

Affordable Farm Scale Digesters for Single Waste Streams

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.

By the late 1990s, dairy farmers were faced with increasing federal and state regulation of manure and were looking for ways to comply. Digesters were being built once again because the owners hoped to reduce the environmental hazards of dairy farms and other animal feedlots.

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 were considering expanding their dairy operation from 100 cows to 850 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. It is also interesting to note that Dennis serves on the Minnesota Feedlot and Manure Management Advisory Committee (FMMAC).

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 conditions 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, in 2006, is still functioning. When fully expanded they expected to use digested manure on all their 1200 crop acres for growing.

The Opportunity

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. The main objectives of the project were:

1. Increase the value of the manure for fertilizer.

The sandy acres at Haubenschild Farms requires 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, reducing the use of herbicides.

2. Reduce animal waste odour.

An increase in herd size could bring a significant increase in odour and fly problems. This would not only create a more unpleasant work environment, but could also cause tension with neighbours and regulatory agencies.

3. Produce Electricity

Produce and sell sufficient electricity to recover digester capital and operating costs in five years or less and continue to receive an on-going revenue stream.

4. Produce Hot Water

Produce sufficient hot water to offset propane use and supply heat for the barn in the winter and to ensure the digester remains at the proper temperature and is mixed by convection.

5. Demonstrate Viability

Demonstrate the viability of a simple, inexpensive but dependable anaerobic digester system on an operating dairy farm in north eastern Minnesota (cold climate digester).

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 in late 1998. 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 Digesters (Berkley, California), a company with a proven track record of building successful on-farm digesters, to assist with the project. After submitting a manure management plan, the Minnesota Pollution Control Agency granted the farm a feedlot permit. The digester qualified as manure storage, reducing the size of the storage pond required for storing digested manure.

Because the Haubenschilds were planning the digester as 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 is used for 420-430 cows. With a herd size of about 850, approximately 1 ton per day would need to be used. Using newspaper bedding, the volatile solids fraction in the manure stream was increased.

Components of the Haubenschild Digester System

The type of digester installed at Haubenschild Farms is a simple plug flow design and is limited in its application to cow manure and newspaper, collected by scraping, and cannot be used for swine or dilute cow manure, since the solids concentration would be too low (<10%). The complete plug flow digester system required several components:

- Manure collection pit
- Mix tank
- Piping system

- Plug-flow digester
- Effluent storage
- Gas utilization

During the most recent additions to the facility, underground collection trenches were installed in the animal barns, therefore fresh manure is scraped into the barn collection pit, where it flows by a gravity system into a 14,000 gallon mix tank below the generator house, where the solids fraction is reduced to 10 %. 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, approximately 20,000 gallons of mixed manure per day. A flush system for manure collection is not compatible with a plug-flow digester.

The 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. 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. Hot water pipes installed in the floor of the milking parlour, holding pen, breezeway and tanker bay (where the milk is stored) 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 ten horsepower fan. The hot water to heat the digester is recovered from the engine-generator’s cooling jacket. Hot water is stored in a large single axle milk tanker system beside the generator house. The Huabenschilds supplied the tanker.

The digester was designed to process manure from 1000 cows. Currently, with 850 cows, it takes about 15 days for the manure to travel through the digester, five 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.

The digested effluent, odour reduced, flows from the digester via gravity and a 36” buried culvert, to a lined 3.5 million gallon lined storage pond where it is kept until it can be injected or broadcast spread on fields for crop production.

The facility is referred to as a cold climate digester by U.S. standards. The average temperature from October to March in the Princeton Minnesota area (45 degrees N) is -5°C (23.8°F). In comparison in Central Alberta (Red Deer 52 degrees N), the average temperature according to Environment Canada is -6.4°C (20°F). Minnesota does not experience the long duration cold spells of -25°C (or greater).

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. The farm chose a Caterpillar 3406 engine, attached to a generator with a capacity of about 135 kilowatts, to produce the electricity from the biogas. 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 odour 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. Dennis's experience with CAT engines directed him to buy the highly reliable six cylinder (non-turbo) model.

The original engine ran continuously since the plant was started with a utilization of greater than 98 %. In late 2005, after more than 40,000 hours of use, the shaft connecting the engine and the generator failed in the middle of the night, causing the engine to vibrate to the point of destruction. A new 135 kW engine was purchased at a cost of \$30,000 U.S. in 2002.

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.

As the bacteria in the digester grew and flourished, and as the herd size 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. With 425 cows, the biogas output per cow was almost twice projections. With 850 cows, the output per cow has come down somewhat to about 40 % above projections. Haubenschild's cows are producing about 50 % more manure per cow than the digester was engineered for, which somewhat explains the high biogas production per cow. Excess gas is simply flared.

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 five year surplus power purchase contract proposed by the local electric cooperative, East Central Energy at \$.073/kWh. 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 favourable contract.

On the expiration of that contract the regional power authority, Great River Power, would not permit East Central Energy to enter into a new "favourable" contract with the Haubenschilds. The new contract is for \$0.043/kWhr whereas the previous was for \$0.073/kWhr. Including carbon credits, Dennis estimates break even between his power purchase costs and power sales. According to state regulations, the farm puts all electricity produced into the grid and purchases its power from the grid system. In order to avoid "brown outs" on the farm, Great River Power installed a diesel generator that "kicks in" when power shortages or power outages occur to maintain the digester conditions.

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. The \$355,000 total was approximately \$47,000 higher than original estimates. Construction took approximately six months.

Project Funding Source	Amount Funded (U.S. \$)	Comments
AgStar Program	\$40,000	Technical Assistance, In-kind
Minnesota Department of Commerce and Department of Environment	\$87,500	Grants
Minnesota Department of Agriculture	\$150,000	No interest loan
Haubenschild	\$77,500	Equity
Sub-total	\$355,000	Repayable portion \$227,500
Haubenschild Labour	\$145,000	Sweat Equity
Total Investment	\$500,000	

Financial Viability

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 \$4,000 annually is saved in internal heating costs for a total of \$85,000/year. Including fertilizer savings that were erratic in the first few years, the payback on the repayable investment was approximately three years and on the total investment was just over five years.

Further Analysis

Biogas production at the Haubenschild farm was optimized by paying attention to the following factors:

1. Animal Rations (high value)
2. Solids Content of the Manure (10 %)
3. Frequency and Regularity of Manure Collection (2x daily)
4. Maintaining Optimal Digester Temperature (95 – 105 F)
5. Residence Time in the Digester (20 days)
6. pH Balance (7.0)
7. Addition of volatile solids (newspaper)
8. Introduction of antibiotics (minimize)

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

- Payback of five years on investment is possible, total capital cost <\$1 million

- 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
- Acting as your own general contractor and providing labour can have a big dollar impact
- Simple, reliable design, single manure stream and source all components locally.

Expected Benefits	Accomplished Yes/No	Comments
Odour and Fly Control	Yes	Odour is definitely low, fly control is somewhat better
Renewable Energy Production	Yes	
Distributed Electricity Generation	Yes	
Increase in Fertilizer Value	Same	Same
Pathogen Reduction	Yes	
Weed Seed Destruction	Yes	Less herbicides required each year, pre-emergent only by year three
Greenhouse Gas Reduction	Yes	This has been measured by state officials 4500 – 5200 tpy
Sales of Digested Fibres	No	
Reduced Total Oxygen Demand	Yes	
Potential Concerns	Realized Yes/No	Comments
Nitrogen Ammonia Emissions	No	There has not been a problem in this area
Water Pollution	No	No issues with leakage
Air Emissions Issues	No	Minor, when flaring gas
Safety Issues	No	No problems to date

Acknowledgements

Many thanks to the U.S. AgStar program, Dennis and Tom Haubenschild and Mark Moser of RCM Digesters for their input into this case study. Many articles and reports written about the Huabenschild digester project were very useful in compiling the information used in this case study.

Appendix: General Facts (as of January 2000 – all US figures):

Business Proposition	Sole ownership, power utility contract, 450 (1999) 850 (2006), free stall dairy operation, Princeton Minnesota, USA
Type of Plant	135 kW, CAT 3406 diesel engine, heated plug flow design
Cost of Plant	\$355,000 U.S. (2000)
Estimated Payback Period (Actual)	Five years
Feedstock	Dairy manure and paper bedding
Reactor Dimensions	350,000 gallons, heated concrete tank
Feed Rate	20,000 gallons per day
Operating Temperature	95° – 105° F, mesophilic
Dry Matter	10 % - 14 % solids into the digester
Retention Time	15 – 20 optimal, 15 days in practice
Agitation	14,000 gallons pre-mix tank before digester, heat pipes in digester
Biogas Production	70,000 ft ³ /day, remainder unmetered and flared
Sulphur output	1.1 tons/year @ 25.3 million ft ³ biogas/year
Energy Output	>1,000,000 kWh/year
Waste Heat Usage	Digester and barn floor heat
Waste Water Management System	Lined storage pond for field application, 3.5 million gallons
Operating Personnel	Owner and family member
Use of digestate	Field application
Annual Savings Fertilizer/Herbicide	\$40,000/\$7,000
Electricity Purchase Price	\$.073/kWh, first 5 years, currently \$.043/kWh
CO ₂ – annual mitigation	4500 - 5200 tons annually (2005)
Total Annual Revenue Projection	>\$85,000 U.S. (2,000), \$47,000 U.S.

Note: Initial payback analysis is based on the original cost of \$355,000 and annual power revenues of \$85,000/year, minus operating costs.

Haubenschild estimates that the general contracting, labour and hot water tank components saved approximately \$145,000 U.S. Current replacement cost is estimated by RCM Digesters at \$1,000,000 Canadian

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

1. Large confined livestock facility (300 head of cows, 2000 swine)
2. Year round stable manure production
3. A manure management strategy compatible with digester technology
4. A use for the recovered energy
5. Someone to efficiently manager the system
6. A sound business model (added by the author)