (910)	Microgy complete-mix, thermophilic	Electricity generation	Digester
Wild Rose Dairy LaFarge	Dairy (900)	Microgy complete-mix , thermophilic	Electricity generation	Digester
Baldwin Dairy Baldwin	Dairy (1,225)	Clay-lined lagoon with poly cover (ambient temperature)	Flared, no use	None
Emerald Dairy Emerald	Dairy (1,600)	Poly-lined lagoon with poly cover (ambient temperature)	Flared, no use	None
Double S Dairy Markesan	Dairy (1,100)	Mixed plug-flow loop	Electricity generation	Digester, parlor floor, offices, shop floor
Gordondale Farms Nelsonville	Dairy (850-900)	Mixed plug-flow loop	Electricity generation	Digester, dairy parlor, offices, engine room, warm water flush flume
Stencil Farm Denmark	Dairy (1,000)	Plug-flow mesophilic	Electricity generation	Digester
Quantum Dairy Weyauwega	Dairy (1,200)	Modified plug-flow, mesophilic	Electricity generation	Digester
Vir-Clar Farms Fond du Lac	Dairy (1,350)	Complete-mix, mesophilic	Electricity generation	Digester
Holsum Dairy Hilbert – Irish Rd	Dairy (3,000)	Modified plug-flow, mesophilic	Electricity generation	Digester
Norswiss Digester Elk Mound	Dairy (1,300)	Complete-mix, thermophilic	Electricity generation	Digester
Suring Community Dairy, Suring	Dairy (1,000)	Complete-mix, mesophilic	Electricity generation	Digester
Green Valley Dairy Green Valley	Dairy (2,500)	Complete-mix, mesophilic	Electricity generation	Digester
Lake Breeze Dairy Malone	Dairy (3,000)	Modified plug-flow, mesophilic	Electricity generation	Digester
Holsum Dairy Hilbert – Elm Rd	Dairy (3,000)	Modified plug-flow, mesophilic	Electricity generation	Digester
Clover Hill Dairy	Dairy (1,050)	Modified plug-flow, mesophilic	Electricity generation	Digester
Crave Brothers Farm	Dairy (700 + whey)	Complete-mix, mesophilic	Electricity generation	Digester

The anaerobic digestion systems summarized in Table 1 represent a relatively broad range of design-types and operational arrangements. The following paragraphs describe the unique characteristics of several of the anaerobic digestion systems in Table 1, with digesters having similar design and operational arrangements grouped together.

Anaerobic Digesters in Wisconsin – Complete-mix Mesophilic

Vir-Clar Farms and Green Valley Dairy utilize complete mix, above ground, Biogas Nord digester systems. These systems are constructed as cylindrical concrete tanks, featuring an inner expandable membrane cover under an outer conical top that is kept inflated by positive air pressure. Mixing in these systems is accomplished by several stainless steel propeller blades within the tanks. The Vir-Clar Farm system uses two tanks in series, the first serving as storage for solids and biogas, and the second operating as a mesophilic digester with a retention tine of about 33 days. Enough biogas is produced to power a 350 kW engine-generator at about the 330 kW level. The Green Valley Dairy system operates the two tanks in parallel to accommodate the waste stream of 2,500 dairy cows. Even though enough biogas is produced to power a 600 kW engine-generator, electrical generation is kept at about 550 kW because of capacity limitations in the local electric distribution system. The Green Valley Dairy anaerobic digestion system can be seen in Figure 3.

Figure 3: Green Valley Dairy Anaerobic Digestion Systems (Source: Krom, 2006).



Suring Dairy and Crave Brothers Farm utilize complete mix, above ground, AMBICO digester systems. These systems are constructed similarly to the Biogas Nord systems except they are single tanks constructed from stainless steel. Mixing in the Suring Dairy system is accomplished by several stainless steel propeller blades. The Suring system generates enough biogas to power a 250 kW dual fuel engine generator utilizing about 10% diesel fuel. The Suring Community Dairy anaerobic digestion system can be seen in Figure 4. Mixing in the Crave Brothers Farm system is accomplished by a 45^{o} bladed shaft that extends from outside the tank to the inside bottom of the tank. Co-digestion with 10% whey, from the on-site cheese factory, allows more biogas to be generated than with animal waste alone. The Crave system generates enough biogas to power a 250 kW spark ignition engine-generator fueled by 100% biogas.

Figure 4: Suring Dairy Anaerobic Digestion System (Source: Krom, 2006).

Anaerobic Digesters in Wisconsin – Complete-mix Thermophilic

Five Star Dairy and Wild Rose Dairy use nearly identical digesters and operational arrangements. Each farm has installed a Microgy complete-mix above-ground tank in which the manure flows from top to bottom. The tanks are roughly 40 feet in diameter and 40 feet tall and can hold approximately 660,000 gallons of manure. These systems are designed to operate at thermophilic temperatures (135°F) and have 20 day detention times, although the actual detention times may vary. Additionally, the systems are designed to have small footprints, making them easy to install at existing dairies. Similar digesters have been installed by Microgy on roughly 20 European farms over the last 15 years. The digesters were installed on each farm to take advantage of a variety of benefits including reduced operating costs (through sales of biogas), odor reduction, and weed seed and pathogen control. These farms sell their biogas to Dairyland Power Cooperative, which owns the electricity generation equipment and is responsible for its maintenance on-site. Microgy is also responsible for maintaining the digesters, which are owned by the farms, for the life of the project. Both farms may eventually add local food-grade waste to their digesters and charge tipping fees for accepting these materials. Additionally, Five Star Dairy may sell its digested solids as certified organic fertilizer. Both Five Star Dairy and Wild Rose Dairy expect 10 year payback periods on the digesters (Kramer 2004). Both co-digest 10% fats, oils and grease for operation.

Anaerobic Digesters in Wisconsin – Mixed Plug Flow

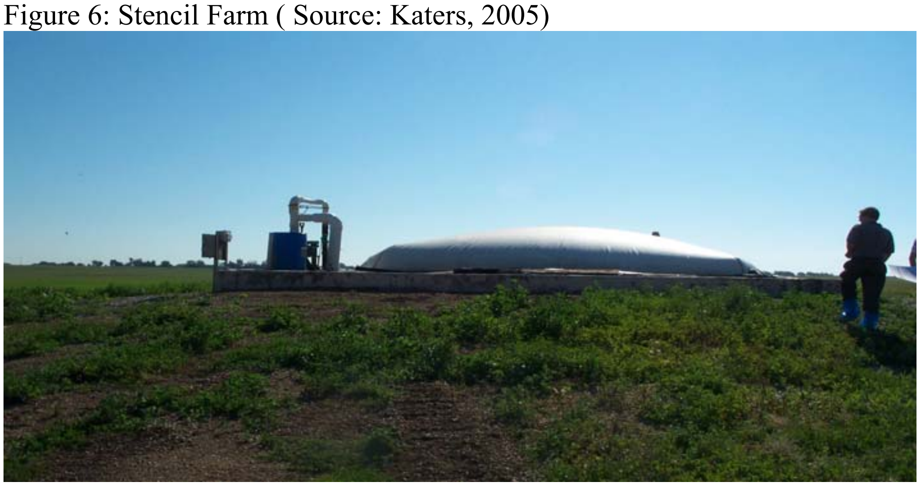
Double S Dairy and Gordondale Farms each use mixed plug-flow digesters. Double S Dairy produces 30,000 gallons of manure per day. Their digester is a two stage (acidogenic and methanogenic) plug-flow system with a fixed cover and an operating temperature of approximately 100°F. The designed detention time is 20 days, but the actual detention time is slightly less. Mixing is accomplished by re-circulating biogas at the bottom of the digester. The digester, which cost $500,000, requires approximately 20 minutes of inspection and maintenance per day. Double S Dairy sells the electricity they produce and also uses the process heat to heat the digester, parlor floor, shop floor, and offices. The digested solids as used as bedding, which saves them an additional $30,000 annually. Gordondale Farms uses a similar two stage digester to handle its approximately 35,000 gallons of manure each day. It has virtually the same vital statistics, although it only cost about $290,000 and is designed to operate at 101°F. The electricity is sold to Alliant Energy, which purchased the electrical generation equipment associated with this anaerobic digestion system at a cost of $230,000, thereby reducing the initial capital costs for the farm. Gordondale Farm earned approximately $23,000 in electricity sales during 2003 and also reported savings in several other areas. In 2003, the farm saved $28,800 by using the digested solids as bedding and avoided $30,000 in commercial fertilizer purchases, $2,000 in propane purchases, and $5,000 in pest control services. The dairy also benefits from odor reduction, which is obviously not a direct economic benefit to the farm, but does have a positive impact on neighbor relations (Kramer, 2004). The Gordondale anaerobic digester can be seen in Figure 5.

Figure 5: Gordondale Farm (Source: Krom, 2006).

Anaerobic Digesters in Wisconsin – Plug Flow

Stencil Farms operates a plug-flow digester that handles approximately 20,000 gallons of manure per day. The digester is a 450,000 gallon combined phase design with a flexible cover and operates at 100°F. The designed detention time is 20 days, though the actual time is 22 to 23 days. The entire system cost approximately $500,000, with benefits achieved from electricity sales, bedding production, high quality fertilizer production and odor reduction (Kramer 2004). The Stencil anaerobic digester can be seen in Figure 6.

Figure 6: Stencil Farm (Source: Katers, 2005)



How Does Wisconsin Compare to Other States

It can be seen in Table 2 that Wisconsin currently leads the nation in both the number of operating farm anaerobic digestion systems, as well as the total energy production in kWh/yr.

Table 2: Anaerobic digester energy production (Source: AgSTAR, 2006).

State	Operating anaerobic digestion systems	Total energy production (1,000 kWh/yr)
Wisconsin	21	72,927
California	18	49,380
New York	13	8,935
Pennsylvania	11	9,966
Iowa	5	3,066
Illinois	4	3,154
Texas	3	19,447

This can be attributed to a number of factors including the collaborative efforts of the Wisconsin Biogas Development Group, the financial and technical assistance available from Focus on Energy, and the cooperation of several Wisconsin utilities. It should also be noted that Wisconsin was one of the first states to start installing a significant number of farm anaerobic digestion systems and, therefore, benefited greatly from the USDA funding that was available through the Renewable Energy and Energy Efficiency Program (U.S. Farm Bill Section 9006). For instance, in 2004 alone nearly $5 million in grants ranging from $180,000 to $500,000 were made available to 19 different anaerobic digestion projects in the state of Wisconsin.

Conclusions

Nationally and in the State of Wisconsin, interest in farm anaerobic digestion systems continues to increase, with Wisconsin currently leading the nation in both the number of installed farm anaerobic digestion systems and the total energy production from these systems. In particular, anaerobic digesters provide excellent economic and operational opportunity for large dairies, which often benefit from economies of scale. Anaerobic digestion systems can not only help mitigate potential environmental problems often associated with these larger farms, but also offset operating costs and expand and diversify the ability of the farm to earn revenue by providing products such as electricity, bedding, and high quality fertilizer. Overall, the success rate of installed systems has been extremely high and is currently lead by a growing number of engineering and equipment supply companies, including the installation of an increasing number of European style systems (AgSTAR, 2006). Given the increased emphasis on green power programs and renewable portfolio standards, it is likely that farm anaerobic digestion systems will continue to be viewed as a long-term source of reliable renewable energy, particularly in states like Wisconsin with a sizable dairy industry and an increasing number of large farms.

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