Anaerobic digester use in dairy farms in the United States

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Abstract

Anaerobic digestion is a highly efficient process, trapping the methane gas from cow manure and processing it into energy. The steep initial capital costs make anaerobic digesters short-term liabilities, but the long-term benefits far outweigh the long-term costs. An anaerobic digester unit will begin to show a profit after approximately five years of operation. During the lifetime of the unit, estimated at 15 years, the digester will have produced about $1,000,000 in profits for the dairy farm, while also providing invaluable benefits to society as a whole.
Purpose

The purpose of this study is to use both market and non-market values to estimate all benefits and costs of establishing an anaerobic digester on a dairy farm in the United States. Using tradition cost-benefit analysis, this study will examine the profit-maximizing levels, both private (MB = MC) and social (MSB = MSC), of an anaerobic digesters. In addition, this study will also focus on the positive and negative externalities concerning anaerobic digesters to calculate economic feasibility.

Background

Anaerobic digestion is a multi-faceted process that allows a group of microorganisms to convert organic material to a form that a second group of organisms then utilize to form organic acids. Methane-producing anaerobic bacteria utilize these acids and complete the decomposition process\(^1\). The digester needs to be kept at constant temperatures due to the sensitivity of the methane-producing anaerobic bacteria to maximize the production of methane. If other factors, such as carbon/nitrogen ratios, water/solids ratios, particle size and consistency, are at optimal levels, then the sludge drawn from the digester will be rich in nutrients and an excellent soil conditioner\(^2\). The sludge from an anaerobic digester is, in addition to an optimal fertilizer, an odorless solid that can be used as compost or as animal bedding.

The topic of anaerobic digestion in the United States is important for many reasons. First, agriculture in the U.S. produces more than 350 million tons of manure each year and only 23% of large dairy farms are applying manure on enough cropland to

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meet a nitrogen-based standard to protect water quality\textsuperscript{3}. In 2002, a national census recorded a cattle herd size of over 95 million\textsuperscript{4}. One 1,200-pound dairy cow produces the same amount of waste as 23 human beings\textsuperscript{5}. This large production of methane waste causes many environmental problems. Methane gas is produced naturally from dairy manure in the absence of oxygen and released into the atmosphere. The produced and released methane gas is a major air-pollution contaminant, causing global warming\textsuperscript{6}. Currently, methane gas represents 19\% of total greenhouse gas emissions of global-warming agents\textsuperscript{7}. Finding a way to effectively utilize this over-abundance of manure as well as cutting the discharge of a harmful greenhouse gas is an incredibly powerful use of modern technology.

Another benefit of anaerobic digesters is the energy it produces. An anaerobic digester energy system promotes methane production, captures and converts it to electricity and heat for on-farm use or sale to the local utility\textsuperscript{8}. With the recent rolling blackouts around the United States and sharply rising energy costs for traditional fossil-fuel sources, alternative energy production is crucial for local utility companies. In 2001, over 95\% of Total Energy Consumption in the United States was by non-renewable sources, while only 2.56\% was via biomass\textsuperscript{9}. Also, anaerobic digesters could, if legislation is passed enabling it, allow for farmers to sell excess energy to the local utility.

\textsuperscript{4} United States Department of Agriculture, “2002 Census of Agriculture.” \url{http://www.nass.usda.gov/census/census02/volume1/us/st99_1_014_016.pdf}
companies. Current legislation allows farms to send back excess energy to the grid as a form of energy-credit only\(^{10}\).

One final benefit of anaerobic digestion is the resulting improved air quality. Methane gas can contribute to human health problems linked with high ozone concentrations. Current global ozone concentrations are in the 30-40 ppb range, but commonly exceed the EPA standard of 84 ppb during the summer months in U.S. cities. Some possible harms related to elevated ozone concentrations include asthmatic problems, reduced lung capacity, and increased risk of respiratory illness\(^{11}\).

There are some drawbacks to the construction of an anaerobic digester on a dairy farm. Establishing an anaerobic digester on a farm is a costly process. The Governor’s Office of Energy Management & Conservation in Colorado estimates the entire cost of the anaerobic digester system to be $375,000\(^{12}\). Pre-existing toxic compounds (pesticides, etc.) that are in the digester feedstock material may become concentrated in the effluent\(^{13}\). The construction and use of an anaerobic digester may lower the farm’s aesthetic value, especially if the farm is near a residential area. Also, the noise created by the anaerobic digester may create an unpleasant atmosphere for neighbors.


\(^{12}\) Colorado Governor’s Office of Energy Management & Conservation.

Hypotheses

- The private and social costs of an anaerobic digester system will be greater than the benefits in the short-run (commonly defined as less than one year).
- The private and social benefits of an anaerobic digester system will be greater than the costs in the long-run (commonly defined as longer than one year).

Approach

In order to determine the level of private and social efficiency, I will focus on conducting literature research, which will enable me to establish market and non-market values. These values relate to the criteria of an anaerobic digester that I have considered significant. My literature research will consist of government documents, case studies, executive summaries, university studies, and electronic journal sources. I will also focus on pre-existing studies which place values on the advantages and disadvantages of anaerobic digesters that I have established. In addition to the literature reviews, I will also gather information directly from various websites, such as the Environmental Protection Agency’s AgSTAR program and the United States Department of Agriculture.

Methods

In order to determine the monetary value of the benefits of a digester, I must first determine which benefits are most significant. I have established four general benefits of an anaerobic digester, which can then be separated for further scrutiny: methane reduction, potential revenue from the sludge, improved water quality, and savings from the electrical use. All four of these criteria will be based off a farm size that mirrors an average dairy farm with a plug-flow operating anaerobic digester system in the United States.
In order to assess a value to the minimization of methane gas pollution, I will focus on pre-existing studies that have determined the cost of improving air quality. The cost associated with improving the air quality will provide a basis for the value connected to reducing methane gas from the environment.

The second benefit that I have recognized as significant is the potential revenue created from the sludge. The sludge can be harnessed in three different ways. First, it can be used as a premium fertilizer. My literature research will examine the cost associated with turning the sludge into a fertilizer and compare that cost with the price of purchasing fertilizer. Second, the sludge can be turned into animal bedding, which can reduce the cost linked to traditional animal bedding. I will focus on the costs of various animal beddings, which consist of materials such as wood shavings and sawdust. Once I determine the price of traditional animal bedding, I can establish a value for replacing that cost on a dairy farm. Finally, effluent sludge can be used as compost. Similarly to the other research methods of sludge, this research will establish the cost of compost on a dairy farm and use that as a basis for shaping a monetary value.

The third benefit of an anaerobic digester that I have established is the improved water quality for the surrounding environment. In order to place a monetary value on the improved water quality, I must first conclude what toxic compounds the sludge will replace. I will then look at the cost associated with purifying the waters, which will allow me to place a value on the benefits related to the improved water quality.

The fourth and final benefit of an anaerobic is the savings from the use of electricity that the digester will provide. To determine this value, I will examine the efficiency of an anaerobic digester through literature research to establish a level of
electrical output. Comparing that data with the level of energy consumption of a farm, I will be able to calculate a surplus or shortage of energy use. That number, then multiplied by the cost of electricity, will give me a value for the potential electrical savings associated with an anaerobic digester.

In order to assess the costs related to an anaerobic digester, I will examine three disadvantages that I have already established. The first disadvantage of an anaerobic digester is the initial capital costs. In order to settle on a universal dollar amount for the digester system, I will compare the production costs associated with a plug-flow digester system that handles manure using the scrape method. Also, I will view the current legislation for any circumstances in which the price of a digester will be reduced through government grants.

The second and third disadvantages of an anaerobic digester are costs associated with non-market values. The second disadvantage, noise pollution, will be difficult to establish a price on. My literature research will consist of previous studies concerning noise pollution generally and, specifically, those relating to agricultural noise pollution. Similarly, my study to determine the cost linked to a decrease in aesthetic values will focus on studies that have already been completed. The studies that I will highlight are those that relate to rural areas and the impacts of industrialization on the residents.
Results

The average dairy farm in the United States, according to a 1996 report, operates at 61 cows. Approximately 60% of the dairy farms in the United States had 50 cows or less, while over half of all the dairy cows counted were on farms containing more than 100 cows. Of the 40 dairy farms that were constructing or already had constructed anaerobic digesters, they were split into two distinguishing categories: number of cattle or number of milkers.

*Aerobic Digester Cost vs. Number of Milkers*¹⁵

<table>
<thead>
<tr>
<th># Of Milkers</th>
<th>Digester Cost ($)</th>
<th>Methane Reduced (MTCO2E/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7000</td>
<td>1,800,000</td>
<td>296</td>
</tr>
<tr>
<td>170</td>
<td>200,000</td>
<td>1179</td>
</tr>
<tr>
<td>730</td>
<td>150,000</td>
<td>5061</td>
</tr>
<tr>
<td>850</td>
<td>400,000</td>
<td>1779</td>
</tr>
<tr>
<td>340</td>
<td>300,000</td>
<td>2357</td>
</tr>
</tbody>
</table>

*This table was edited to include only the plug-flow operating digester systems that handled manure using the scrape method.*

**Aerobic Digester Cost vs. Number of Cattle*¹⁶

<table>
<thead>
<tr>
<th># Of Cattle</th>
<th>Digester Cost ($)</th>
<th>Methane Reduced (MTCO2E/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>450000</td>
<td>2965</td>
</tr>
<tr>
<td>525</td>
<td>295700</td>
<td>3640</td>
</tr>
<tr>
<td>900</td>
<td>425000</td>
<td>3706</td>
</tr>
</tbody>
</table>

**This table was edited to include only the plug-flow operating digester systems in the U.S. that handled manure using the scrape method.*

The average size and cost of a plug-flow anaerobic digester system in the U.S. that handled manure using the scrape method was 741 cattle, 1,818 milkers, or approximately $350,000. This figure will be used to determine the methane output and used as a basis for the cost-benefit analysis.

The reduction in methane emissions, on a carbon dioxide basis, has been determined to be 3.03 tons per cow-year\textsuperscript{17}. At the rate of $9 per ton of decreased methane emissions in the United States\textsuperscript{18}, the value of the methane emissions total approximately $27 per cow and $20,207 per year. There was no significant impact in the reduction of both Nitrous Oxide and Ammonia emissions in the air\textsuperscript{19}, and therefore no financial value was assessed.

The fertilizer resulting from the excess sludge is priced at approximately $27,000 per year\textsuperscript{20}, based on the amount of input manure. The amount of output sludge could not be determined, so the best approximation of the fertilizer benefit is the input quantity.

One lactating dairy cow would generate enough biogas from manure to generate 2.5 to 3 KWh per day\textsuperscript{21}. At a rate of $0.07 per KWh\textsuperscript{22}, the energy produced daily would equal approximately $148 per day and $54,093 per year. The cost of operating the anaerobic digester is $0.0125/kWh\textsuperscript{23}, which amounts to $10,142 per year, not including significant maintenance that may occur during the lifetime of the digester.

\begin{footnotesize}
\textsuperscript{17} Martin, John Jr., “A Comparison of Dairy Cattle Manure Management With and Without Anaerobic Digestion and Biogas Utilization,” AgSTAR Digest (2004).
\textsuperscript{19} Ibid, 26.
\textsuperscript{21} Henry, Chris and Koelsch, Ray, “What is an Anaerobic Digester,” UNL’s Livestock Environmental Issues Committee.
\textsuperscript{22} Iowa State University, Odor Control Demonstration Project (1998).
\textsuperscript{23} Hope, Chris, 25.
\end{footnotesize}
The pathogen reduction in the water could not be assessed financially, as it is
difficult to place a dollar value on the reduction of pathogens in the water. The two
pathogens that have been significantly reduced can be viewed as benefits to society.

There were no studies found that financially assessed the impact of noise
pollution or the aesthetic value of the farm. The impact of both noise pollution and the
aesthetic value on the farm have been found to be insignificant\(^24\).

**Short-Term Benefits of Anaerobic Digester Use on a Dairy Farm**

<table>
<thead>
<tr>
<th>Benefit</th>
<th>With Anaerobic Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Air Quality</td>
<td></td>
</tr>
<tr>
<td><em>Methane Reduction</em></td>
<td>$20,207</td>
</tr>
<tr>
<td><em>Nitrous Oxide Reduction</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td><em>Ammonia Reduction</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Fertilizer From Sludge</td>
<td>$27,000</td>
</tr>
<tr>
<td>Improved Water Quality</td>
<td></td>
</tr>
<tr>
<td><em>Pathogen Reduction</em></td>
<td></td>
</tr>
<tr>
<td>Fecal coliforms</td>
<td>~99.9%</td>
</tr>
<tr>
<td><em>M. avium paratuberculosis</em></td>
<td>~99.9%</td>
</tr>
<tr>
<td><em>Nutrient Enrichment</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Savings From Electricity</td>
<td>$54,093</td>
</tr>
<tr>
<td><strong>Total Benefits</strong></td>
<td><strong>$101,300</strong></td>
</tr>
</tbody>
</table>

**Short-Term Costs of Anaerobic Digester Use on a Dairy Farm**

<table>
<thead>
<tr>
<th>Cost</th>
<th>With Anaerobic Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital Cost</td>
<td>$375,000</td>
</tr>
<tr>
<td>Noise Pollution</td>
<td>No significant impact</td>
</tr>
<tr>
<td>Aesthetic Value on Farm</td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Operating and Maintenance Fees</td>
<td>$0.0125/kWh</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$385,142</strong></td>
</tr>
</tbody>
</table>

\(^{24}\) Martin, John, Jr., AgSTAR Digest (2004).
### Long-Term Benefits of Anaerobic Digester Use on a Dairy Farm

<table>
<thead>
<tr>
<th>Benefit</th>
<th>With Anaerobic Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Air Quality</td>
<td></td>
</tr>
<tr>
<td><em>Methane Reduction</em></td>
<td>$303,105</td>
</tr>
<tr>
<td><em>Nitrous Oxide Reduction</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td><em>Ammonia Reduction</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Fertilizer From Sludge</td>
<td>$405,000</td>
</tr>
<tr>
<td>Improved Water Quality</td>
<td></td>
</tr>
<tr>
<td><em>Pathogen Reduction</em></td>
<td></td>
</tr>
<tr>
<td>Fecal coliforms</td>
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<tr>
<td><em>M. avium paratuberculosis</em></td>
<td>~99.9%</td>
</tr>
<tr>
<td><em>Nutrient Enrichment</em></td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Savings From Electricity</td>
<td>$811,395</td>
</tr>
<tr>
<td><strong>Total Benefits</strong></td>
<td><strong>$1,519,500</strong></td>
</tr>
</tbody>
</table>

### Long-Term Costs of Anaerobic Digester Use on a Dairy Farm

<table>
<thead>
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<tr>
<td>Aesthetic Value on Farm</td>
<td>No significant reduction</td>
</tr>
<tr>
<td>Operating and Maintenance Fees</td>
<td>$152,130</td>
</tr>
<tr>
<td>$0.0125/kWh</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$527,130</strong></td>
</tr>
</tbody>
</table>
Discussion

The results of this study support my two hypotheses. The implementation of an anaerobic digester on a dairy farm would not be economically beneficial to either the private owner or society. The anaerobic digester is economically beneficial to both the private owner and society when viewed in the long-term perspective. According to this study, the farm would reach a financial benefit after 5 years and continue to profit from the anaerobic digester until 15 years. After 15 years, the existing digester commonly needs extensive repairs, or a new digester is installed. The benefits for both society and the private owner are much more widespread than just financial.

Air Quality

The improved air quality is the main deciding factor for many farms to choose an anaerobic digester. The digester is able to stifle the odors, which is a very common negative impact of a large-sized dairy farm in the United States. As concern over the climate change related to greenhouse gases continues to rise, anaerobic digesters may be looked at as a local solution to the problem. Methane gas is incredibly potent, compared to other greenhouse gases, and is significantly reduced through the anaerobic digester process.

Fertilizer

Another source of financial benefit from the anaerobic digester is the use of the remaining sludge as a fertilizer, compost, or as animal bedding. The solids can be sold as soil amendments, which can be used to reduce soil erosion. Also, the nutrients are concentrated in this solid product, allowing for it to be exported out of the watershed and thus reducing the impact on water pollution.
Water Quality

The reduction of pathogens is an overlooked yet incredibly significant benefit of the digester. One of the fecal chloroforms reduced is *E. coli*, which can cause considerable human health concerns whenever there is an outbreak. By reducing the pathogens almost completely, an anaerobic digester will aid in the social fight against this bacterium. Another specific pathogen that is reduced is *M. avium paratuberculosis*, which has been linked to the Chron’s disease, a chronic inflammatory disease of the intestines. Reducing the probability of this disease will greatly help society in ways that are impossible to financially assess.

Saving From Electricity

The financial savings from an anaerobic digester are best shown with the savings from electricity. Anaerobic digestion will become increasingly popular as more people search for alternate forms of energy. European communities utilize the potential that anaerobic digesters offer, as they are much more common in countries such as Germany and Denmark.

Initial Capital Cost

The high capital cost is the greatest deterrent in constructing an anaerobic digester. Some factory farms may be able to afford large anaerobic digesters because of their increased revenue and output. Many smaller farmers cannot afford the cost of a small anaerobic digester, nor do they live in close proximity to one another to justify the construction of a community anaerobic digester. Some states have passed legislation which decreases the interest rates on loans, as long as the money is spent on a project
such as an anaerobic digester. In some instances, there also have been grants dispersed for the implementation of an anaerobic digester.

**Cattle Population**

One drawback of the digester system itself is that it is more commonly beneficial to large-sized dairy farms and not to smaller farms that practice traditional farming methods. Once a large-sized dairy farm constructs an anaerobic digester, it promotes the increase of cattle on that farm. Based on the results of this study, the increased income of a farm is approximately $136 per cow-year. Theoretically, the farm could continue to enlarge the cattle population as long as the digester system could sustain it.

**Quality of Life**

Another drawback of the digester system is the reduced quality of life for the cow itself. This argument is a common argument made against large-sized dairy farms. A dairy farm that utilizes an anaerobic digester must focus on the method of retrieving manure from the cattle. The most efficient way to collect the manure is to keep the cattle confined to limited spaces, which could diminish the quality of life for the cattle. A common practice on large-sized dairy farms is to keep the cattle in a restricted area where milk and manure can be easily collected.

**Assumptions**

This study was conducted under several assumptions, any of which could alter the outcome of the yearly financial assessment. I do not believe the impact of these changes would reverse the long-term result of the digester. It would still be considered advantageous to construct an anaerobic digester on the farm, even if these assumptions do not come to fruition.
My first assumption was that there would be no interest rates if a loan was taken out for the cost of the digester. There has been precedent in Minnesota, where farmers were given loans at 0% interest rate if the money was used to construct a digester. Based on that knowledge, I did not include a loan rate in my capital cost.

Another assumption I made was that the digester would run at 100% efficiency, with no serious or severe repairs needed during the 15-year period. Mechanical breakdowns that are abnormal could create more of a financial deficit for the farmer, but I do not believe that it is significant enough to turn the digester into a liability.

My final assumption I made was that the farmer would utilize all the benefits of the farm, including using the filtered water as a source of irrigation. If a farmer would use the excess sludge as animal bedding instead of fertilizer, the decrease in profits would not be large enough to reverse my decision.

Future Research

I would like to see several topics relating to anaerobic digesters researched in more detail. The first topic would look at the legislative influence behind the construction of digesters. For instance, California is currently leading the country in state legislation that would encourage more anaerobic digesters to be built. The differences in state legislation is very noteworthy when considering why digesters have not been built.

Another study I would like to see is one that researches why anaerobic digesters are more common in Europe than they are in the United States. I believe a large reason for this is the lack of natural resources found in Europe, which in turn causes European nations to seek out alternative means of energy.
Conclusion

An anaerobic digester unit is incredibly beneficial to both private farmers and society as a whole. Not only will it make money for the farmers, but it will also reduce the emissions of methane, a powerful greenhouse gas. The technology is available for the farmers to utilize one of their biggest problems, the quantity of waste on the dairy farm. The biggest hurdle for society is being able to get the knowledge of anaerobic digesters out to the dairy farmers and show them how beneficial this unit can be on their farm. An anaerobic digester unit is something that should be seriously considered in any possible location that would be able to produce the amount of waste needed. Not only will a digester remove the methane gas from the air, but also provide relief from the local power companies. Both of these gains highlight two problems in our society today, greenhouse gases and energy shortage. An anaerobic digester can be part of a solution for both of these tribulations.
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