Final Report:
Haubenschild Farms Anaerobic Digester

Updated!

August 2002

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the minnesota project

Acknowledgments:

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Page 5 Paula Mohr, Dairy Today

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A note about the updated report…

Much has changed in the world of agricultural biogas systems since the original publication of this report in December 2000. In Minnesota, the success of the Haubenschild project captured the imagination of many policy leaders and led to initiatives to encourage more projects like the Haubenschild's (see page 30).

Meanwhile, the Haubenschild's continue to have great success with their digester, which continues to exceed expectations for performance. This updated report expands upon the half year of operating data available at the time of the original report, and gives the results of nearly 3 years of operating experience. Although the report has not been entirely overhauled, other information available to the author on digesters in general has been added as well.

--Carl Nelson, August 2002

Executive Summary

This report is an update of the December 2000 report and documents the installation and 34-month performance of a heated plug-flow anaerobic digester for managing dairy manure at Haubenschild Farms. This type of digester is appropriate for treating manure with a high solids content, such as cow manure that is collected by scraping.

Haubenschild Farms is a 1000-acre, family owned and operated dairy farm near Princeton, Minnesota. In 1998 the owners were planning to increase the size of their operations, and considered the possibility of installing an anaerobic manure digester. They knew that this type of system could result in environmental benefits while offering a return on their investment.

Some of the key expected benefits of an anaerobic digester are:

- Odor control
- Renewable energy production
- Pathogen reduction
- Greenhouse gas reduction
- Reduction in total oxygen demand of the treated manure (total oxygen demand is a measure of potential impact on aquatic systems)

Haubenschild Farms applied for and was selected as an AgSTAR "Charter Farm," one of 13 such farms selected nationwide to demonstrate farm-scale anaerobic digestion technologies. AgSTAR is a joint program of the Environmental Protection Agency, Department of Energy and Department of Agriculture, designed to promote the use of anaerobic digestion systems. In addition to the AgSTAR program, the Haubenschild Farms project received assistance from the Minnesota Department of Agriculture, Department of Commerce and Office of Environmental Assistance. With financing complete, construction of the digester was started in the summer of 1999 and completed in October of the same year. Total construction cost of the digester and generator system was about $355,000.

The Haubenschild Farms digester is a covered 350,000-gallon concrete tank installed in the ground, with suspended heating pipes to heat the manure inside the digester where bacteria breaks down the manure, creating methane. A 135-kilowatt engine-generator set is fueled with methane captured from the digester. The hot water to heat the digester is recovered from the engine-generator's cooling jacket. Barn floor space is also heated with the recovered heat. The digested effluent, odor reduced, flows to a lined storage pond where it is kept until it can be injected or broadcast spread on fields for crop production.

When the digester was started, it was processing manure from about 425 dairy cows, which was about half of its total design capacity of 1000 cows. In 2000, Haubenschild Farms built a second free stall barn and has expanded to a current size of about 750 cows.

Since startup in the fall of 1999, the biogas output of the digester steadily increased to about 65,000 cubic feet by May 2000. Currently, more biogas is being produced than can be used by the engine-generator, so it is hard to estimate exactly how much biogas is being produced. The Haubenschilds are considering adding generation capacity to utilize the

excess biogas. Approximately 70,000 cubic feet/day of biogas is used by the engine-generator; the rest is currently flared. With 425 cows, the biogas output per cow was almost twice projections – with 750 cows, the output per cow has come down somewhat to about 40 percent above projections. Haubenschild's cows are producing about 50 percent more manure per cow than the digester was engineered for, which somewhat explains the high biogas production per cow.

The sale of the electricity generated is an important benefit of the project. Before the digester was built, Haubenschild Farms entered into a power purchase contract proposed by the local electric cooperative, East Central Energy, who greeted the project with enthusiasm and offered Haubenschild Farms a very favorable contract. Since the expansion of the milking herd size from 425 to about 750 cows in the summer of 2000, the digester has been producing enough electricity to provide all the electric needs on-farm, plus enough surplus electricity to power about 75 additional homes.

The building and operation of the Haubenschild Farms project has offered several key lessons for future digesters:

- Payback of 5 years on investment is possible
- A good time to install a digester is when changing or expanding operations
- Electric utility cooperation is important
- Active management is crucial for stable digester and engine operation
- Digester design and engineering expertise is key
- There are barriers to financing digester systems
- Cooperative agency participation reduces the barriers to a project's success
- Manure collection method and collection frequency are important

Purpose

This report documents the installation of a heated plug-flow anaerobic digester at Haubenschild Farms. It is intended to serve a broad audience, including the nearly 800 people who attended tours at the farm in early April 2000. We provide answers to some of the questions raised by project observers during the course of the installation and the first few months of operation. This report is intended to provide a base of information for continued discussion.

Introduction

Dairy farms and other confined animal feedlots, especially larger ones, have been under increasing public and regulatory pressure to manage their animal manure to control environmental problems. A major concern is odor, which has been a prime force behind local ordinances to control feedlot expansion. There are also potential problems with storing and spreading the manure, along with the potential for catastrophic spills (see sidebar). Anaerobic digesters have been getting attention in the last several years for their potential to address some of the environmental impacts of manure management while providing farmers with economic benefits.

Environmental Concerns with Animal Feedlots

Improperly managed manure can result in severe consequences to the environment.

Groundwater Contamination

Manure contains pathogens and the nutrients phosphorus and nitrogen. When properly managed and applied, growing plants use these nutrients, and a healthy soil and water can absorb limited pathogens. Spreading more manure than can be used by growing plants can result in the extra nutrients leaching into and contaminating groundwater. As well, an improperly designed or damaged storage facility can leak manure, where it can enter the groundwater. The MN Department of Agriculture and counties test livestock and other nearby wells for the presence of nitrogen and bacteria.

Surface water runoff

The improper application of manure to fields can pollute rivers and lakes with runoff of nitrates, phosphorus and pathogens. Manure in water consumes oxygen required by fish and other aquatic life. If too much oxygen in the water is used to break down manure, natural stream life will suffer or be killed.

Catastrophic spills

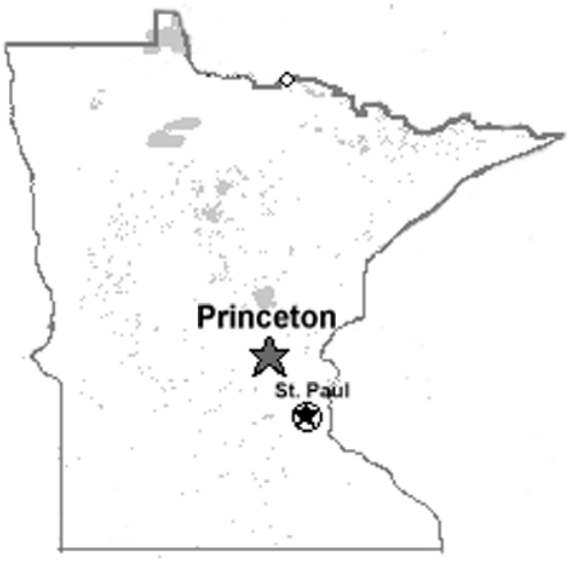
An accidental spill during storage or transport of manure can also result in sudden ground and surface water contamination.

Anaerobic digesters biologically treat manure and produce a stable effluent with slightly different chemical characteristics than raw manure. In the process, a biogas composed primarily of methane is produced, captured, and the gas is then combusted in an engine, boiler or flare. Manure treatment reduces total oxygen demand, odors and pathogens.

There are many questions that Minnesota farmers and policy-makers have about anaerobic digesters:

- What are the environmental benefits and what are the concerns?
- What is the cost of building a digester?
- Can the energy produced pay back the investment?
- Who should install a digester?
- What are the pitfalls and barriers to installing a digester?
- What is the potential for digesters in Minnesota?
- What are the impacts on the community?

The installation in September of 1999 of an anaerobic digester at Haubenschild Farms Inc., a dairy farm in east central Minnesota, provides an opportunity to examine some of these questions. The results of 34 months of operation at the Haubenschild Farms digester are examined in detail. The type of digester installed at Haubenschild Farms is limited in its application to cow manure collected by scraping, and cannot be used for a swine or dilute cow manure, since the solids concentration would be too low. Thus the lessons learned from the Haubenschild Farms digester do not apply to all feedlots in Minnesota.



Available information from the Haubenschild Farms digester and other sources is synthesized in this report as a baseline for looking at the future of anaerobic digestion in Minnesota and recommendations are suggested.

A Resurgence of Interest

Anaerobic digesters have been used successfully for sewage and industrial waste treatment in the U.S. since the 1940s. Over one million small-scale digesters have been used in China and India for decades, and nearly 2,000 farm-based digesters operate in Europe.[1] Anaerobic digestion and power generation at the farm level began in the United States in the early 1970s, largely in response to rising energy prices. Many universities installed small digester systems and conducted basic digester research, including the University of Minnesota, which operated a 10,000-gallon digester on a swine farm for about 10 years.

[1] Erwin Koeberle, "Animal Manure Digestion Systems in Central Europe," Second Biomass Conference of the Americas, August 21-24, 1995, Portland OR reports at least 450 digesters, more recent information suggests about 90 in Austria, 45 in Denmark, 70 in Switzerland and 1,650 in Germany (personal communication, Joe Kramer, Resource Strategies, July 2002.

In the 1980s, federal tax credits spurred the construction of over 100 digesters in the United States. However, many of these systems failed because of poor design, faulty construction, improper operation and lack of a service infrastructure. By the end of the decade, adverse publicity about the system failures and operational problems reduced enthusiasm for farm-scale anaerobic digesters.

In recent years, however, there has been a renewed interest in the technology. This has been stimulated by an increasing awareness that properly designed and operated anaerobic digesters can help control animal waste odor and other environmental problems. Dairy farmers faced with increasing federal and state regulation of manure are looking for ways to comply. Digesters are now being built because the owners hope to reduce the environmental hazards of dairy farms and other animal feedlots. As of spring 2002, there were over 40 digester systems in operation at livestock farms in the United States, with dozens more in the planning stage.[2]

Digester Types[3]

Anaerobic digesters work on the principle that in the absence of oxygen (anaerobic means "without oxygen"), naturally occurring bacteria will break down the manure. The digestion of the manure occurs in four basic stages (hydrolysis, acidogenesis, acetogenesis, and methanogenesis). It is the final stage, methanogenesis, that breaks down the intermediate compounds to produce methane.

Anaerobic plug-flow digester. Haubenschild Farms, Inc.

Anaerobic digesters capture the gas released in the digestion process. This biogas is composed of about 55 to 70 percent methane. Most of the rest of the biogas is carbon dioxide, with a small amount of hydrogen sulfide and other trace gases. The digested manure needs to be stored until land applied.

Methane producing bacteria flourish at around body temperature (95°-105°F),[4] and thus heated digesters are more efficient producers of methane than non-heated ones. There are three conventional digester designs for on-farm use. Design standards for all three have

[2] See the AgSTAR website for a partial list of operating digesters: www.epa.gov/agstar/.
[3] Parts of this section are adopted from a report from the Oregon Office of Energy entitled "Anaerobic Digester at Craven Farms: A Case Study," by John G. White and Catherine Van Horn (September, 1998).
[4] This range is called the mesophillic temperature range. There is also a set of methanogenic bacteria, which flourish at much higher temperatures (125°-135°F), called the thermophillic range, which can digest waste faster than bacteria in the mesophillic range. Thermophillic digesters are not commonly used on-farm because they require more heat input, the bacteria at this range are more prone to upset by small temperature fluctuations, and thus thermophillic digesters require close monitoring. There is a third set of methanogenic bacteria that flourish at around 70°F, but digest waste slower than bacteria in the mesophillic range.

been adopted by the US Department of Agriculture's Natural Resource Conservation Service (NRCS).[5] The designs differ in cost, climate suitability and the concentration of manure solids they can digest.

Covered Lagoon Digester

A covered lagoon digester consists of a manure treatment lagoon with an impermeable cover and is generally not heated. The cover traps gas produced during decomposition of the manure. Covered lagoon digesters are used for liquid manure (less than 2 percent solids) and require large-volume lagoons. Because the methane production rate is dependent on ambient temperatures with a covered lagoon system, it is not considered cost-effective to use the biogas for energy production in Minnesota's climate. It has been used in cold climates for odor control, however, including in Wisconsin. This type of digester is the least expensive of the three.

Complete Mix Digester

A complete mix digester is suitable for manure that is 3 to 10 percent solids, such as swine manure or dairy manure collected by a flush system. Complete mix digesters process manure in a heated tank above or below ground. A mechanical or gas mixer keeps the solids in suspension. However, complete mix digesters are expensive to construct and cost more than a plug-flow digester to operate and maintain.

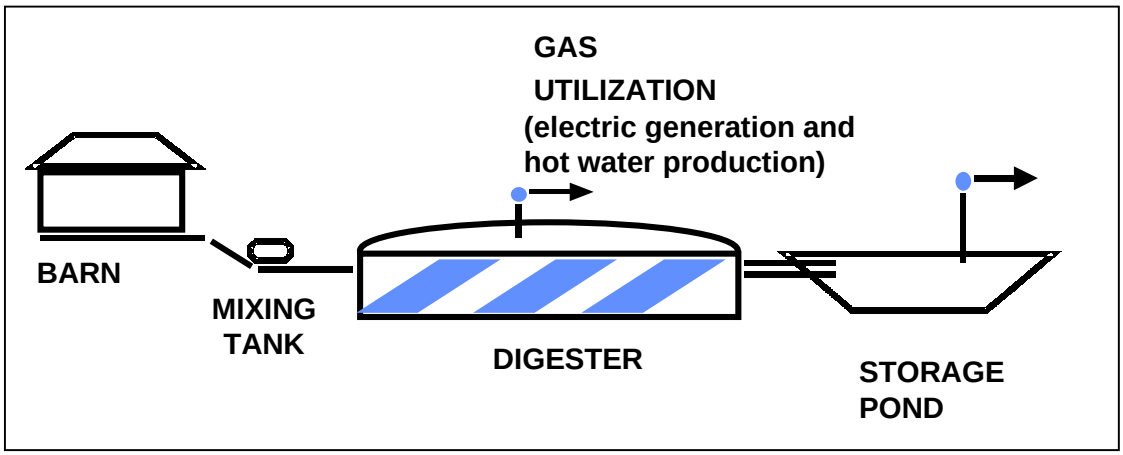
Shredding newspaper for bedding, Haubenschild Farms Inc.

[5] See the AgSTAR website (www.epa.gov/agstar) for an on-line version of these standards.

Plug-Flow Digester

Plug-flow digesters are suitable for ruminant animal manure having a solids concentration of 11 to 14 percent, such as cow manure collected by scraping. A flush system for manure collection is not appropriate for this system, since this would reduce the total solids content of the manure below specified levels. In manure with lower solids concentrations, such as swine manure, solids cannot stay in solution and tend to settle to the bottom of the tank, limiting their digestion. A plug-flow digester has few moving parts and requires minimal maintenance.

Figure 1: Anaerobic Plug-Flow Digester System



Before entering the digester, raw manure is mixed in a mix tank. It then enters one end of the plug-flow digester, a rectangular tank, and decomposes as it moves through the digester. New material added to the digester tank pushes older material to the discharge end. Coarse solids in ruminant manure form a thick sticky material as they are digested, limiting solids separation in the digester tank. As a result, the material flows through the tank in a "plug". Anaerobic digestion of the manure slurry creates biogas as the material flows through the digester. A flexible, impermeable cover on the digester traps the biogas. For optimal digestion, it should take about 15 to 20 days for a plug to pass completely through the digester.

Inside the digester, suspended heating pipes allow hot water to circulate and heat the digester. The heating pipes also serve to mix the slurry through convection. Recovered heat from an engine fueled with digester gas usually provides the hot water required for heating the digester. Figure 1 shows how a plug-flow digester system works.

There is a variation on the basic plug-flow design called a slurry loop digester. It works on the same principle as a plug-flow, except the digester tank is designed in a U-shape or circular configuration, so that the discharge end of the tank is near the point of entry. This design is used in Wisconsin, at Gordondale Farms near Stevens Point. The Gordondale digester represents a hybrid of complete mix and plug-flow designs, as collected biogas is injected into the digester to further mix the slurry.

Other Digester Types

Besides the three digester types discussed above, there are many other anaerobic digester designs that have been used for processing municipal sewage as well as industrial waste.[6] Most of them treat waste streams with a low solids content, and thus have found various ways to speed up the digestion process or increase solids content in order to reduce the volume required for digesting, thereby reducing costs. Without providing details of how they work, other digester designs include:

1) batch-fed reactor, such as the anaerobic sequential batch reactor (ASBR);
2) temperature-phased anaerobic digester (TPAD);
3) suspended particle reactor;
4) anaerobic filter reactor;
5) upflow solids reactor;
6) continuously stirred tank reactor with solids recycle;
7) upflow anaerobic sludge blanket reactor;
8) anaerobic pump digester;
9) fluidized- and expanded-bed reactors,[7] and
10) fixed-film anaerobic digester.[8]

In the last several years, there has been a tremendous growth in the farm digester industry, including research and development to attempt to apply these technologies to the treatment of agricultural animal waste. For example, the Iowa Energy Center is operating a test project to investigate the use of an ASBR, and a TPAD design is being tested at a dairy south of Green Bay, Wisconsin. These designs tend to be much more capital intensive and operationally complex, however, and are not currently commercially viable compared to more established and proven designs. This could change quickly, however.

Midwest Operating Digesters

As of spring 2002 in the Great Lakes region (Minnesota, Iowa, Wisconsin, Illinois and Michigan) there were 16 digesters, most constructed within the last 2 years, and half of which were still in the start-up phase.[9] Three more digesters were still under construction. Of the total 19 digesters:

- 15 are at dairies (12 plug-flow or modified plug-flow, 2 covered lagoon, and one temperature-phased anaerobic digester or TPAD);
- 3 are at swine operations (2 complete mix and one anaerobic sequential batch reactor or ASBR)
- one is at a duck farm (complete mix)

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[6] Industries that use anaerobic digestion to treat their wastes include: food processing (milk and milk products, starch products and sugar confectionery, brewing, and distilling and fermentation are some of the largest), and the paper industry. The treatment of the industrial waste, as well as municipal sewage, is often driven by regulations.

[7] For a description of these digester designs, see, for example, David Chynoweth and Ron Isaacson, "Anaerobic Digestion of Biomass," Elsevier Applied Science: New York, 1987.

[8] "Reducing Dairy Manure Odor and Producing Energy," Ann C. Wilkie, Biocycle, September 2000.

[9] From a forthcoming Agricultural biogas case studies report from the Great Lakes Regional Biomass Energy Program, a link to which will be provided at www.mnproject.org when the report is available.

Benefits of Anaerobic Digesters

Anaerobic digesters offer many potential benefits to farmers and the environment, including:

- **Odor and fly control**. Anaerobic digesters consume odor-causing compounds in manure as it moves through the digester, reducing odor problems (note that odors will still exist at normal levels until the manure enters the digester). One study showed that anaerobic digestion reduced odor by 97 percent over fresh manure.[10] For some projects, odor control is a primary reason for installing a digester, especially covered lagoon systems. Fly propagation is also extremely limited in digested manure compared to fresh manure.

- **Renewable energy production**. Not all digester systems are used to produce energy; in some cases odor is removed and the gas produced is simply flared. However, using the gas to produce energy may offer significant economic payback depending on farm scale. Most commonly the gas is burned in an engine-generator to produce electricity, and the waste heat can be used to produce hot water for heating the digester and other applications, such as space heating.

- **Distributed generation of electricity**. The electricity generated by an anaerobic digester, as opposed to a large central station power plant, is a distributed form of electricity generation. This offers potential benefits to the electric utility, including increased generation capacity (especially valuable during periods of peak electric demand), voltage support, deferred transmission and distribution line construction, and less loss of power through transmission. The benefits of distributed generation to the utility have been estimated to be from $100 to $800 a year per kilowatt of capacity.[11]

- **Potential increase in value as a fertilizer**. Manure is already widely spread on fields as a soil amendment. For many farmers, anaerobic digestion may increase the value of their manure as a fertilizer. The digestion process converts organic nitrogen into a mineralized form (ammonia or nitrate nitrogen) that can be taken up more quickly by plants than organic nitrogen.[12] Timing of the plant uptake of ammonia and nitrate nitrogen, similar to that used in commercial fertilizers, is more predictable than the plant uptake of organic nitrogen from raw manure. However, nitrogen in ammonia form can easily be lost to the air (called volatilization), where it is a pollutant (see below). Therefore, care must be taken to handle the digested manure in such a way as to minimize nutrient leaching and volatilization.

  In addition, some research suggests that the mircroflora present in digested manure may lead to increases in crop yields. One study found yields to increase an average

[10] As reported in Philip Lusk, "Methane Recovery from Animal Manures: The Current Opportunities Casebook," Department of Energy, National Renewable Energy Lab (DOE/NREL), 1998.
[11] Philip Lusk, 1998 (see reference 10).
[12] See, for example, Andrew Wheatley, "Anaerobic Digestion: A Waste Treatment Technology," Elsevier Applied Science: New York, 1990.

of 10 percent over commercial fertilizer.[13] The Minnesota Project is partnering with the University of Minnesota to study the effectiveness of digested manure compared to raw manure and commercial fertilizer.

Manure Wagon with Injectors, Haubenschild Farms, Inc.

- **Pathogen reduction**. Anaerobic digestion at mesophillic temperatures (95°-105°F) has the potential to practically eliminate many, but not all, kinds of pathogens, greatly reducing this potential source of water pollution.[14] The effectiveness of a particular digester in pathogen destruction will vary.

- **Weed seed destruction**. Weed seeds in manure subjected to anaerobic digestion can exhibit reduced weed seed germination and viability compared to weed seeds contained in untreated manure. The Minnesota Project is also partnering with the University of Minnesota to study the extent to which this occurs.

- **Greenhouse gas reduction**. Methane is a greenhouse gas 23 times more potent than carbon dioxide in causing global warming. By capturing and burning the methane produced from animal manure, anaerobic digesters help to slow down the rate of global warming. (Note: manure management systems that result in aerobic decay of manure, such as grazing systems and dry manure packs, do not produce significant amounts of methane; thus the benefit of methane reduction reported here is only in comparison to other anaerobic systems of treating manure, such as a lagoon system).[15]

- **Sale of digested fibers**. With the addition of a solids separation system, the fibers can be separated from the digested effluent and sold as a soil amendment. After solids separation, the effluent can still be spread on the fields, retaining about 75

[13] As reported in Philip Lusk, 1998 (see reference 10).
[14] See, for example, John Olsen and Holger Larsen, "Bacterial Decimation Times in Anaerobic Digestions of Animal Slurries," Biological Wastes, Vol. 21,1987, pp. 153-168.
[15] Note that a calculation of the methane prevented from entering the atmosphere is equal to the amount of methane emitted by the manure management system that would be used in place of the digester, and not the amount of methane that is simply captured by the digester. The methane produced by a digester is considerably more than, say, a 90-day storage tank.

percent of the total nutrients of the original manure. Although Haubenschild Farms chose not to separate the fibers, many other digester owners have sold the fibers as a soil amendment off the farm. These fibers, if sold, could raise as much as $40,000 per year for a farm the size of Haubenschild Farms.[16]

- **Reduction in Total Oxygen Demand**. Total Oxygen Demand (TOD) is a measure of how much oxygen could potentially be consumed by breaking down organic matter, such as that found in manure. This is an issue if there is a catastrophic spill of manure that enters surface water. If too much oxygen in the water is used to break down manure that spills into a stream, natural stream life will suffer or be killed. By reducing TOD, anaerobic digestion reduces the hazards of a potential catastrophic spill.

Potential Concerns about Anaerobic Digesters

- **Nitrogen and ammonia emissions.** Care must be taken in the storage and application (spreading or injection) of digested manure, since ammonia can be lost to air through volatilization. Ammonia in the air is a pollutant. Maintaining a crust on the storage pond or reducing its surface area can reduce this loss. Nitrogen loss can also be minimized by injecting the digested manure into the soil as opposed to spreading it, where it will be exposed to air.

- **Water pollution.** As with managing untreated manure, care must be taken to minimize the risk of contaminating surface and groundwater. Digested manure must still be applied in a manner that will minimize the risk of nitrate leaching to groundwater. It must also be managed to minimize the risk of surface runoff.

- **Air emissions from combusting biogas.** Generally this is a cleaner burning fuel than coal, but some sulfur dioxide and other emissions will be exhausted in the combustion of the biogas (see page 25).

- **Safety.** Well-designed and managed anaerobic digesters have few safety concerns. However, care must be taken in designing the gas handling components of the digester and engine-generator to ensure safety. Inhalation of biogas can pose health risks, and biogas is flammable.

Haubenschild Farms Project Description

Haubenschild Farms is a 1000-acre, four-generation family owned-and-operated dairy farm near Princeton, Minnesota. In 1998 Haubenschild Farms president Dennis Haubenschild and his wife Marsha Haubenschild were considering expanding their dairy operation from 100 cows to 500 and eventually 1000 cows. Their two sons, Tom and Bryan, were interested in moving back to the farm with their families and an expansion was necessary to make this plan feasible. Dennis, who serves on the Minnesota Feedlot and Manure Management Advisory Committee (FMMAC), was very aware of the problems involved in

[16] Personal correspondence, Mark Moser, Resource Conservation Management, July 25, 2000.

expanding feedlot operations. He was also aware of the potential of anaerobic digesters to reduce these problems while at the same time producing energy and providing other benefits.

The Opportunity

The Haubenschilds: Dennis, Bryan, Marsha and Tom (l to r)

In order to see if an anaerobic digester would work at his farm, Dennis submitted an application for consideration as an AgSTAR Charter Farm, and after completing a pre-feasibility assessment was one of 13 farms selected. AgSTAR is a national program, sponsored jointly by the Environmental Protection Agency, the Department of Energy and the Department of Agriculture. The Charter Farm Program was designed to facilitate demonstration of appropriate digester systems at various livestock farms. As a Charter Farm, AgSTAR provided Haubenschild Farms design and operational assistance in building their digester. AgSTAR contracted with RCM, a company with a proven track record of building successful on-farm digesters, to assist with the project. Mark Moser was the engineer, while RCM's Richard Mattocks handled all onsite issues and helped to build the system.

The farm also required a feedlot permit, including a manure management plan. The Minnesota Pollution Control Agency granted the permit. The digester qualified as manure storage, reducing the size of the storage pond required for storing digested manure. Even with this assistance, there were still barriers to be overcome, since traditional lending agencies in Minnesota are reluctant to provide the full financing for such projects, and Dennis needed help in securing financing.

At this point the unique opportunities of the digester project at Haubenschild Farms were brought to the attention of several Minnesota governmental and non-profit agencies. The Onanegozie Resource Conservation and Development Council, The Minnesota Project, Minnesota Department of Commerce, Minnesota Office of Environmental Assistance, and Minnesota Department of Agriculture joined together to assist with the Haubenschild Farms project. These agencies saw the unique potential of manure digesters to mitigate negative environmental impacts while providing a source of renewable energy and promoting sustainable economic development. They agreed to help with the financing if the Haubenschild Farms project could be studied to determine its feasibility for other farms in Minnesota.

Haubenschild Farms' Goals for Installing a Digester

The Haubenschilds have a long-term outlook on their farming operations. When looking at the expansion of their farming operations, they considered the future needs of the land and the impact of the increased operations on the environment. An anaerobic digester seemed to fit in well with their plans.

Specifically, Haubenschild Farms wanted to design, build, start-up, and operate a digester with the following goals:

1. **Increase the value of the manure for fertilizer.** The sandy acres at Haubenschild Farms needs the addition of organic matter supplied by manure. By applying digested effluent to the fields instead of raw manure, the Haubenschilds expected to increase the useable nutrient value of the manure, and thereby phase-out the use of commercial starter fertilizer. At the same time, weed seeds and pathogens would be reduced. This fit the Haubenschild's strong environmental ethic by reducing outside inputs to the land while returning value.

2. **Reduce animal waste odor.** An increase in herd size could bring a significant increase in odor and fly problems. This would not only create a more unpleasant work environment, but could also cause tension with neighbors and regulatory agencies.

3. **Produce enough electricity** and hot water to recover digester installation costs.

4. **Produce enough hot water** to offset propane use and supply heat for the barn in the winter.

5. **Demonstrate the viability** of an anaerobic digester system on an operating dairy farm in Minnesota.

Haubenschild Family Farms

Dennis's father and mother, Don and Myrtle, started farming at the present location in 1952 with 160 acres and 10 cows. The farm is in the Green Lake watershed on the Anoka Sand Plain in southwestern Isanti County, about 40 miles north of the Twin Cities metropolitan area.

In the early 1960s the family began to notice a decrease in organic matter content in their soils. They realized that by increasing manure use, they could improve soil tilth and reduce erosion potential. Dennis, who went to college and worked a number of years, returned to the farm with Marsha in 1972. By 1979 their milk herd numbered 80. Dennis had researched digesters while at college and was interested in alternative energy production. In the 1970s they installed a solar collector system for heating water for the dairy which is still functioning.

They were milking 150 cows in 1998 when sons Tom and Bryan and their families wanted to farm with their parents and grandparents. The family decided that they should expand the dairy. When fully expanded they expect to use digested manure on all their crop acres for growing their 600+ acres of corn silage, 300 acres of alfalfa haylage, 30 acres of soybeans, and 40 acres of pasture. Freshening cows use the pasture. They purchase additional fresh hay to add to their total managed rations.

An anaerobic digester requires a manure handling method that is compatible with the operation of the system. A water flush system for collecting the manure makes it unsuitable for a plug-flow digester, because the manure slurry will become too diluted. Animal bedding systems using sand are also not appropriate for an anaerobic digester, due to sand build-up, which will eventually clog the system.

Will a digester work for my farm?

The AgSTAR Handbook lists 5 criteria for preliminary screening of project opportunities for installing an anaerobic digester at a dairy or swine feedlot:

1. **"Large" confined livestock facility**. AgSTAR defines large as at least 300 head of dairy cows/steers or 2000 swine, although digesters have successfully been used at smaller farms. The issue of a "threshold" size at which digesters are economic is discussed later in this report.
2. **Year-round, stable manure production and collection**. A digester needs to be constantly and regularly "fed" manure to maintain methane-producing bacteria.
3. **A manure management strategy that is compatible with digester technology**. Digester technology requires the manure to be: managed as a liquid, slurry, or semi-solid; collected at one point; collected regularly; and free of large quantities of bedding and other materials (rocks, sand, straw, etc.). A water flush system for manure collection is not compatible with a plug-flow digester.
4. **A use for energy recovered**. Can a generator be installed to produce electricity, and is the local utility willing to purchase this electricity? Are the electricity costs for on-farm use high? Is there another use for the energy on-farm?
5. **Someone to efficiently manage the system**. Successful digester operation requires an interested operator who will pay attention to performing daily routines and possesses a basic "screwdriver friendliness" for necessary maintenance.

Farmers interested in installing a digester should do a complete pre-feasibility assessment. The AgSTAR handbook can assist with this.

Source: Kurt Roos and Mark Moser, "AgSTAR Handbook," Environmental Protection Agency, EPA-430-B-97-015, 1997. See "Resources…" section, page 32 for more information.

Because Haubenschilds were planning the digester to be a part of the expansion of their whole operations, it was easier to design a manure management strategy compatible with the digester. They chose a free-stall barn for their expansion, which allows for easy scraping of the manure into a collection pit, without the use of water. For bedding, the Haubenschilds shred used newspaper, which is picked up from a local recycling facility. About 600 pounds per day of newspaper were used for 420-430 cows. With the current herd size of about 750, approximately 1 ton per day is used. The newspaper bedding is scraped three times a day along with the manure into the collection pit.

Components of the Digester System

The complete digester system required several components:

- Manure collection pit
- Mix tank
- Piping system
- Plug-flow digester
- Effluent storage
- Gas utilization

Fresh manure is scraped into the barn collection pit, where it flows by a gravity system into a 14,000-gallon mix tank. The mix tank also allows any sand and rock to settle out.

From the mix tank, the manure slurry is pumped to the plug-flow digester twice a day. About 20,000

gallons of manure enter the digester per day. The digester was designed to process manure from 1000 cows. When the original report was written, the digester was operating at less than its design capacity, and the manure took about 30 days to pass through the digester. Currently with 750 cows, it takes about 15 days for the manure to travel through the digester, 5 days shorter than it was designed for. This is due to a higher production of manure per cow than was accounted for in the design (see table 3). The digested manure slurry flows to a lined storage pond, where it is kept until it can be applied on the fields for crop production. The biogas collected in the digester is piped to an engine-generator for combustion. Before entering the engine, the gas pressure is increased with a blower to a half-inch water column pressure.

Engine - Generator

Haubenschild Farms chose a Caterpillar 3406 engine, attached to a generator with a capacity of about 135 kilowatts, to produce the electricity from the biogas.[17] The engine, originally designed for commercial natural gas usage, required retrofitting with larger-orifice carburetor valves and a larger regulator but was otherwise unchanged.

Should gas pressure build up in the system, for example when the engine shuts down or gas production exceeds engine capacity, a safety valve diverts the gas from the digester to a self-igniting odor control flare.

The equipment used to connect the generator to the public electric grid ensures that the connection is both safe and reliable. The generator's field is excited with line voltage from the electric grid, thus when power to the farm is interrupted, the generator will shut down. The fused output of the generator is fed directly to the secondaries of the on-site (75 kva) transformer.

The heat from the engine coolant and engine exhaust is captured through heat exchangers to heat water, which is used to heat the manure slurry during the digestion process. A regulator maintains a constant manure temperature of 95 to 105 degrees inside the digester. Hot water pipes were installed in the floor of the milking parlor, holding pen, breezeway and tanker bay (where the milk is stored) to heat barn space and keep the floors free of ice during the winter. Excess hot water is piped to a radiator outside the engine building, and cooled with a 10 horsepower fan.

[17] The engine rated capacity is 150 kilowatts, but the lower Btu content of the biogas results in a lower actual peak capacity.

Electricity Sales

The sale of the electricity is an important part of the success of the project. Before the digester was built, Haubenschild Farms entered into a surplus power purchase contract proposed by the local electric cooperative, East Central Energy. Unlike the electric utilities servicing some digester projects installed in other parts of the country, East Central Energy greeted the project with enthusiasm and offered Haubenschild Farms a very favorable contract.

Normally a utility will offer the customer full retail prices to off-set electricity purchases for electricity used on-farm, and buy any excess electricity at the utility's avoided cost of generating power (typically 2-3 cents per kilowatt-hour).[18] However, East Central Energy offered to buy all excess electricity produced at the full retail rate (at the time, 7.25 cents per kilowatt-hour; currently 7.3 cents per kilowatt-hour), as well as giving them the same retail rate for all electricity generated and used on-farm. East Central Energy sees this as achieving their business goal of customer service to Haubenschild Farms, as well as providing a reliable source of electricity for its green power program, which it sells to its customers at a slight premium. East Central was the first utility in the nation to offer its customers "cow power," or electricity specifically generated from digesters. This program is now fully subscribed.

Construction

Construction for the project was started in the spring of 1999 and finished by September. Construction was performed by local contractors, supervised on-site by Richard Mattocks and Dennis Haubenschild. Table 1 compares projected with actual costs of installing the system. Only the incremental costs of adding a digester system are included. Other costs of the manure management system, such as the storage pond, would have occurred whether or not the digester was built. However, the costs of storage may have been higher had the digester not been constructed.

Construction costs overran projections by about $47,300. There were several reasons for this. The cost of the engine-generator was higher than expected, perhaps due to increased demand for generation sources around the turn of the century. The digester itself was also more expensive than projected, due to changes in design specifications that were suggested by the Minnesota Pollution Control Agency (MPCA). The original digester design called for 8-inch thick walls. Because of the newness of the technology, the MPCA asked Haubenschild Farms to increase the thickness to 12 inches. As well as increased concrete, the amount of re-bar required for a 12-inch thickness approximately tripled.

Electrical wiring costs were also higher than projected. Haubenschild Farms installed extra wiring to allow for the possible future installation of a second engine-generator set that could be used just to supply only on-farm energy usage (using a stand-by generator). If this is installed, it will add to future costs as well as supply future benefits.

[18] Minnesota has a "net metering" rule that requires utilities to buy back power at the average retail rate for excess electricity from renewable energy sources (MN Rules 7835.3300). This is limited to less than 40 kW, however, and thus Haubenschild Farms would not have been eligible under this rule.

Table 1: Projected and Actual Costs of Haubenschild Farm Digester System

Component	Projected $	Actual $
Mix Tank/ Manure Collection		
Excavation/grading	3,400	0*
Cement work	12,500	18,800
Manure pump	10,000	11,300
Other (piping, installing)		2,300
Subtotal	***25,900***	***32,400***
Digester		
Excavation/grading	10,600	8,500
Digester tank	68,500	88,700
Heating	8,500	19,800
Cover	4,600	8,100
Start-up	5,000	0*
Miscellaneous	7,800	0*
Subtotal	***105,000***	***125,100***
Energy Conversion		
Building	17,400	16,400
Gas pipes	2,000	2,100
Gas pump/meter	6,000	2,000
Engine-generator/hot water recovery	87,000	106,000
Components and installation	13,700	31,000
Subtotal	***126,100***	***157,500***
Miscellaneous		
Engineering	25,000	40,000
Contingencies	25,700	0*
Subtotal	***50,700***	***40,000***
TOTAL	**307,700**	**355,000**
COST/COW (assuming 1000 cows)	**$307**	**$355**

*Costs for these items are embedded in other items for which costs are shown

Project Financing

Haubenschild Farms had difficulty financing the digester project from traditional lending institutions. Project financing was achieved by a collaboration of government agencies, through a combination of direct technical assistance, grants and low-interest loans. Total project financing is outlined in Table 2. The AgSTAR program provided the technical assistance for the project, estimated at $40,000. The Minnesota Department of Commerce and the Minnesota Office of Environmental Assistance offered grants totaling $87,500 for construction of the system. Due to a legislative action creating a $200,000 revolving loan fund for the installation of anaerobic digesters, the Minnesota Department of Agriculture was able to offer a $150,000 no-interest loan to Haubenschild Farms for the project. This left $77,500 that Haubenschild Farms paid directly.

In addition to this, The Minnesota Project received $67,500 from the MN Office of Environmental Assistance, the MN Department of Commerce and Unity Avenue Foundation to coordinate publicity, collect data, and document and evaluate the project.

Table 2: Project Financing for Installation of Digester

Source	Type of assistance	Amount
AgSTAR	technical assistance	$40,000
MN Office of Environmental Assistance	grant	$37,500
MN Department of Commerce	grant	$50,000
MN Dept. of Agriculture	no-interest loan	$150,000
Haubenschild Farms	equity	$77,500
TOTAL		$355,000

System Operation

Operation of the digester and engine/generator requires a certain amount of "screwdriver friendliness." Dennis Haubenschild performs most of the operation and maintenance of the digester. To help prepare Dennis for this task, Richard Mattocks conducted a series of walk-around sessions on system operations. Routine operation takes approximately 45 minutes per day. This includes system inspection, mixing and pumping manure into the digester twice a day, and checking and recording gauges to measure biogas and electricity output.

The engine-generator requires the most maintenance. The engine oil needs to be changed every month. Valve adjustment and spark plug cleaning is also performed periodically by Dennis. Other routine maintenance performed since 1999 includes replacing the battery, alternator and the mag needle (which creates the spark). It is estimated that engine maintenance for an on-farm biogas engine-generator, including periodic engine overhaul, costs about $3,700 per year.[19] Other operating costs include periodic maintenance of the gas blower, gas flare and manure pumps and checking pipes for gas leaks.

In May 2000 the manure pump broke and required replacement under warranty. Because Haubenschild Farms used a manure pump for manure management before the digester was installed, this is not a potential problem unique to an anaerobic digester system.

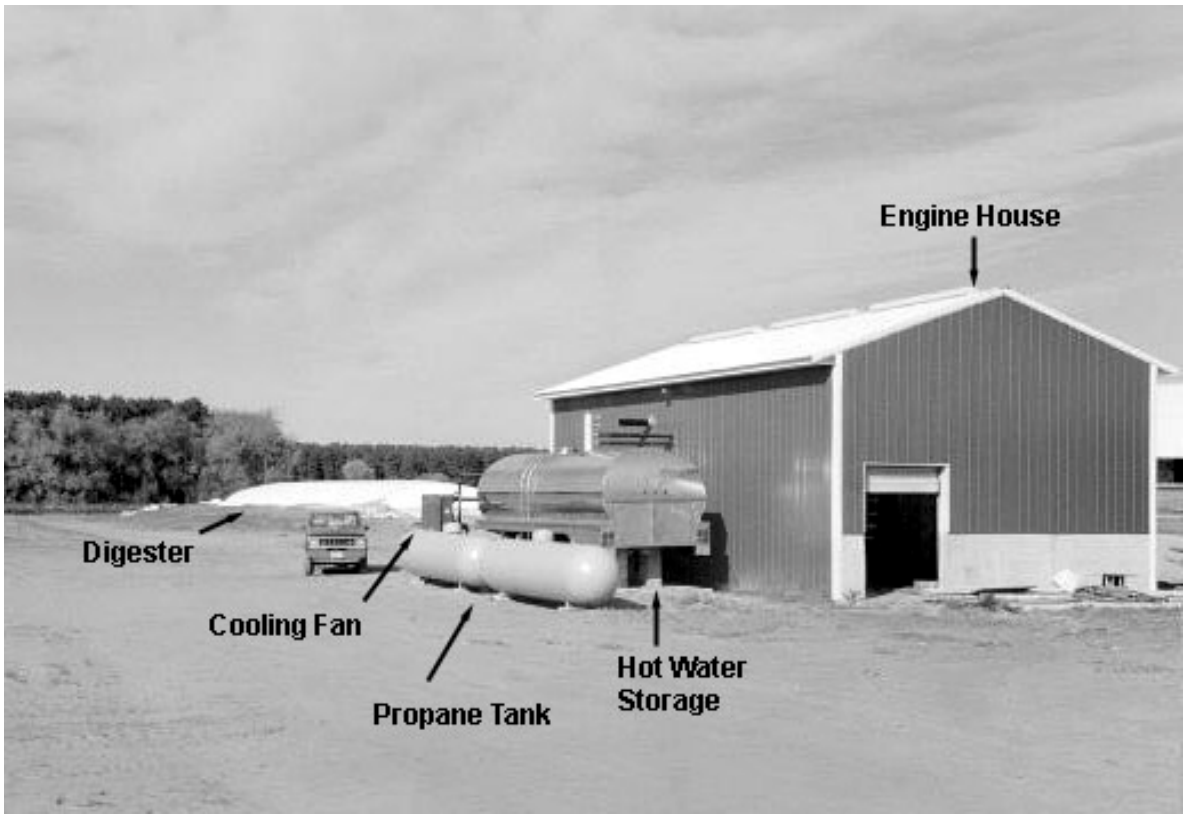
On June 5, 2000, the generator circuit breaker blew out due to defective manufacturing and was also replaced under warranty. The generator was out of commission for about four days while this was being replaced. The biogas was flared during this period.

[19] About 1.5 cents/kwh, as projected in the Charles Ross and James Walsh, "Handbook of Biogas Utilization," United States Department of Energy, Southeastern Regional Biomass Energy Program: Muscle Shoals, Alabama, 1996.

In January 2002 the heat exchanger suffered a breakdown and was out for about a month, during which time propane had to be used to heat the milking parlor and the holding pen. Another maintenance issue occurred after the air filter was replaced in the spring of 2002. It turned out that the air filter was defective from the manufacturer, slightly affecting engine performance and electrical output, but it took some time to correctly identify that it was a defective air filter that was causing the problem.

When the digester was started, it was processing manure from between 420 to 430 dairy cows, about half of its total design capacity. In June 2000, Haubenschild Farms finished building their second free-stall barn and began expanding their herd size. Since the fall of 2000, the herd size has averaged about 750 cows.

There are at least two unique features of how Haubenschild Farms operates the digester compared to other digesters nationally. First is their use of newspaper bedding. Shredded newspaper is easily digestible, and increases the amount of methane produced, although it is not clear by how much. Dennis Haubenschild also currently adds a very small amount of liquid propane (less than 1 gallon/day) into the engine and to be burned along with the biogas. The propane is not necessary for system operation, but he feels that it may increase engine life, as well as reduce emissions by helping to more completely burn the biogas in the engine.



Haubenschild Farms, Inc.

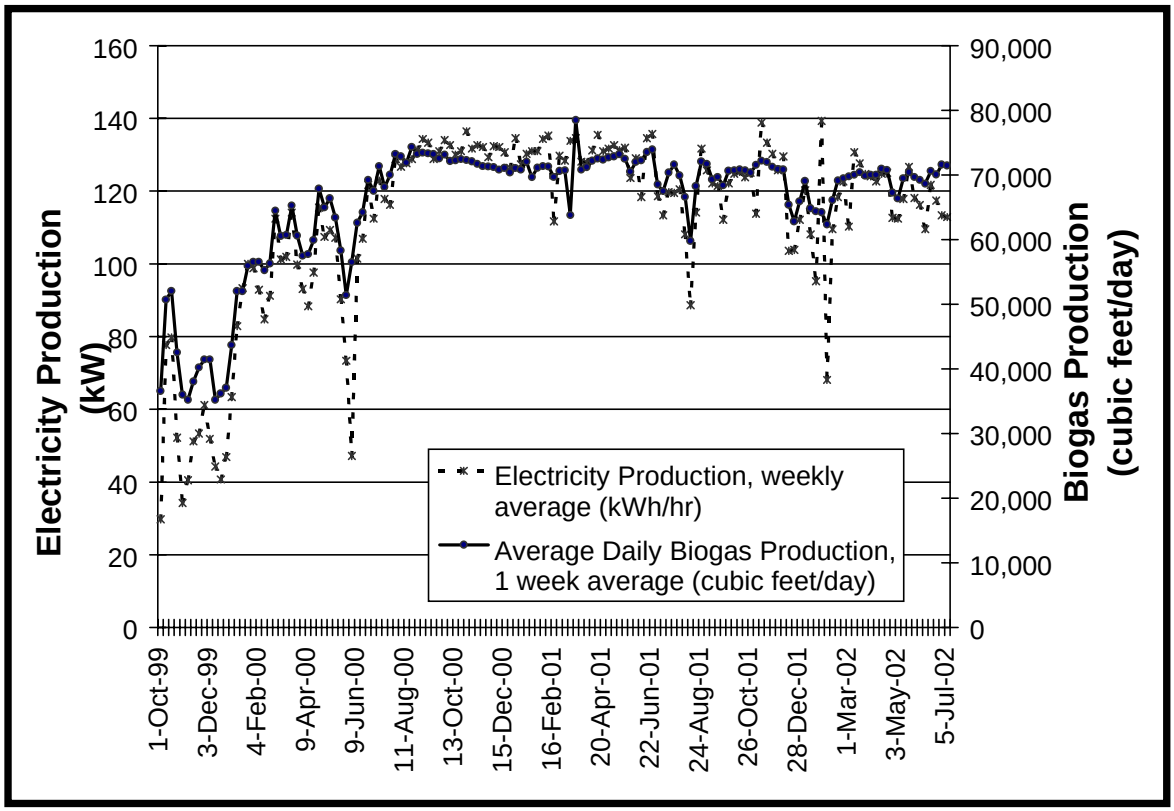
Results to Date

In September 1999, construction was complete and the manure began to be fed to the digester. On September 9, the engine was started using propane in order to heat the manure in the tank. By October 1, biogas production was sufficient to fuel the engine.

Electricity and Biogas Production

Figure 2 shows the production of biogas and electricity by the installation from October 1, 1999 until July 7, 2000. As the bacteria in the digester have grown and flourished, and as the herd size was expanded, the measured biogas output of the digester steadily increased from about 30,000 cubic feet/day of biogas in October 1999 to about 70,000 cubic feet/day by July 2000, where it has remained fairly constant.

Figure 2: Measured Biogas and Electricity Production to Date[20]



[20] Biogas volume is calculated from meter readings of biogas going into the generator. If the generator is down or cannot accomidate the full volume of biogas produced, the biogas is flared and will not be metered. During engine down time, biogas production is estimated from the average biogas production during engine operating hours on a weekly basis. However, since at least July 2000, the digester has been producing excess biogas that cannot be accommodated even with the engine in service, so full biogas production is not known.

Since summer of 2000, more biogas was produced than could be accommodated by the engine, which means it is then flared. Since this flared biogas is not metered, it is impossible to know much biogas is being flared. The excess biogas tends to be produced just after manure is added to the digester, and doesn't occur constantly, perhaps 5 hours per day. Haubenschild Farms are currently considering options for adding to their generating capacity to utilize the biogas that is currently being lost in this manner. Since summer 2000, the generator has been running nearly constantly at peak capacity, producing enough electricity to supply the electric needs on-farm and enough surplus electricity to provide for about 75 average homes. The engine has been running a remarkable 98.8 percent of the time (1.2 percent down-time).

The performance of Haubenschild Farms digester to date has been excellent, exceeding expectations. Table 3 on page 22 compares the system design performance calculations with the actual performance for two periods, representing 425 cows (from January 14 to June 2, 2000) and after the herd size had been expanded to about 750 cows (September 1, 2000 to July 15, 2002).

Initial output per cow was about twice design specifications

In the initial design specifications, AgSTAR calculated that the Haubenschild Farms digester would eventually produce 65,000 cubic feet/day of biogas from 1000 cows or 65 cubic feet/day of biogas per cow. The daily biogas production was estimated to result in electricity generation of 2.3 kWh per cow per day. The estimated biogas production is in the range of biogas output from other plug-flow digesters installed around the country, which a 1998 study showed to vary from about 44 to 118 cubic feet/day per cow.[21] Shortly after the Haubenschild Farms digester started (with 425 cows), the design calculations were exceeded, and biogas production was over twice the expected output at about 139 cubic feet/day per cow, resulting in electricity generation of 5.5 kWh per cow per day.

Silage Pillows, Haubenschild Farms, Inc.

Current output per cow is slightly higher than design specifications

With 750 cows, current output per cow is over 93 cubic feet/cow/day, and electricity production is about 4.0 kilowatt hours/cow/day, or about 40 percent greater than design specifications. Again, because some of the biogas is being flared and thus not metered, it is impossible to know the exact biogas production.

[21] Derived from Philip Lusk, 1998 (see reference 10).

Comparing apples with apples: performance vs. design specifications

In looking for an explanation of the high biogas production of the Haubenschild digester, an important factor to consider is the high manure production of Haubenschild's cows. More manure means more volatile solids that can be converted to biogas. Haubenschild Farm's cows are high milk producers, and since there is a direct relationship between milk production and manure production, it makes sense that their cows would also produce more manure than average.

An examination of Table 3 reveals that Haubenschild's cows produce about 50 percent more manure slurry than the design specification.[22] So it might be more appropriate to compare biogas production *per gallon of manure* instead of *per cow.* The Haubenschild digester, at 425 cows, had about a 40 percent higher biogas production per gallon of manure than design specifications, while at 750 cows it is operating very near design specifications per gallon of manure, not considering the biogas that is flared.

Reasons for high performance

The especially high performance of the digester in its first year of operation with 425 cows may be due in part to the fact that the digester was operating at less than design capacity. This resulted in the manure staying in the digester for about 30 days instead of 20 days, and thus capturing more biogas. However, studies suggest that most of the potential biogas is captured within the first 15 to 20 days of being in the digester, so this may not fully explain the first year's high production.

There are other factors influencing biogas production that may explain the high biogas output of Haubenschild Farms digester (Refer to the box on page 23 – "What determines how much biogas is produced?"). Manure is scraped and almost immediately fed into the digester, resulting in higher methane capture. Dennis Haubenschild is an incredibly knowledgeable and careful manager of the digester. He monitors the performance closely, taking careful records and making adjustments as necessary, such as keeping the solids content of the manure slurry above 10 percent.

[22] Manure slurry is excreted manure plus wash water and bedding. Since the Haubenschilds are careful to minimize water usage to keep solids content above 10 percent, it is likely that most or all of the 50 percent increase in volume of the total manure slurry over design specifications is from manure excreted from the cows.

Table 3: Digester Design and Actual Performance

	Design	Actual, 425 cows	Actual, 750 cows
Time frame	1998	Jan - May 2000	Sep 2000 - Jul 2002
Cows (average)	1,000	425	750
Manure production			
gallons (per cow per day)	14	n/a	n/a
Manure slurry (including wash water and bedding)			
gallons (per cow per day)	17.5	27	27
total gallons slurry (per day)	17,500	11,500	20,000
Digester size			
volume (cubic feet)	47,000	47,000	47,000
volume (gallons)	352,000	352,000	352,000
retention time (days)	20	31	15
Gas production			
per gallon of manure slurry (cubic feet/day)	3.7	5.1	3.5*
per cow (cubic feet per day)	65	139	93*
total (per day)	65,000	58,900	70,000*
Electrical output			
per cow (kWh per day[23])	2.3	5.5	4.0
total (kWh per day)	2340	2350	2970
generator capacity (kW)	120	135	135
generator availability	90%	98%	98.8%
yearly output (kWh)	766,500	860,000	1,080,000
Thermal output			
total thermal output (mmBtu/day)	18	n/a	n/a
Revenue Generation			
offset heating costs (per year)	$4000	$4000	$4000
offset electricity use on-farm ($/kWh)	$0.07	$0.0725	$0.073**
excess electricity sales ($/kWh)	$0.02	$0.0725	$0.073**
projected annual electric revenue[24]	$40,300	$62,200	$80,957 *(actual, 2001)*
total projected annual revenue	$44,300	$66,200	$84,957

n/a means not available

* Actual biogas production is higher than reported here, because more biogas is being produced than the engine can accommodate, and thus cannot be metered with the current metering configuration

** A rate increase from 7.25 cents/kWh to 7.3 cents/kWh occurred effective Jan 1, 2001.

[23] For the design calculations of kWh per cow, this assumes an energy value of 600 Btu per cubic foot biogas and a heat rate of 15,000 Btu per kWh.

[24] Projected annual electric revenue for the 425 cow column is calculated based on the average electric production from January 14 to June 2. See later discussion on revenue generated.

What Determines How Much Biogas is Produced?

Haubenschild Farms exceeded initial estimates of how much biogas they would produce. The heart of the digester is composed of living organisms, and thus a certain amount of nurturing is necessary to maximize their efficiency. It can take a year before the methane-producing bacteria grow to their maximum potential. The microchemistry of digesters is not yet fully understood, and undoubtedly there are other factors, but based on research and the experience of existing digesters, the following can influence how much biogas is produced:

1. **Animal rations**. Higher-energy food will tend to produce manure with more potential to produce methane. Studies suggest that a higher-energy diet can more than double the methane potential of manure compared to manure from animals fed a lower energy diet.
2. **Solids content of the manure**. The solids portion of manure contains volatile organic matter, which is what the anaerobic digestion breaks down. The higher the solids content, the greater the biogas production per gallon of manure. In the case of a plug-flow digester, the solids content of manure entering the digester should be kept about 10 percent or above, or the solids will tend to settle to the bottom of the digester, where they will slowly fill the digester. As well, solids not in suspension have less exposed surface area and are harder for bacteria to digest.
3. **Frequency and regularity of manure collection**. The more frequently the manure is added to the digester, the less biogas is lost. The manure should also be added to the digester on a regular basis.
4. **Maintaining optimal digester temperature**. Maintaining an even temperature throughout the digester is also important, and is determined by the engineering of the heating rack inside the digester as well as tank insulation. Reducing temperature fluctuations inside the digester will stabilize the methane-producing bacteria and increase biogas output.
5. **Residence time in the digester**. The longer the manure remains in the digester, the more methane will be produced. For cow manure in a plug-flow digester, after approximately 20 days, 70 to 80 percent of the methane potential of the manure will be captured.
6. **pH balance**. A pH level that is too high or low can kill the methane-producing bacteria.
7. **Addition of volatile solids**. The addition of other digestible solids to the manure slurry can increase biogas production. Newspaper is one such solid that is easily digestible.
8. **Introduction of antibiotics**. Antibiotics and other disease-inhibitors like hoof baths introduced to the digester can kill the methanogenic bacteria.

Source: This section derived from Kurt Roos and Mark Moser, "AgSTAR Handbook," Environmental Protection Agency, EPA-430-B-97-015, 1997, See "Resources…" section, page 34 for more information; Wheatley, 1990 (see reference 11); Stafford, Wheatley and Hughes, ed., "Anaerobic Digestion," Applied Science Publishers, Ltd: London, 1979; Elizabeth Bird and Marty Strange "Mares Tales and Mackerel Scales," Center for Rural Affairs: Walthill, NE, 1992.

Hot Water Production

Hot water is produced from recovered engine heat. In addition to providing the necessary heat for the digester, in the winter the hot water is used to heat barn space, saving about $4000 per year in propane gas costs.

Odor Reduction

The reduction in odor from the digester is very noticeable. Near the pond where the digested manure is stored, there is only a slight odor. Haubenschild Farms injected the digested manure on their fields several times in the spring of 2000. Neighbors have not reported noticing a smell, where as when Haubenschild Farms would apply raw manure neighbors would notice the smell for several days, although no complaints were made.

Weed Seed Destruction

Dennis Haubenschild did a simple germination test of the digested manure to test for presence of weed seeds and no weeds were detected. The Minnesota Project is partnering with the University of Minnesota to study weed seed germination of samples run through the Haubenschild digester, and results will be available in 2003.

Greenhouse Gas Reductions

Burning methane at Haubenschild Farms has resulted in a reduction in greenhouse gases. In the first 10 operating months, it was estimated that the equivalent of approximately 680 tons of carbon dioxide were mitigated.[25]

Emissions

Anaerobic digestion, besides methane and carbon dioxide, also produces small amounts of hydrogen sulfide (toxic to humans in certain situations[26]), nitrogen, ammonia and other trace gases. After combustion, this results in emissions of sulfur dioxide (SO_2) and small amounts of nitrogen oxides (NO_x) and particulate matter (PM). It should be noted that hydrogen sulfide would be emitted without the digester, and that by burning the biogas, hydrogen sulfide is converted into sulfur dioxide, which is less toxic to humans.

Using generic estimates of emissions from engines run on biogas, and assuming that Haubenschild Farms engine ran at current production rates as reported in Table 3, it could be expected to annually produce 3.1 tons SO_2, 1.1 tons NO_x, and 0.1 tons PM.[27] Emissions

[25] Estimated by Peter Ciborowski, Minnesota Pollution Control Agency, based on comparative emissions from an earthen basin system for storing manure. More recent estimates of the global warming potential of methane would slightly increase the figure reported here (ie, scientists have increased their estimate of the global warming potential of methane from 21 times to 23 times more potent than carbon dioxide).

[26] Anaerobic digestion of manure typically results in hydrogen sulfide concentrations of around 1500 parts per million (ppm). Concentrations over 1000 ppm can result in severe health problems for humans.

[27] Given an assumed annual biogas production of 25.6 million SCF (standard cubic feet), hydrogen sulfide (H_2S) concentration of 1500 ppmv (parts per million by volume), H_2S density of 0.0901 lb/SCF, sulfur dioxide (SO_2) emission rate from H_2S of 1.78 lb/lb H_2S, SO_2 emission rate from methane of 0.6 lb/10^6 SCF, biogas methane content of 60%, particulate matter emission rate from methane of 13.7 lb/10^6 SCF, Nox emission rate of 140.0 lb/10^6 SCF. Derived from "Handbook of Biogas Utilization," Charles Ross, Thomas Drake III and James Walsh, 1996.

testing of the engine exhaust could provide a more precise estimate of emissions, although these numbers suggest that emission rates from digesters are small compared to similar-sized power generation sources, for example diesel fueled.

Financial Viability

During the reporting period of the original report (September 10, 1999 until July 7, 2000), the Haubenschild Farms digester generated $41,307 in revenue from offset electricity costs and electricity sales. In 2001, the digester's generator offset $38,655 worth of electricity used on-farm, and Haubenschild Farms sold $42,302 of electricity back to East Central Energy, for a total 2001 electricity value of $80,957. In addition, an estimated $4000 annually is being saved in winter heating costs.

In order to examine the financial viability of the Haubenschild Farms project and its applicability to other projects, several hypothetical scenarios are compared and presented in Table 4. For the purposes of this analysis, it was assumed that the entire project cost ($355,000) would have to be paid back, although this is not the case for Haubenschild Farms, who received some grant assistance. We calculated only the simple payback period for each scenario described below. The simple payback method is not a rigorous indicator of feasibility, but does provide a useful comparison for hypothetical situations.

For all of the scenarios, net annual revenue is the total revenue minus assumed operating and maintenance costs of 1.5 cents per kWh of electricity generated.[28] The scenarios considered are as follows:

A. **1998 Projection**. This uses the projections made for electrical output before the digester was built (lower than actual production), offset on-farm electricity value of 7 cents/kWh, and an electricity sales price for excess electricity of 2 cents/kWh (Table 3).

B. **1998 Projection with high price for electricity**. Assumes the original design calculations of electrical output (lower than actual performance), but that both the offset on-farm electricity value and excess electricity price is 7.3 cents/kWh (current price that Haubenschild Farms is receiving for their electricity).

C. **750 cows (actual results for 2001)**. This scenario uses the actual electricity generated in 2001 at the actual price (7.3 cents/kWh), carried through the life of the project.

D. **750 cows, mid-range electricity price**. Same as scenario 3, but assumes a 3.5 cent/kWh buy-back rate from the utility, which seems a plausible rate for future digester owners in Minnesota.

[28] The figure is probably high compared to actual experience at other digesters, even after more than 10 years of operation. See Mark A. Moser and L. Langerwerf, "Plug Flow Dairy Digester Condition After 16 Years of Operation." Proceedings of the Eighth International Symposium on Animal, Agricultural, and Food Processing Wastes, Des Moines, IA, July 9-12, 2000, American Society of Agricultural Engineers, St. Joseph, MI.

Table 4: Financial Analysis

Scenario	Value of offset electricity (cents/kWh)	Value of excess electricity sales (cents/kWh)	Net annual revenue	Simple payback (years)
A. 1998 Projection	7.0	2.0	$31,489	11
B. 1998 Projection w/ high electricity price	7.3	7.3	$53,538	7
C. Actual, 2001	7.3	7.3	$72,616	5
D. Actual 2001 w/ mid electricity price	7.3	3.5	$50,596	7

Table 4 presents the results of this analysis. The financial viability of the project is sensitive to the selling price of excess electricity. With a selling price of 2 cents/kWh (scenario A), the simple payback for the 1998 Projection scenario is 11 years, but reduces to 7 years if the sale price of excess electricity increases to 7.3 cents/kWh (scenario B). The selling price of electricity could make or break a project for a farmer, unless they received some other financing assistance, or were able to achieve high biogas production, as Haubenschild Farms has.

In the scenario with actual results from 2001(scenario C), the simple payback is 5 years. If a mid-range price is assumed for excess electricity sales (scenario D), the simple payback would increase to 7 years.

There are other potential financial benefits that are not included in this analysis:

- Lawsuits over odor may be avoided with a digester;
- The increase in value as a fertilizer may have significant economic value if it displaces commercial fertilizer;
- Herbicide use may decrease with the destruction of weed seeds.

Lessons Learned

The scope of our documentation for this project was limited to the Haubenschild Farms digester. Also, in the course of our review of other digesters and through discussions with project advisors, we have learned some general lessons to offer the reader.

- **Demonstrable benefits.** There are significant benefits to the operation of a plug-flow anaerobic digester. The most important are undoubtedly production of a high-quality fertilizer, odor control and the generation of electricity.
- **Reliable operation.** Haubenschild Farms has operated the generator at over 95 percent availability. This far exceeds even the highest-performing coal plants.
- **Payback of 5 years on investment is possible.** If Haubenschild Farms continues operating at current levels, the total cost of the digester and generator system will pay for itself in about 5 years though energy savings and revenue.

There may be other elements of risk, however, that cannot be assessed even after nearly 3 years of operating experience. For example, engine lifetime may be shorter using biogas than the fuel it was originally designed for and could add to operation and maintenance costs.

- **Electric utility cooperation is important**. Many digester projects have had a more difficult time interconnecting and selling electricity to their utility companies. Contracts to buy electricity for less than half the amount Haubenschild Farms receives are common. The financial success of the project is in a great part due to the cooperation of East Central Energy.

- **Utilities can profit from sale of this "green power."** Capturing methane for generating electricity reduces our dependence on fossil fuel power sources and customers are willing to pay a small surcharge for this benefit.

- **There are many non-market benefits**. Greenhouse gas reductions, odor control and benefits to the neighbors from reduced odors and reduced impacts from catastrophic spills are all benefits that are not captured by the market.

- **A good time to install a digester is when changing or expanding operations**. The digester system needs to be integrated and compatible with the manure management system on-farm. A good time to install a digester is when a dairy farm makes large capital investments, such as installing a new barn or modifying their manure management system.

- **Good management is crucial**. The operation of a digester requires a certain amount of "tinkering," regular oversight and attention to detail. If this is not done, digester and engine performance can suffer.

- **Good digester design is key**. A digester must be designed to be compatible with the needs of the farm, sized appropriately to the volume of manure to be digested, and engineered to provide the proper heating and movement of the manure through the digester. As digesters are still an emerging technology, there is a wide variance in digester performance and design testing. It is safest under these circumstances to design and build the digester with the help of an engineer with a proven track record.

- **Barriers to financing digester systems**. The difficulty Haubenschild Farms had with securing project financing suggests a barrier that potential digester owners may encounter while getting funding from traditional lending sources.

- **Cooperative agency participation helped the success of the project**. In addition to the support received from the AgStar program, several Minnesota agencies (Onanegozie RC & D Council, MN Department of Commerce, MN Department of Agriculture, MN Office of Environmental Assistance) embraced the technology with interest and enthusiasm. They believed that the project had potential to demonstrate multiple benefits for agriculture and would stimulate interest and investigation across many sectors.

Trends Affecting the Future for Anaerobic Digesters

Regulation and Conflict

Farmers, especially those considering building larger regulated feedlots, will be under increasing pressure to find solutions to treating waste. The odor and potential for pollution from animal agriculture are increasingly coming into conflict with neighbors and will likely result in greater regulatory controls. Anaerobic digesters can offer multiple benefits to the farmer and the environment.

Size of Farms

Trends in dairy size suggest that herd size is increasing, and in another 10 years, there will be 300-400 Minnesota family farms with herds greater than 400 cows. Some experts have calculated that there is a threshold size below which installing a digester is not economic for generating electricity. One such estimate is that it would require a minimum of 400 cows on a dairy, earning a $0.06 kWh electric rate, to operate a profitable digester enterprise.[29]

There are various reasons for this. The minimum expense required to install a digester system with all its parts is great, and thus there are economies of scale in construction.

Specialization

On a smaller dairy labor is usually less specialized than on a larger one, and requires fewer workers. Haubenschild Farms employs 11.5 full time equivalent workers, with a small percentage of total time devoted to digester operation. On a smaller farm with fewer workers, operating a digester would probably require the same amount of effort, thus a higher percentage of time available from the work force. However, it may be economic to install and operate at smaller farms where thermal energy is captured by methane combustion, reducing the cost required for electric generation. For the Haubenschild Farms project, electrical generation represents over one third of the project cost, but without it the system probably would not be able to pay for itself.

Cooperative Ventures

Building a centralized digester where manure is pooled and blended to proper consistency from surrounding farms may be a possibility, and is fairly common in Europe. The manure transport costs to get manure to and from the digester can be quite costly, and this may limit the extent to which centralized digesters can operate.

Another possibility is “turn-key” operations. Digester operation and maintenance requires time and learned skills. Farmers may not be interested in performing this job. It may make sense for a utility or enterprise to build and operate multiple digesters in multiple locations and either charge a manure management fee or return part of the profits of energy generation or carbon credits (if they become a reality), or sale of the separated solids.

[29] 7/19/00 telephone conversation with Mark Moser, RCM, Inc.

Policy

Since the Haubenschild digester was built, Minnesota leaders have implemented several initiatives to encourage digesters, many of which were policy recommendations in the original Haubenschild report:

- A state production payment of 1.5 cents per kilowatt-hour was extended to include on-farm digesters;
- The Minnesota Department of Agriculture's zero interest loan program for digesters was expanded;
- The Minnesota Department of Commerce released a report in August 2002 that considers the total potential for biogas production on Minnesota farms;
- The Minnesota Pollution Control Agency has considered anaerobic digesters as a mitigating technology when negotiating with feedlot operators;
- Great River Energy, the electric generation and distribution cooperative utility for a majority of farms in Minnesota, has recently announced a special grant program for digesters; and
- East Central Energy, Haubenschild's utility, has instituted the first green electricity marketing program in the country exclusively for digester-produced power, by offering their customers the option to purchase "cow power".

Policies to encourage digesters are rolling along, not only in Minnesota and other states, but at the federal level as well. The near future may see a rapid expansion in the number of digesters on farms, without the need for additional incentives.

Digester policy and equity

The capital-intensive nature of digester systems, as well as economies of scale in their construction and operation, are major barriers to their development on smaller and mid-sized farms. The way policies are currently structured, this means that tax dollars to encourage the construction of digesters will tend to go towards larger farms. Unless there is a way to balance this out, smaller operations will be at a competitive disadvantage, since they don't have as easy access to these funding sources as larger operations do. Future policies should consider this equity question.

Resources for More Information on Anaerobic Digestion

Minnesota Project website: www.mnproject.org contains links to many of the other resources described in this appendix, as well as other useful sources of information.

AgSTAR provides assistance to farmers considering installing an anaerobic digester system. They can be reached by calling 1-800-95AgSTAR. The AgSTAR web site **www.epa.gov/agstar** contains a wealth of information for farmers interested in installing a digester, including:

- The AgSTAR Handbook, a guide to thinking about installing an anaerobic digester. This can be downloaded from the web site.
- FarmWare, a free software program that can assist a farmer with a pre-feasibility analysis of installing a digester. Available for downloads.
- List of vendors with contact information and a description of project experience with farm-scale digestion.

Methane Recovery from Animal Manures: The Current Opportunities Casebook. This report was published by the Department of Energy's National Renewable Energy Lab and gives an overview of digester technology, as well as information on currently operating digesters in the United States. Available for downloading at the Minnesota Project web site.

Haubenschild Farms web site:
www.ecenet.com/%7ehauby/farmpresentation.prz/odyframe.htm

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