

## Viability of Methane Production by Anaerobic Digestion on Iowa Swine Farms

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#### Summary and Implications

Energy production and use has long been a major policy issue in Iowa. The 1990 Comprehensive Energy Plan for Iowa established two statewide goals around which current energy policy is structured:

- to meet all future demand for energy by increasing efficiency rather than supply, and
- to increase the use of alternative energy resources from 2% of Iowa's total energy consumption to 5% by the year 2005 and 10% by 2015.

A currently available and potential alternative energy source that can move Iowa nearer these goals is methane recovery. It is projected that about 5 MW of energy are produced from methane gas in Iowa (8). This represents a minuscule amount of the energy produced in Iowa. Most of this energy comes from methane recovery at landfills and municipal sludge digesters, but some is produced by methane recovered from anaerobic digestion at industrial sites such as meat packing plants..

Chapter 473.3 of the Iowa Code states that the goal of Iowa energy policy should be to develop and promote programs that promote energy efficiency and conservation "through the development of indigenous energy resources that are economically and environmentally viable." The purpose of this report is to evaluate the economic viability of methane production from anaerobic digestion of swine manure. This analysis will use a series of budgets to accomplish this purpose. However, with the stated purpose of Iowa's energy policy in mind, this report also will identify potential environmental viability issues related to the economics of methane production by anaerobic digestion.

Anaerobic digestion occurs when bacteria produce biogas by decomposing an organic matter in an environment without air (14). Interest in on-farm biogas generation is hardly a recent phenomenon. Prompted by the

energy crisis of the 1970s, several farm operations throughout the country—including Iowa—experimented with anaerobic digesters. This experimentation was frequently marked by dissatisfied operators and/or system failure. The technology was frequently concluded to be a promising idea, but only technically and economically feasible to those who were willing to spend a great deal of time tinkering with the technology on the farm.

Like many other alternative energy technologies, the rate of anaerobic digester failure is high. Historically, there is a 63% chance in the United States for a farm to install a presently nonoperating digester (11). Many of the digesters that failed were those installed during the energy crisis of the 1970s. This failure is difficult when added to the already high management demands of managing a farm. Anaerobic digestion appears to be a management-intensive enterprise that has rapidly evolved. Managers face the demand to stay current with changes and technology. Advancements in an emerging or sparsely used technology typically magnify the demand on management.

Several of the early adopters nonetheless continue to successfully use anaerobic digester technology today. These operations, most prominently several commercial dairy farms across the country, have expanded or updated their digester technology as the technology has advanced and their experience has increased. Many of those who have been able to successfully develop and adopt the technology have used the methane produced to offset energy expenses. They also have used their systems to control odor and produce a waste product more easily used and, in some cases, marketed.

The success of anaerobic digesters in the dairy industry has not been mirrored in the swine industry. According to phone interviews with the Iowa Department of Natural Resources and Iowa Pork Producers Association, there were approximately 1 dozen swine operations using or installing anaerobic digesters in Iowa during the 1970s. There appears to be only one still in operation, the McCabe farm in Mount Pleasant. This facility, established in 1972, currently produces about 1,800-head farrow-to-finish market pigs annually.

The McCabe digester will soon be replaced due to a relocation of the production facility. One digester has recently been built in Nevada, IA, and is presently in the start-up phase. A second digester was under construction in Iowa at the time this report was prepared. The system under construction, located at a facility at the Crestland Cooperative near Creston, uses a more advanced

technology. The onset of advanced technology as modeled by these new systems, combined with the development of lagoon-based digesters, may make anaerobic digestion more feasible as a part of a typical swine production system.

Speaking strictly from the standpoint of cash costs, on-farm methane production by anaerobic digestion has not attracted a huge crowd of enthusiasts due to the lack of demonstrated financial feasibility. However, potential benefits of anaerobic digestion expand beyond the cash or direct economic benefits. Anaerobic digestion offers an alternative for dealing with a number of social and economic issues, particularly those related to agriculture. These issues, which were only beginning to emerge in the 1970s, could be termed “volatile” today. Of special interest in the agricultural sector is the role anaerobic digestion could play in controlling livestock operation odors.

*Review of the literature.* The first prominent project in the United States on applying anaerobic digestion to swine production was conducted at the University of Missouri in the late 1970s (6,7). Researchers there evaluated many different aspects of applying anaerobic digestion to manure from the University of Missouri swine farm. Most recently in the United States, the University of Illinois published results of the use of an anaerobic digester on an Illinois swine farm (21). This digester was eventually shut down because of technical and budget concerns.

Published research on applying anaerobic digestion to the dairy industry also has emerged, not only in the United States, but also around the world (9,13). Many countries, such as India, have used smaller-scale anaerobic digesters to produce energy. Models also were developed for centralized or cooperative anaerobic digesters in Canada (18). Smaller, more densely populated countries such as Belgium also have successfully experimented with practical application of anaerobic digesters on swine operations (15).

#### *Nutrient composition of anaerobically digested manure.*

Concentration of nitrogen, phosphorous, and potassium is generally the same between manure that has gone through an anaerobic digester and manure that has not. There are two major differences between the digested and undigested products: 1) more volatile nitrogen is contained in anaerobically digested manure, and 2) nutrients are more uniformly distributed in anaerobically digested manure. On average, manure consists of about 30% ammonia nitrogen. The ammonia level rises to about 70% after going through a digester (7). This means the effluent from the digester consists of about 70% ammonia-nitrogen. There is no significant nutrient difference in the organic versus inorganic nitrogen concentrations; however, ammonia-nitrogen is more quickly lost into the atmosphere if rain does not occur soon after manure application. An applicator would have to adjust the amount of digested manure applied accordingly. Because of this difference in volatility,

there is a potential for increased atmospheric and environmental impact from the application of digested manure.

Manure that has been subjected to anaerobic digestion has been found to produce similar crop yields to manure that has not been anaerobically digested. Fischer et al. (7) found that corn yield was the same when both kinds of pig manure were applied at the same nitrogen rate. Manure that has undergone anaerobic digestion does contain a higher ratio of phosphorous in proportion to nitrogen than is necessary for corn production. At the same time, it is easier to adjust the amount of digester effluent to the soil's nutrient needs because the nutrient content of effluent is less variable than regular pit manure (7). Dahlberg et al. (1) found that wheat yields were no different when applications of dairy manure subject to anaerobic digestion and regular pit dairy manure were compared at equal nitrogen levels.

*Manure odor and anaerobic digestion.* As was previously mentioned, one of the more volatile social issues surrounding the livestock industry concerns odor. Anaerobic digestion has met with success in controlling odors from the swine operation described in this report. Empirical research supports the thesis that odor reduction by anaerobic is not a phenomenon isolated to Mount Pleasant.

The earliest study found in evaluating odor from manure subjected to anaerobic digestion occurred in Canada in the mid-1970s (20). Manure odors were rated on an 11-point hedonic rating scale with 11 being the most offensive olfactory rating. The study found undigested manure to average a 6.5 rating in panel tests compared with a 4.6 rating for digested manure. An additional decrease in odor offensiveness occurred when digested manure was stored for a period of a month and then evaluated. Although anaerobic digestion does not totally eliminate the offensiveness of the swine manure odor, it definitely can dramatically reduce the relative offensiveness of the odor to the human observer.

Powers et al. (16) found that anaerobic digestion had a favorable effect on the composition of dairy manure relative to the level of key chemicals in odor issues. A panel evaluation in this study also ranked the odor from digested manure about half as offensive as undigested manure on a 10-point scale. Powers also investigated the effect of further manure additives on digested manure, and concluded that the most accurate evaluation of odor offensiveness must be site specific.

*On-farm economics of anaerobic digesters.* Efficiency of anaerobic digestion systems has historically been measured in the total cost per cubic meter of digester space. In 1981, Fischer et al. (7) reported the cost range to be between \$28/m<sup>3</sup> and \$672/m<sup>3</sup> for digester systems at that time.

Feasibility estimations vary depending on the calculated price of energy and measured benefits to producers. The aforementioned University of Illinois study indicated that the digester there would probably not be economically efficient for the operation that produced 3,000 head of farrow-to-finish pigs (21).

Conclusions on the economic feasibility of on-farm methane production by anaerobic digestion are mixed. Results of economic analyses are varied based on the size and location of operations. However, one general conclusion can be drawn from the existing research: Unless operators can reap economic benefits from an anaerobic digester, or justify installing a digester to prevent externalities from impeding the business' operation, the technology will go unused in agricultural production systems.

*McCabe farm case study summary.* Harold McCabe built his swine confinement facility in Mount Pleasant, Iowa in 1968. It remains in use today by his son, Richard, but soon will be rendered inoperable by a new highway that will cut through the farm. The production facilities have remained very similar to the way they appeared in 1968. Hogs are housed in a two-story remodeled dairy barn. Farrowing and nursery facilities are located on the upper level, with growing and finishing rooms on the ground level. When the barn was adapted for pig production in 1968, a flush gutter system and lagoon were installed for handling the manure.

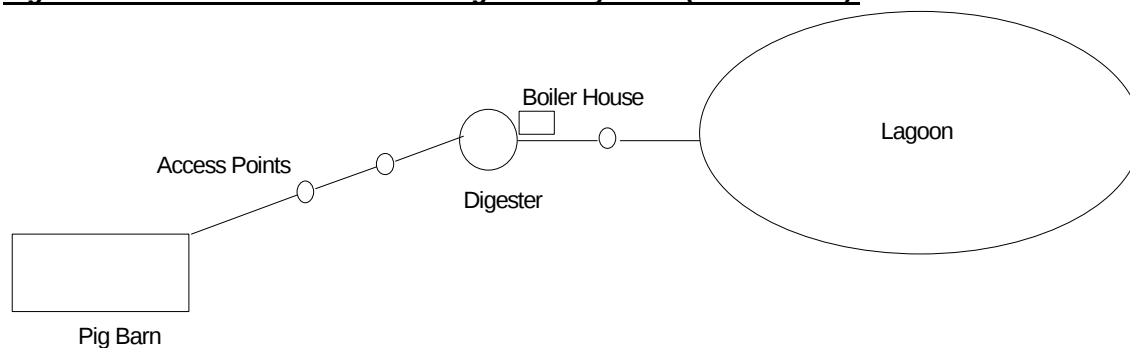
The McCabe Farm is located near several Mount Pleasant businesses, including a family restaurant. From the advent of the hog operation, McCabe began to receive complaints from the restaurant and a nearby motel about the pig odor. This led him to install an aerating system in the manure lagoon, a simple electrically driven drum that slowly aerated the manure at a nominal monthly cost (\$80-100). Although this system reduced the odor, complaints were still received. Harold McCabe and his neighbors were still not entirely pleased with the way things smelled in Mount Pleasant.

To solve the odor problem, McCabe applied the same technology that had been used to treat municipal wastes for nearly a century: anaerobic digestion. The total construction costs of the system have been estimated at \$60,000 with matching value in design and other costs of installation. This results in an estimated total capital cost of \$120,000 when the system was completed in 1972.

The heart of the McCabe system is a 55,000-gallon tank (approx. 21,900 ft<sup>3</sup>) to which manure is transported from the pig facility via a gravity flow system. Approximately 4,000 gallons of water is added to the manure in the barn. This addition of water is important for two reasons:

- The composition of the manure is changed to facilitate anaerobic digestion.
- The waste can then move via gravity flow to the digester.

**Figure 1. McCabe Farm Anaerobic Digestion System (not to scale).**



The addition of water to the manure in this system is not significantly different from that in a normal lagoon system. Approximately 4,700 gallons of water is required to handle the manure from a 1,500 head farrow-to-finish operation with the production of 300 additional feeder pigs in a typical lagoon system. About 1,480 gallons of water would be required to handle the manure from this size operation in a typical liquid pit operation (10). As the anaerobic digester combines attributes of both kinds of systems, the estimate of 4,000 gallons (as also estimated in

the 1997 Opportunities Casebook McCabe Farm case study) was judged to be reasonable.

The waste flows approximately 150 feet from the barn to the digester, where the retention time for 3,000 gallons of water is approximately 18 days. The effluent then moves out of the digester to the  $\frac{3}{4}$ -acre holding lagoon. The manure has been changed by anaerobic digestion to a dense, high-nutrient sludge and wastewater. The lagoon has been pumped only twice because the digester was installed, the last time being 8 years ago.

It is necessary for the temperature of the influent in the digester to be at 90–93°F for anaerobic digestion to occur. This requires supplemental heat, a need provided by means of a boiler that is part of the digester system. The boiler is powered by natural gas and uses considerably more energy in the colder winter months.

Generally speaking, the installation of the anaerobic digestion system at the McCabe Farm has been viewed as advantageous by both the operator and the surrounding community. The digester has accomplished its original purpose by virtually eliminating the odor from the manure lagoon or “biosolid reservoir.” All directly and indirectly involved parties seem to be satisfied with the digester. In Mount Pleasant, at least, there has definitely been some benefit from the anaerobic digester on the McCabe Farm. The local community has benefited. Furthermore, Rich McCabe is preparing to relocate his farming operation because of new road construction. He is intent on including an anaerobic digester as part of his operation.

*Budget discussion.* The budgets that follow reflect the McCabe digester. They show the net present value of assets solely devoted to the digester of \$282,361.90. The value of the methane produced from the digester offsets that cost by \$77,901.58. However, it is important to remember that the primary reason the digester was installed at the McCabe farm was to keep the operation socially and environmentally viable by reducing the manure odor. To that extent, then, the cost assigned to the digester might be best described as the cost for the McCabe swine operation to stay in business. This cost is \$204,460.32.

*Costs.* The principle amount was calculated based on the \$120,000 value assigned to the digester when it was installed in 1972. A 2.5% discount rate was applied to this value, resulting in its net present value of \$228,035.10.

Both time and expense relating to repairs and maintenance on the digester have been minimal in its 28-year life. Approximately 5–10 min is spent per day monitoring the digester. Some additional labor time is required in the barn because the time it takes to clean the pens and add water to the manure is more than what a normal scraping of the pens would entail. The digester is pumped once or twice a year to remove lignin, hog hair, and other solids that cannot be anaerobically digested. This process takes several days due to the necessity of keeping a constant pressure within the digester, but takes little actual labor time. Slightly more than 30 min per day (150 h annually) was estimated to be directly affiliated with the digester.

The labor rate was discounted annually to 1972 with the farm labor index contained in Table B-101 of the 1998 Economic Report of the President. This yielded a value of \$21,772.63 over the life of the digester.

Maintenance costs were assigned at \$200 per year currently and discounted at the rate for the price of all farm inputs from Table B-101 of the 1998 Economic Report of the President over the 26 year life of the digester. The total value assigned for maintenance was \$3,870.69.

Energy costs vary throughout the year due to seasonal changes in temperature. They have averaged \$125 per month over the past year. An annual value of \$1,500 (\$125/month) was tied to the index for fuel prices paid, Table B-61 from the 1998 Economic Report of the President, to arrive at a final estimate of all energy used in this system. The total value is \$28,683.45.

*Benefits.* The only recognized benefit from this system over a traditional lagoon system was the potential benefit of the biogas produced. Methane produced was based on the characterization of swine waste as reported in Part 651 of the Agricultural Waste Management Field Handbook. According to McCabe, 25 sows are currently farrowed every 6 weeks with 1,500 market hogs per year, and an additional 300 feeder pigs are produced per year. Based on an average litter size of slightly more than nine pigs per litter, this indicates an average current herd size of 110 breeding animals.

Volatile solids production is calculated by pounds of waste produced per day per 1,000 lb of animal body weight. An average of 330 lb was used for the weight for breeding females. Average weights for the growing pigs were calculated at an average of .82 lb gain/day for animals up to 40 lb and 1.8 lb gain/day for the finishing animals. These values are consistent with the average range of gain for growing swine as reported in ISU Extension Publication Pan-489, Life Cycle Swine Nutrition.

Using the following values, we calculated the total volatile solids production for the McCabe Farm this year to be 1,722,408.60 lb.

One pound of VS will yield 4–5.5 ft<sup>3</sup> of methane (19). In the McCabe system, a value of 4.5 ft<sup>3</sup>/lb VS is a reasonable estimate to establish methane production (19). Assuming this conversion, 382,757.47 ft<sup>3</sup> of methane is estimated to be produced in the McCabe system. The methane produced can be optimally used in the following manner: 35% for electricity production, 50% for heat production, and 15% lost (19). The following table converts the total production of 382,757.47 ft<sup>3</sup> of methane to these uses.

The energy was then converted into respective units for estimating value. The 188,301.36 MJ of electricity converts to 52,305.93 kWh. At an average energy price of \$.0603 (8), this yields an annual value of \$3,154.05. The heat produced was estimated to be worth \$.361/Therm, about \$.01 kWh and the approximate opportunity cost of a therm of natural gas for McCabe at the present. The 269,001.94 MJ converts to 2547.96 Therms. This yielded a value of \$919.81 for the heat produced. No value was assigned to

energy that was lost. The total value of the energy produced in the McCabe system was thus estimated to be the combined value of the electricity potential plus the heat value, or \$4,073.86. This value was tied to the index contained in Table B-66 of the 1998 Economic Report of

the President for the producer price index for energy costs for finished goods. When discounted over the life of the digester, the total energy produced yields an estimated value of \$77,901.58.

**Table 1: Labor affiliated with digestion system on McCabe Farm.**

| Labor Item                                  | Daily Time    | Total Annual Time<br>(minutes) | Total Time<br>(hours) |
|---------------------------------------------|---------------|--------------------------------|-----------------------|
| Monitoring                                  | 10 min        | 3,650                          | 60.83                 |
| Washing (additional)                        | 10 min        | 3,650                          | 60.83                 |
| Pumping                                     | Two 8 h days  | 1,920                          | 32.00                 |
| Repairs, cleaning, etc.                     | 1.53-8 h days | 740                            | 12.34                 |
| Total Labor Time                            |               | 9,960                          | 166.00                |
| <b>Total Annual Labor Cost (@\$7.50/hr)</b> |               | <b>\$1,245</b>                 |                       |

**Table 2: McCabe Farm volatile solids production.**

|                | Avg. Weight         | Number of<br>Animals | Number<br>of Days | Total Volatile<br>Solids Production |
|----------------|---------------------|----------------------|-------------------|-------------------------------------|
| Lactating sows | 330                 | 220                  | 35                | 6,860.70                            |
| Gestating sows | 320                 | 110                  | 330               | 24,742.08                           |
| Starting pigs  | .85 lb gain per day | 1,800                | 50                | 16,560.72                           |
| Growing pigs   | 1.8 lb gain per day | 1,500                | 110               | 1,674,245.10                        |

**Table 3: McCabe Farm energy potential (megajoules).**

|                 | ft <sup>3</sup> Methane | m <sup>3</sup> Methane<br>(0.028 m <sup>3</sup> /ft <sup>3</sup> ) | Conversion<br>units | Total<br>megajoules<br>(MJ) |
|-----------------|-------------------------|--------------------------------------------------------------------|---------------------|-----------------------------|
| 35% electricity | 133,965.11              | 3751.0232                                                          | MJ/m <sup>3</sup>   | 188,301.36                  |
| 50% heat        | 191,378.73              | 5358.6044                                                          | MJ/m <sup>3</sup>   | 269,001.94                  |
| 15 % loss       | 57,413.62               | 1607.5814                                                          | MJ/m <sup>3</sup>   | 80,700.59                   |

**Table 4: Estimated value of energy produced.**

|                    | <b>Megajoules<br/>Produced</b> | <b>kWh<br/>(3.6 kWh/MJ)</b> | <b>Therms<br/>(105.575 Therm/MJ)</b> | <b>Value<br/>Per Unit</b> | <b>Value</b>      |
|--------------------|--------------------------------|-----------------------------|--------------------------------------|---------------------------|-------------------|
| Electricity        | 188,301.36                     | 52,305.93                   | --                                   | \$0.0603                  | \$3,154.05        |
| Heat               | 269,001.94                     | --                          | 2,547.96                             | 0.3610                    | 919.81            |
| <b>Total Value</b> |                                |                             |                                      |                           | <b>\$4,073.86</b> |

**Table 5: Cost/benefits summary over life of McCabe digester.**

| <b>Costs</b>                        | <b>NPV</b>          | <b>Benefits</b>     | <b>NPV</b>          |
|-------------------------------------|---------------------|---------------------|---------------------|
| Principle                           | \$228,035.00        | Energy Produced     | \$77,901.58         |
| Labor costs                         | 19,884.15           | (\$4073.86 in 1998) |                     |
| Maintenance costs                   | 3,871.00            |                     |                     |
| Energy cost                         | 28,683.45           |                     |                     |
| <b>Total cost</b>                   | <b>\$280,473.31</b> |                     |                     |
| <b>Net Cost of Digester System:</b> |                     |                     | <b>\$202,572.82</b> |

**Conclusion**

Anaerobic digestion has not been widely used in agricultural settings due to technological failure and lack of economic feasibility. The anaerobic digestion system located on the McCabe Farm in Mount Pleasant, IA, has performed admirably with minimal mechanical failure in its 27-year life. The system also has achieved its primary goal made at the time of its inception: to enable the farm to keep producing pork.

The energy production of the McCabe system can only be estimated because the biogas produced has never been harnessed for energy. Even with a generous estimate of the full energy potential produced on the McCabe Farm, the system falls short of any kind of reasonable economic payback. Because its cost was fully borne by the operator, the cost of the digester in this system could be viewed as an annual cost of staying in business.

There are definitely economies of scale affiliated with anaerobic digestion systems on swine farms. The literature that exists on the economics of swine production systems using anaerobic digestion systems indicates that this size may be more than twice the size of the McCabe system. On-farm use of this technology would only be feasible for a producer who was willing to incur the cost of an anaerobic digestion system as a cost of staying in business, or as a way of compensating an externality. Methane production by anaerobic digestion continues to offer some promise for solving problems of swine odors and alternative energy in Iowa.

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