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

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Abstract

Energy production and use has long been a major policy concern 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
- 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

While much of the current interest in Iowa concerning new applications of anaerobic digestion focuses on agriculture, the primary application of the process in the United States has been to treat wastewater from industrial sites. These applications include slaughterhouse, dairy and cheese, distillery, and starch production processes. This report begins with a general discussion of anaerobic digestion and then moves to two primary focal points: the first examining an anaerobic digester in a swine (livestock) production setting, and the second focusing on an anaerobic digester within a packing plant (industrial) setting. The report ends with a summary of key considerations in the viability of methane production by anaerobic digestion.

The Viability of Methane Production by Anaerobic Digestion in Iowa

Foreword

Energy production and use has long been a major policy concern 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
- 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 potential alternative energy source that may move Iowa nearer these goals is methane recovery. Currently, about five megawatts of energy are produced from methane gas in Iowa (Iowa Comprehensive Energy Plan 1998). This represents a minuscule amount of the energy produced in Iowa. Most of this energy comes from methane recovery at landfills, but some is produced by methane recovered from anaerobic digestion at industrial sites.

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 at agricultural and industrial sites in Iowa. This analysis will use cost benefit analysis to accomplish this purpose. However, with the stated purpose of Iowa's energy policy in mind, this report will also identify potential environmental viability issues related to the economics of methane production by anaerobic digestion.

While much of the current interest in Iowa concerning new applications of anaerobic digestion focuses on agriculture, the primary application of the process in the United States has been to treat wastewater from industrial sites. These applications include slaughterhouse, dairy and cheese, distillery, and starch production processes. The report will begin with a general discussion of anaerobic digestion and will then move to two primary focal points: the first examining an anaerobic digester in a swine (livestock) production setting, and the second focusing on an anaerobic digester within a packing plant (industrial) setting. The report will end with a summary of key considerations in the viability of methane production by anaerobic digestion.

Methane Production by Anaerobic Digestion

Anaerobic digestion has long been used to treat municipal sewage wastes. Application of this technology to treat wastewater in the meat packing industry was utilized as early as the 1950s (Sollo 1960). Since then, many packing plants have utilized the technology to render plant wastewater suitable for disposal into municipal sewer systems. Municipal waste treatment technology was first applied on a commercial farm site by Harold McCabe of Mount Pleasant, Iowa. This anaerobic digester is still in operation and will be examined in the first case study contained in this report.

Anaerobic digestion occurs when bacteria produce biogas by decomposing an organic matter in an environment without air (Parsons 1986). The process involves three steps:

1. Hydrolysis of the organic matter by enzymes
2. Conversion of the decomposed matter to fatty acids
3. Conversion of the acids to methane and carbon dioxide by anaerobic bacteria

(Jones and Ogden 1986)

The key to successful anaerobic digestion is maintaining a proper environment for the bacteria converting fatty acids. Thus, the entire anaerobic digestion process is highly dependent on the composition and temperature of the wastes involved (Mackie and Bryant 1990). The primary energy input into anaerobic digestion systems is used to heat wastes and maintain a proper environment in which the bacteria can thrive.

The impetus for research and practical interest in anaerobic digestion has arguably changed since its emergence as a viable technology. Application of anaerobic digestion at industrial sites was fueled by a need to treat wastewater and suppress odor. During the 1970s, a burst of research into alternative energy sources came about as the result of economic factors and the relatively high fuel costs. These costs have receded. For example, the average price for electricity in Iowa was 6.03 cents per kWh in 1995, one of the lowest prices of any Midwestern state (Iowa Comprehensive Energy Plan 1998). Speaking strictly from the standpoint of economic costs, then, it should not be surprising that on-farm methane production by anaerobic digestion has not attracted a huge crowd of enthusiasts.

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 emerging agricultural concerns. These issues, which were only beginning to emerge in the agricultural sector during the 1970s, could be termed "volatile" today.

The vast majority of both industrial and farm sites that utilize or are considering anaerobic digestion indicate that air and water quality issues are a primary concern. Of special interest in the agricultural sector is the role anerobic digestion could play in controlling odors from livestock operations.

Agricultural Applications of Anaerobic Digestion

Introduction

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 that of other alternative energy technologies, the rate of anaerobic digester failure is high. Historically, there is a 63% chance in the U.S. for a farm to install a presently non-operating digester (Lusk 1997). 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 an enterprise which requires managerial expertise. Managers face the demand to stay current with changes and technology. Advance in an emerging or sparsely utilized technology typically magnifies the demand on management.

Several of the early adopters nonetheless continue to successfully utilize 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. Those who have been able to successfully develop and adopt the technology have used the methane produced to offset energy expenses. They have also used their systems to control odor and produce a waste product more easily utilized 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 DNR and Pork Producers Association, there were approximately a 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 Mt. Pleasant. This facility, established in 1972, currently produces about 1800 head farrow-to-finish annually.

The McCabe digester will soon be replaced due to a relocation of the production facility. At least two additional digesters were under construction in Iowa at the time this report was prepared. The systems under construction, located on a private farm near Nevada and a facility at the Crestland Cooperative near Creston, employ 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.

Review of the Literature

University research has examined the use of anaerobic digesters on swine and dairy operations over the past two decades. The first prominent project in the United States was conducted at the University of Missouri in the late 1970s (Fischer et al. 1981, 1984; Prince et al. 1983). Researchers there evaluated many different aspects of applying anaerobic digestion to manure from the University of Missouri swine farm. Most recently in the U.S., the University of Illinois published the results of the use of an anaerobic digester on the Illinois swine farm (Zhang et al. 1990). This digester was eventually shut down because of technical and budget concerns.

Published research on applying anaerobic digestion to the dairy industry has also emerged, not only in the U.S., but also around the world (*see e.g.* Maramba 1978; Kobayashi and Masuda 1993). Many countries, such as India, have utilized smaller-scale anaerobic digesters to produce energy. Models were also developed for centralized or cooperative anaerobic digesters in Canada (Sullivan 1981). Smaller, more densely populated countries such as Belgium have also successfully experimented with practical application of anaerobic digesters on swine operations (Poels et al. 1983).

The *Methane Recovery From Animal Manures 1997 Casebook* (DOE 1997) provides the most comprehensive, current picture of on-farm anaerobic digestion in the United States. It identifies the three general types of anaerobic digestion systems recognized by the Natural Resource Conservation Service for processing animal manures. These systems are the complete mix system, plug flow system for dairy operations, and covered anaerobic lagoon systems. They are briefly overviewed below. Other emerging system designs also appear to be viable, such as a loop design employed by a 2,200 head Pennsylvania dairy.

Complete Mix Digester

A complete mix digester, namely the digester located at Iowa's McCabe farm, was the first anaerobic digester present on a swine farm in the U.S. From the advent of his hog operation in 1968, Harold McCabe began to receive complaints about the pig odor from the nearby Jerry's Family Restaurant and other Mt. Pleasant businesses. This led McCabe to install an aerating system in the manure lagoon, a simple electrically driven drum that slowly aerated the manure. In 1972, the digester (still in operation) was completed.

Manure at the McCabe Farm is presently transferred by gravity flow from the barn to a mixing pit. It is then deliberately mixed within a digester reactor where methane is produced and collected (Lusk 1997). The methane may then be converted to energy or, as at the McCabe farm, simply burned off. A more detailed description of the McCabe system will follow in the budget case study.

Plug Flow Digester

Plug flow digesters essentially consist of a long trough. Manure is collected daily at one end and then pushed down the trough by subsequent manure collections (Lusk 1997). Methane is produced as the manure moves down the trough and decomposes. The methane can then be collected and utilized in an end form elsewhere on the site.

Anaerobic Lagoons

The anaerobic lagoon method will be discussed in further depth later in this report since it is the primary method used for anaerobic digestion in the industrial applications to be examined. A cover is installed on the manure or wastewater lagoon. This cover traps the methane that is produced by the anaerobic bacteria in the lagoon. Biogas is collected from under the cover by means of a collection manifold; the biogas is then removed to its final application (Lusk 1997).

There are many modifications to these basic systems, but they have historically been the primary designs for on-farm anaerobic digestion systems. A digester currently being installed at a farm in Nevada, IA uses a more advanced design developed at Iowa State. Similarly, there exist many modifications and site-specific innovations to the general systems of digesters around the country. Economic analysis of anaerobic digesters, then, is frequently inhibited by the lack of universality in system design, preference, needs, and operation.

Nutrient Composition of Anaerobically Digested Manure

Much attention has been given to proper nutrient management from manure in recent years. Some criticism has been levied against farmers in the past for treating manure strictly as a waste product and disposing of manure as cheaply as possible with little regard for its potential value. The flurry of interest in farm nutrient management relating to the *Pfiesteria piscicida* outbreaks on the East Coast has also been noted in the rationale for pursuing further application of anaerobic digestion technology (Lusk 1997).

The 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
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 (Fischer et al. 1984). This means the effluent from the digester consists of about 70% volatile nitrogen. There is no significant nutrient difference in the volatile vs. non-volatile nitrogen concentrations; however, volatile 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. (1984) found that corn yield was the same when both kinds of pig manures 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 (Fischer et al. 1984). Dahlberg et al. (1988) 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. It was with odor in mind that the McCabes of Mount Pleasant installed the first on-farm anaerobic digester. They indicate it has helped control swine odors for the past 25 years. Prior to the digester’s construction, they had previously received numerous complaints about their facility. There were several businesses in close proximity. Odor complaints all but ceased after the digester was put into operation.

Empirical research supports the thesis that odor reduction by anaerobic digestion 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 (Welsh et al. 1977). 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 to 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. While 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. (1995) 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. While not relating specifically to manure odor, de la Noire and Basseres (1989) conclude that anaerobic digestion inhibits the performance of some potential manure management tools, especially the potential for algae treatment. These findings might indicate that digested manure may warrant different treatment by emerging manure management technologies.

Significant efforts have recently been underway to evaluate the economic impact of swine odors. Last February, a team of economists from North Carolina State University published the results of an exhaustive study of hog concentration versus property values (Palmquist et al. 1997). The study found that property values in areas of the heaviest hog concentration fell by as much a 9.5% from the average. Hog operations were concluded to produce localized externalities. These placed some burden on both the surrounding neighbors and on the whole of society in the area surveyed.

An earlier Minnesota study concluded an actual positive relationship between feedlots and property values (Taff et al. 1996) However, the authors of the Minnesota study acknowledged that the relationship could actually be negative, depending on the effect of statistical "noise" and other factors that may have been present in the analysis. Some of the suggested factors affecting that study might be identified as the fact that the study was conducted within a few years of the construction of the feedlots, thus disabling the potential of a long-term analysis.

On-Farm Economics of Anaerobic Digesters

Research involving on-farm economic analyses of anaerobic digesters has generally reached the conclusion that on-farm anaerobic digestion is a technology that will demand the demonstration of financial feasibility before it becomes widely utilized. This has been demonstrated in several studies.

A 1986 Georgia study projected that utilizing an anaerobic digester in a farrow-to-finish system annually producing 7,200 head was economically feasible (Jones and Ogden 1986). This was full cost recovery. Efficiency of anaerobic digestion systems has historically been measured in the total cost per cubic meter (m^3) of digester space. In 1981, Fischer et al. reported the cost range to be between $28/$m^3$ of digester volume and $672/$m^3$ of digester volume for systems at that time (Fischer et al. 1981). 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 which produced 3,000 head of farrow-to-finish pigs (Zhang et al. 1990).

Some measures were found to be constant in the Georgia and Missouri studies regarding the way costs were assigned to the digester operations. Jones et. al followed the same pattern as the Missouri study in assigning fixed costs: a 12-year depreciation of digester facilities after a 10% investment tax credit and an energy tax credit of 10% (these measures are now outdated), and an additional tax savings allowed based on the original investment minus one-half the credits. A value of 1% of initial investment was assigned for taxes and insurance, and 2% of initial investment for repairs and maintenance.

The reduction of odor and pollution problems has been noted in at least one economic analysis of anaerobic digesters. Parsons (1986) used the cost of an aeration system intended to produce a reduction in chemical oxygen demand similar to digestion as a basis for dairy systems comparison.

Conclusions on the economic feasibility of on-farm methane production by anaerobic digestion are mixed. Results of economics 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, IA in 1968. It remains in use today by his son, Richard, but will soon be rendered inoperable by a new highway which 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. From the advent of the hog operation, McCabe began to receive complaints from local businesses 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). While this system reduced the odor, complaints were still received. Harold McCabe and his neighbors were still not totally pleased with the way things smelled in Mount Pleasant.

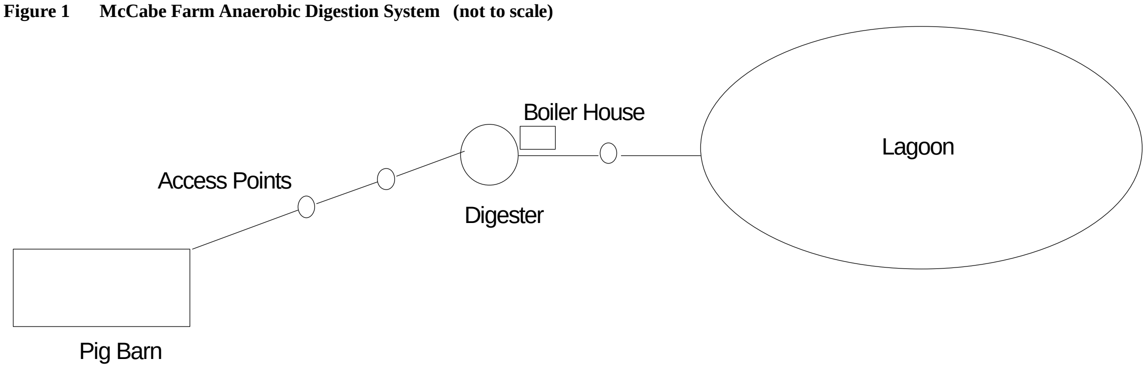
To further solve the odor problem, McCabe applied the same technology that had been used to treat municipal wastes for nearly a century: anaerobic digestion. McCabe essentially designed his own pig waste treatment system. The total construction costs of the system have been estimated at $60,000 with 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 (app. 21,900 cu. ft.) to which manure is transported from the pig facility via a gravity flow system. Approximately

4,000 gallons of water are 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 are required to handle the manure from a 110-sow operation producing 1500 market hogs and 300 feeder pigs. Based on this theoretical estimate, combined with discussion with McCabe, 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 4,000 gallons of water is approximately 18 days. The effluent then moves out of the digester to the ¾ acre holding lagoon. The manure has been changed by anaerobic digestion to a dense, high nutrient sludge and wastewater. The lagoon has only been pumped twice since the digester was installed, the last time being eight years ago.

It is necessary for the temperature of the influent in the digester to be at 90-93^{o} F in order 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. Energy costs have historically ranged from a low of $80 per month in the summer months to highs of $180 in the coldest winter months. Overall, the energy bill averages about $125/month or $1500 per year. The current rate being paid when the farm was visited on June 24, 1998 was $.361/Therm. The farm qualifies for the gas business rate.

Both time and expense relating to repairs and maintenance on the digester have been minimal in its 28-year life. Approximately 5-10 minutes are 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 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 are not able to 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 minutes per day (150 hours annually) were estimated to be directly affiliated with the digester.

Table 1: Labor Affiliated With Digestion System on McCabe Farm

Labor Item	**Daily Time**	**Total Annual Time (minutes)**	**Total Time (hours)**
Monitoring	10 minutes	3650	60.83
Washing (additional)	10 minutes	3650	60.83
Pumping	Four 8 hr. days	1920	32
Repairs, cleaning, etc.	1.53 8 hr. days	740	12.34
Total Labor Time		9960	166
Total Annual Labor Cost (@$7.50/hr.)		**$1245**	

Major repairs to the digester have been minimal. In the past ten years, one motor has been replaced ($125) and one boiler component has been replaced ($500). Some of the original cast iron pipes within the digester were replaced with PVC pipes in the early 1980s. Total annual repair costs are estimated at $200 annually, with the only expenses being periodic component replacements.

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 $284,684.31. 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 $206,782.73.

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% real discount rate was applied to this value, resulting in its net present value of $228,035.10.

Labor costs were calculated based on the 166 hour annual estimate and a 1998 wage rate of $7.50 per hour. The labor rate was then discounted annually to 1972 using the farm labor index contained in Table B-101 of the 1998 Economic Report of the President. This yielded a value of $24,095.04. 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 over the 26 year life of the digester. This yields a value of $3870.69.

Energy costs vary throughout the year due to seasonal changes in temperature. They have averaged $125 per month over the past year. According to the Energy Information Administration State Energy Price and Expenditure Report of 1994, the commercial price for natural gas in Iowa increased at an annual rate of approximately 8.5% between 1972 and 1994. Natural gas prices have only slowly increased since this time. An annual value of $1500 ($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 $28,683.45 for all energy used in this system over its life.

Benefits

Methane 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 six weeks with 1500 market hogs year and an additional 300 feeder pigs are produced per year. Based on an average litter size of slightly over 9 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 1000 lbs of animal body weight. An average of 330 lbs 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 lbs 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 (Holden et al. 1996).

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

Table 2: McCabe Farm Volatile Solids Production

	Avg. Weight	Number of Animals	Number of Days	Volatile Solids Production (lb/d/1000#)	Total Volatile Solids Production
Lactating Sows	330	220	35	5.40	6,860.70
Gestating Sows	320	110	330	2.13	24,742.08
Starting Pigs	.85 lb/gain per day	1800	50	8.80	16,560.72
Growing Pigs	1.8 lb gain per day	1500	110	5.40	1,674,245.10
Total Volatile Solids Produced					**1,722,408.60**

One pound of VS will yield 4-5.5 cubic feet of methane (Shih Wu Sung, Personal Communication 24 July 1998). In the McCabe system, a value of 4.5 ft^3/lb VS is a reasonable estimate to establish methane production (Sung 1998). Assuming this conversion, 382,757.47 ft^3 of methane are estimated to be produced in the McCabe system. The methane produced can be optimally utilized in the following manner: 35% for electricity production, 50% for heat production, and 15% lost (Sung 1998). The following table converts the total production of 382,757.47 ft^3 of methane to these uses.

Table 3: McCabe Farm Energy Potential (Megajoules)

	ft^3 methane	m^3 methane (0.028 m^3/ft^3)	Conversion Units	Total Megajoules (MJ)
35% Electricity	133,965.11	3751.0232	50.2 MJ/m3	188,301.36
50% heat	191,378.73	5358.6044	50.2 MJ/m3	269,001.94
15 % loss	57,413.62	1607.5814	50.2 MJ/m3	80,700.59

Table 4:

	Megajoules Produced	kWh (3.6 kWh/MJ)	Therms (105.575 Therm/MJ)	Value Per Unit	Value
Electricity	188,301.36	2,305.93	--	$0.0603	$3,154.05
Heat	269,001.94	--	2547.96	0.3610	919.81
				Total Value	**$4,073.86**

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 (Iowa Comprehensive Energy Plan 1998), 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 that energy which 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 5: Cost/Benefits Summary Over Life of McCabe Digester

Costs	**NPV**	**Benefits**	**NPV**
Principle	$228,035.00	Energy Produced ($4073.86 in 1998)	$77,901.58
Labor Costs	24,095.04		
Maintenance Costs	3,870.69		
Energy Cost	28,683.45		
Total Cost	**$284,684.31**		
		Net Cost of Digester System:	**$-206,782.73**

Industrial Applications of Anaerobic Digestion

Introduction

Anaerobic digestion has long been applied to treat industrial wastes worldwide. The most prominent industrial application of anaerobic digestion is treating wastewater from various industrial processes. These applications include those associated with dairy, cheese, distillery, vegetable oils, and starch production. Anaerobic digestion has also proven to be very useful in treating wastewater from meat packing plants. An added benefit is that the plants are then able to harness the methane produced to offset energy costs. This section of the report will examine sites in Iowa where the technology is applied and summarize the viability of such applications.

There are two factors which have driven the development of alternative waste treatment facilities for meat packing plants. First, the meat packing industry became increasingly decentralized and located new facilities in areas nearer the sources of supply (Anderson and Schmidt 1985). Anaerobic digestion proved to be a viable new technology for processing meat packing wastes. It became an important part of new packing plant design.

The second factor for the increased application of anaerobic digestion is that many plants retained their original locations. These are frequently within or near large municipal areas. This has provided packing plants with access to large amounts of labor. However, two key concerns have emerged in these urban locations: Odors associated with the packing plant and the composition of the plant's wastewater that would be disposed into a municipal sewer system. Advanced anaerobic digestion technology has helped provide a solution for both problems.

Review of the Literature

A wide variety of literature exists on the industrial applications of anaerobic digestion. Interest in the process was widespread in the 1950s and regained impetus during the Energy Crisis of the 1970s. The emergence of modified and improved technologies coupled with the push toward sustainability has continued interest in the 1990s.

Anaerobic digestion is used in the meat packing industry in the United States to primarily treat packing plant wastewater. This is slightly different from the way the technology has developed in Europe, where increased regulations and the BSE scare of a few years ago has prompted meat packers to investigate new ways to dispose of slaughter wastes. For example, the following table illustrates the potential for bioprocessing parts of a cattle carcass and demonstrates the feasibility of using anaerobic digestion to dispose of a large part of carcass waste.

Table: Potential for Bioprocessing A Cattle Carcass

Commercial Sale	Rendering/Processing	Potential for Bioprocessing	Other
46%	21%	28%	5%

Source: Woodgate, S. "Commercial rendering," in Meat Strategies for by-product disposal. Proceedings of a Meat and Livestock Commission Symposium, Birmingham, U.K., 1991.

In the United States, there is still an adequate disposal avenue for some of the wastes that might be directly anaerobically digested in Europe. Anaerobic digestion technologies are mostly affiliated with the proportion of blood, trimmings, animal wastes, and other contents of slaughterhouse wastewater. Nonetheless, anaerobic digestion remains a viable way to add value via methane production to by-products that are increasingly difficult to dispose or utilize.

In addition, meat packing plant wastewater contains a high concentration of organic matter yielding a greater potential for methane generation (Jeris 1983). Anaerobic systems also compare very favorably to aerobic wastewater processing systems in that anaerobic systems remove more biological oxygen demand and generate a smaller quantity of sludge (Jones 1995).

Types of Systems

It was not uncommon for a packing plant built in the U.S. in the 1970s to have several anaerobic lagoons. However, odor problems arose at some facilities and there was additional interest in utilizing the methane produced for energy. Two kinds of systems have subsequently emerged: covered anaerobic lagoons and high-rate anaerobic digesters.

Covered Lagoons

The design for covered lagoons used in industrial applications is essentially the same as the anaerobic lagoons used in agricultural applications. An impermeable cover constructed out of a flexible material like high-density polyethylene is placed over the lagoon. The biogas produced in the lagoon is trapped under the cover. The gas is then collected by a collection device around the circumference of the lagoon. This device can be as simple as a length of PVC piping. The gas is pulled into the collection pipe by using a blower/suction device and can then be taken to its end use.

Iowa locations have played a significant part in the way anaerobic lagoon technologies have developed in the meat packing industry. Packing plants at Dubuque, Ottumwa, and Marshalltown use covered anaerobic lagoons for wastewater treatment and biogas production. The development of this technology in Iowa has been due in large part to the influence of the late Dr. Richard Dague, former faculty member at the University of Iowa and past chair of the Civil and Construction Engineering Department at Iowa State.

High Rate Anaerobic Technology

High rate anaerobic technology refers to treating wastewater in reactors, as opposed to large lagoons. They are referred to as “high-rate” because of the increased BOD or COD loadings, which reduce retention times from hours to days (Johns 1995).

The most common kinds of high rate anaerobic technology used in the meat packing industry are the anaerobic contact, upflow anaerobic sludge blanket, and anaerobic filter process (Johns 1995). There are few data available for high rate anaerobic technologies. Stebor et al. (1990) identify a few problems with these technologies as encountered at an Albert Lea, MN facility. Most notably, the high concentration of insoluble fats, oils, and grease in the wastewater slow down these systems.

Similar problems have been cited at other facilities employing high rate anaerobic technologies worldwide (Johns 1995). High rate anaerobic technologies, however, still possess the basic advantages of an anaerobic system over an aerobic system because they more efficiently process and utilize the methane production potential in the waste. During the past decade, more research has been focused on high rate anaerobic technologies (*Ibid.*). Recently, Iowa State University engineers have developed an anaerobic process called the anaerobic sequencing batch reactor. This process, which has had experimental success, could provide a more efficient form of anaerobic digestion.

Wastewater Nutrient Concentration

Meat packing plant wastewater contains high concentrations of volatile fatty acids and ammonia (Banks 1994). The nitrogen content of the wastewater, however, is relatively low (Johns 1995). This results in acceptable methane gas yields owing to a low carbon to nitrogen ratio of the material entering the digester.

Packing plants in the United States typically pipe their water to a municipal wastewater treatment facility. Anaerobic digestion significantly reduces chemical concentrations that are unwanted or unacceptable at municipal wastewater treatment plants. Anaerobic digestion reduces the total suspended solids concentration (TSS) and the total Kjeldahl nitrogen (TKN). On-site anaerobic digestion also reduces the biological oxygen demand (BOD) and the chemical oxygen demand (COD). These are all categories that are subject to fines/surcharges if wastewater treatment facilities exceed municipal standards.

Odor

Odor is one of the obvious concerns affiliated with meat packing plants. Historically, there were a number of obstacles affiliated with odor concerns that anaerobic systems had to face. The primary culprit in odor concerns from anaerobic lagoons at meat packing plants is hydrogen sulfide, which has an odor not unlike that of rotten eggs. It was quickly determined that odor was best controlled by installing some sort of a cover on an anaerobic system. This was also found to be more economical than a comparable aerobic system, explaining why covered anaerobic lagoons have been fairly widely utilized within the meat packing industry (Chittenden et al. 1977).

Economics

Many of the anaerobic lagoons and systems installed in the meat packing industry are obviously private projects. As such, extensive economic information is not readily available. However, Dague et al. (1989) reported a $1.5 million expense affiliated with the anaerobic lagoon at the Farmland Foods plant in Dubuque. The investment was returned in just under two years as the result of savings in operating costs for wastewater treatment and the values of the energy produced from the biogas. In fact, "approximately 12% of all the purchased fuels used for steam generation, heating, and other purposes in the pork processing facility comes from biogas fuels generated by the anaerobic lagoon (Dague et al. 822)."

The fact that several packing plants, both in Iowa and around the country, have utilized anaerobic systems for wastewater treatment is important testimonial support for the claim that these systems are economically viable. The next case studies will examine two locations in Iowa and provide numerical support for this claim.

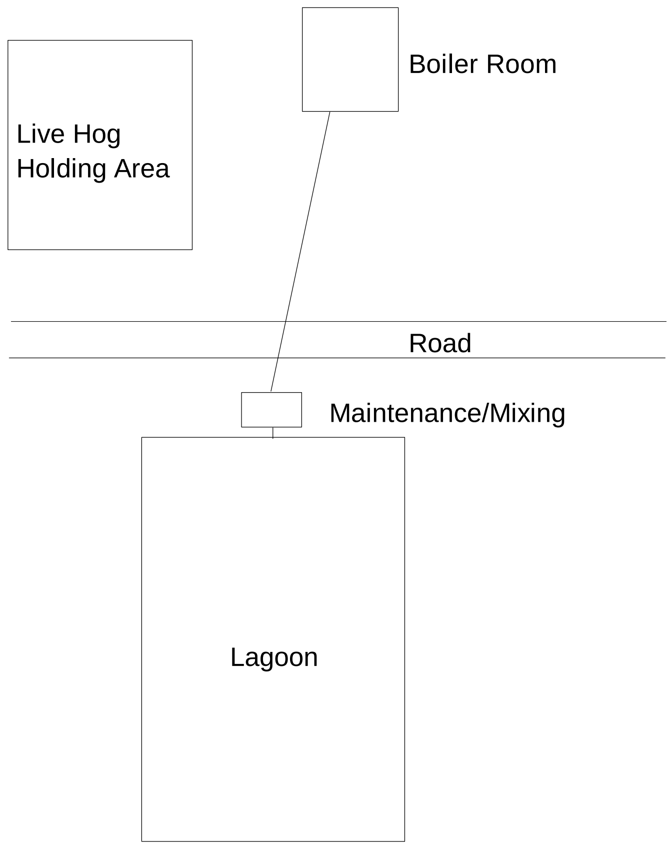
Company A Case Study

Company A has the capacity to process 18,000 hogs daily. The daily water flow from the plant is 2.2 million gallons. In 1989, an anaerobic lagoon was installed to treat wastewater from the plant. The lagoon was installed for three major reasons:

- To lower the amount of surcharges levied by the city on wastewater
- To allow the company to reduce the total amount of wastewater discharged to the city
- To enable the plant's operational capacity to double

The amount budgeted for the project was $2 million. This included the cost of the pipeline from the plant to the anaerobic lagoon. The lagoon is located approximately 500 yards from the processing facility, just across the road. The lagoon is 200 feet wide by 600 feet long, and has a 19 million gallon maximum capacity. The actual construction cost of the project in 1989 was significantly below budget, at $1.2 million.

Figure 1: Company A Anaerobic Lagoon (Not to scale)



In 1989, all wastewater began to be flushed from the packing plant for treatment in the lagoon. The methane produced by the lagoon is captured under a flexible cover. It is then piped to the plant's boiler room where it is utilized for energy. Because of the highly corrosive nature of methane, it is burned in an 80% methane/20% natural gas mixture. Pure natural gas is burned before and after to "clean out" the boiler equipment.

The following is a summary of the costs and benefits affiliated with the anaerobic lagoon producing methane at the plant. The cost of the project was recovered in less than five years. The installation of the anaerobic lagoon at the facility has been viewed as a huge benefit for the company. The lagoon has allowed them to expand their operation, as well as to significantly cut the surcharges imposed by the city to treat the wastewater.

Budget Discussion

Costs

The capital cost of constructing the anaerobic lagoon was $1.2 million in 1989 dollars. This value was discounted at a rate of 2.5% to yield a net present value of $1,498,636.

The methane moves to the boiler room by means of a blower. This is run by a 25 horsepower engine for 60 hours a week. One horsepower equals .74 kWh, and a value of $0.05 per kWh was assigned based on current energy prices and price paid by Company A. This yields 57,720 kWh annually at a value of $2886.

Table 1: Energy Used By Anaerobic Lagoon

Engine Horsepower	Horsepower/kWh	Hours/Week	Annual Hours	Annual Energy Used (kWh)	Annual Value ($0.05/kWh)
25	.74	60	3120	57,720	$2,886

The value of $2,886 was tied to the energy producer price index for finished goods found in Table B-66 of the Economic Report of the President. The total cost of energy used over the nine-year life of the lagoon is estimated to be $26980.99

The repairs and maintenance affiliated with this lagoon have been minimal. Two steel tanks in the mixing room at the lagoon were replaced with fiberglass tanks due to corrosion. The total cost was $1100 for each tank. Six pumps were replaced at a cost of $350 each. This results in an actual total cost of $4300 for capital equipment replacement over the nine-year life of the lagoon. Using this number, an annual repair estimate of $500 was assigned annually. This $500 annual capital repair value was tied to the capital equipment producer price index found in Table B-66 of the Economic Report of the President. The total cost for capital improvements over the life of the lagoon is estimated to be $4,752.71.

Maintenance for the digester was also minimal. The following table describes the annual maintenance time associated with the digester.

Table 2: Labor Cost

Bearings maintenance (30 min. per month)		6 hrs	
Clean 3 flame arresters (4 hrs each, twice annually)		24 hrs	
Daily inspection (0.5 hrs per week)		26 hrs	
	TOTAL	56 hrs	
Wage Rate		$12.05	
Total Annual Labor Cost	(1998 $)		**$674.80**

A current wage rate being paid to workers who would be maintaining the lagoon was found to be $12.05 per hour. This yields a total annual maintenance cost of $674.80 for the 56 hours affiliated with the lagoon. This cost was tied to the Employment Cost Index for Private Industry found in Table B-48 of the 1998 Economic Report of the President. The total labor cost associated with the lagoon was $6115.20 over its nine-year life.

Benefits

There are two benefits that the Company is realizing from the anaerobic lagoon.

1. Methane produced and utilized by the company
2. Reduced surcharges from wastewater treatment

Methane Produced

A flow meter was installed at the beginning of 1996 to measure the methane produced from the lagoon. The average energy benefit to the company was calculated using the average methane production over the two-year period from 1996-97. This production was assumed to be indicative of the methane production from the previous seven years. The average number of Therms produced monthly over these two years is 50,054, yielding an annual production of 600,648 Therms. This was then multiplied by a factor of .75 (heat value of methane in natural gas) and multiplied by a natural gas price of $0.30/Therm to yield an annual savings of $135,145.80.

Therms Methane (Monthly)	Annual Therms Produced	Heat Value of Methane	Value of Methane
50,054	600,648	450,486	$ 135,145.80

This annual benefit was indexed according to the Producer Price Index for energy contained in Table B-66 from the Economic Report of the President. Using the annual value of $135,145.80, the total energy benefit for the lagoon over its nine-year life was $1,263,492.

Surcharge Savings

Surcharges are placed on the wastewater flow from the plant by the city. Surcharges can be imposed based on BOD levels (Biological Oxygen Demand), TSS (Total Suspended Solids), Ammonia Concentration, and a general permit cost that remains constant.

The total monthly surcharge savings due to the lagoon averages $20,000 per month from before the digester was installed. This is based on dramatic reductions in BOD and TSS counts. This data was calculated by the plant assistant engineer.

The annual amount of $240,000 from surcharge savings was tied to the 2.5% discount rate used to discount the capital cost. The total savings over the nine-year life of the lagoon is $2,153,008.

The following table summarizes the costs and benefits associated with the anaerobic lagoon producing methane from wastewater at the plant.

Table 3: Company A Anaerobic Lagoon Net Present Value

Costs		**Benefits**	
Capital Construction	$ 1,498,636.00	Energy	$1,263,492.00
Energy Used	$ 26,980.99	(Methane Produced)	
Repairs	$ 4,752.71		
Labor	$ 6,115.21	Surcharge Savings	$2,153,008.00
Total Costs	$ 1,534,484.46	Total Benefits	$3,416,500.00
Net Present Value of Company A Anaerobic Lagoon			**$1,880,015.84**

The anaerobic lagoon at the plant took just over four years to return the cost of installation. It enables the company to operate at a greater capacity than before, while at the same time significantly reducing the COD, BOD, TKN and TSS concentrations in wastewater discharged to the municipal treatment facility. The anaerobic lagoon at the plant has achieved its initial purposes admirably.

Company B Case Study

The daily water flow from the Company B plant is 2.5 million gallons. An anaerobic lagoon was installed in 1985-86 to treat wastewater from the plant. The lagoon was installed for three major reasons:

- To replace an expensive, outdated chemical treatment method
- To enable the plant to discharge cleaner wastewater to the city
- To harness energy from anaerobic digestion

The following is a summary of the costs and benefits affiliated with the anaerobic lagoon producing methane at the plant. The cost of the project was recovered in less than five years. The installation of the anaerobic lagoon at the facility has been viewed as a huge benefit for the company. The lagoon has allowed them to expand their operation, as well as to significantly cut the surcharges imposed by the city to treat the wastewater.

Budget Discussion

Costs
The capital cost of constructing the anaerobic lagoon was $1.7 million in 1986 dollars. This value was discounted at a rate of 2.5% to yield a net present value of $2,286,311.

Approximately 10,000 kilowatts of energy use are associated with the digester each month. and a value of $0.05 per kWh was assigned based on current energy prices and price paid by Company A. This yields 120,000 kWh annually at a value of $6,000.

The value of $6,000 was tied to the energy producer price index for finished goods found in Table B-66 of the Economic Report of the President. The total cost of energy used over the nine-year life of the lagoon is estimated to be $56,093.53.

The repairs and maintenance affiliated with this lagoon are significantly more than Company A. Maintenance materials costs are estimated at $20,000 per year with an additional $50,000 budgeted per year for other repairs. An average of $15,000 per year was budgeted for lagoon solids removal. This has been performed three times over the 12-year life of the lagoon at a total cost of $170,000 in 1998 dollars.

This annual repair value for Company B was tied to the capital equipment producer price index found in Table B-66 of the Economic Report of the President. The total cost for capital improvements over the life of the lagoon is estimated to be $807,960.95.

Maintenance for the digester was also significantly more than that performed at Company A. Approximately 100 hours a week were estimated to be affiliated with the lagoon. A current wage rate being paid to workers who would be maintaining the lagoon was found to be $12.05 per hour. This yields a total annual maintenance cost of $62,660 for the 5200 hours affiliated with the lagoon. This cost was tied to the Employment Cost Index for Private Industry found in Table B-48 of the 1998 Economic Report of the President. The total labor cost associated with the lagoon was $567,840.05 over its nine-year life.

Benefits

There are three benefits that Company B is realizing from the anaerobic lagoon.

1. Methane produced and utilized by the company
2. Reduced surcharges from wastewater treatment
3. Savings from old, inefficient wastewater treatment facility

Methane Produced

Specific biogas generation data was unable to be obtained from Company B. The company conservatively estimates a benefit of $90,000 per year in natural gas savings from the biogas utilized from the lagoon. This annual benefit was indexed according to the Producer Price Index for energy contained in Table B-66 from the Economic Report of the President. Using the annual value, the total energy benefit for the lagoon over its twelve-year life was $1,040,611.51.

Surcharge Savings

The total monthly surcharge savings due to the lagoon averages $500,000 per year. The annual amount of $500,000 from surcharge savings was tied to the 2.5% discount rate used to discount the capital cost. The total savings over the nine-year life of the lagoon is $5,628,882.30.

Pretreatment Savings

Company B recognized a significant savings in their wastewater treatment cost when they began using the anaerobic lagoon. This savings was estimated in 1989 to be $400,000 annually. This value was compounded annually at the standard 2.5% to yield a total pretreatment savings of $6,056,176.72.

The following table summarizes the costs and benefits associated with the anaerobic lagoon producing methane from wastewater at the plant.

Table 4: Company B Anaerobic Lagoon Net Present Value

Costs		**Benefits**	
Capital Construction	$ 2,286,311.00	Energy (Methane Produced)	$ 1,040,611.51
Energy Used	$ 56,093.53	Pretreatment Savings	$ 6,056,176.72
Repairs	$ 807,960.95	Surcharge Savings	$ 5,628,882.30
Labor	$ 567,840.05		
Total Costs	$ 4,071,047.24	Total Benefits	$12,725,670.53
Net Present Value of Company B Anaerobic Lagoon			**$ 8,654,623.29**

The anaerobic lagoon at the plant took just over two years to return the cost of installation. In addition to the obvious economic benefits, the lagoon has allowed Company B to discharge a much cleaner wastewater product to the city. This was cited by the plant engineer as an important factor in improving the relationship between the company and the city. The anaerobic lagoon at this plant, as in the case of Company A, has achieved its initial purposes admirably.

Conclusion

Similar anaerobic digestion technology has been applied to both industrial and agricultural settings in Iowa. However, anaerobic digestion appears to be more feasible in industrial (meat packing) applications due to differences in size and scale of the two industries.

Agricultural Applications

Anaerobic digestion has not been widely utilized 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 has also achieved its primary goal at the time of its inception: to enable the farm to keep producing pork. This was accomplished through the near elimination of swine odors from the manure lagoon. These in turn resulted in a cessation of the neighboring business and residential complaints.

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 quite short of any kind of reasonable economic payback. Since 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 utilizing anaerobic digestion systems indicates that this size may be more than twice the size of the McCabe system. On-farm utilization 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.

Industrial Applications of Anaerobic Digestion

Industrial applications of anaerobic digestion at meat packing plants in Iowa appear to have succeeded admirably. The Swift and Company facility in Marshalltown analyzed in this study as well as the report of the digester at the Farmland Foods plant in Dubuque (Dague et al. 1989) both indicate a reasonable payback period, satisfactory performance, and problem resolution. The most significant savings in the case of industrial applications were from the reduction of fines and surcharges imposed by the municipal wastewater treatment centers. However, even if there were no savings, the volume of methane produced would result in approximately a 10-year payback. This production was significantly greater than that produced in the agricultural setting. The anaerobic lagoon is considered a valuable asset by Swift and Company, and plays a crucial role in their plant's operating capacity.

Comparison

As long as the current regulatory environment persists, installation of anaerobic digestion systems will generally be economically justifiable at industrial locations. If livestock production continues to become increasingly concentrated and producers realize a need to deal with odor externalities, anaerobic technology in livestock production may prove economically feasible.

A demonstration site in Nevada and construction of a pork production facility in southwest Iowa should further test the technology at its most recent cost and advance. Some 26 years after the installation of the first anaerobic digestion system in Iowa, these will be the first trials of the technology at its most current and advanced level. The economic feasibility and demonstrated production and community viability of these systems may well have an important impact on the popularity such systems gain over the next decade in pork production.

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