Vermont Methane Pilot Project Initial Literature Search Paper

To
Vermont Methane Pilot Project Advisory Committee

Prepared by Daniel L. Scruton,
Vermont Department of Agriculture, Food and Markets
Vermont Department of Public Service
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Abstract

This paper is a summary discussion of the current state of anaerobic digestion of animal manures and attempts to identify the strategic hurdles facing the widespread adoption of anaerobic digestion energy production in Vermont and other northern tier dairy states. It was written for the advisory committee so that we could better steer the project and make the most effective use of our resources. This is not a complete discussion of anaerobic digestion. To achieve a more in depth knowledge of the subject it is suggested that you read Dr. Lusk's booklet *Methane Recovery from Animal Manures*.

Introduction

Technology to digest animal manures into methane has been around since the time of the Assyrians in the 10th century BC where it was used to heat bath water[1]. In the U.S. in the 1970's and 80's much attention was paid to methane digesters due to the high cost of energy and the realization that we were vulnerable in the energy area as long as our primary energy sources were from outside of our political borders. In 1972 the first on-farm digester was built in the U.S. at a swine operation in Iowa. The driving force was not energy however, it was odor. Soon after that farm went into methane production an oil embargo precipitated the "Energy Crisis." This event increased interest in digestion technology and energy production from manure.

In the 70's and 80's many farm methane systems were constructed but most are no longer in production. A 1995 study in California found that of the six dairy producers that constructed digesters in California, only one was still in production.[2] As of 1998 there were 28 operating farm/manure digesters in the U.S. and 29 that are operational but not in use.[1] In 1990 an assessment in the United Kingdom of the 19 research projects done by their Energy Technology Support Unit of the UK Department of Energy found that the pay back was poor and any national benefit would be insignificant.[3] Vermont has one operating farm/manure digester at the Foster Brothers dairy farm in Middlebury. It was constructed in 1982 and digests the manure from 350 cows plus replacement stock.

Digester Types

There are three types of methane digesters in general use: (1) covered lagoons, (2) plug flow, (3). complete mix. In the northern tier states we do not need to discuss covered lagoons as our ambient temperatures are too low for much of the year. The most common systems for our climate will be plug flow systems like the one at Foster Brothers and complete mix systems. Complete mix systems work on the same principle as plug flow, however the effluent may be a lower percentage of solids and may be stirred to maintain a constant suspension. They are more expensive to build than plug flow digesters but they traditionally have the advantage of higher gas production and shorter retention times. There are also hybrid systems, combining some attributes of both plug flow and mixed tank. The vertical storage slurry system used at the Agway research facility would be an example of a continuous flow mixed system. Most of the information about digestion in a mix tank is the same as in a plug flow.

Plug flow is currently the system of choice by most in the dairy field. So the following narrative is principally about plug flow systems. In a plug flow system manure enters a long narrow storage pit that has the ability to heat the manure with a hot water heat exchange system. The hot water is initially heated with purchased energy but once the system is generating, most of the heat will come as a by-product of the generator. The pit is covered by an expandable membrane that captures the resulting biogas. Each day manure is added to one end of the digester and a comparable amount flows out the other end. These systems are low in cost when compared to traditional complete mix systems and provide a steady gas supply.

One of the predominant problems with plug flow digesters is sediment build-up. As sediment builds-up in the bottom of a digester there is less capacity to make gas and the heating system becomes less effective. Shutting down the digester and physically cleaning out the sediment is the only way to restore efficiency. With the advent of reliable plastic heat pipes that can be poured into the concrete walls, flow would be improved and clean out simpler but, the systems are still vulnerable to sediment build-up problems and may not be able to heat the slurry.

Retention time in the plug flow is typically 20 - 30 days and requires a sizable trench as it needs to hold 20 - 30 days of manure. A number of people are working on a variety of attached growth technologies which could cut retention time down to 10 days including a study being funded by this project. Basically, attached growth technologies are a way of “spiking” the effluent in the digester to speed the progression of bacterial activity to the anaerobic range.

Another way to decrease the retention time is to increase the temperature. As the temperature of the effluent increases so does the rate of gas production and retention time is reduced. Methane is produced from 40° F to more than 212° F. Normally plug flow digesters run in the “mesophilic” (95°- 105° F) range with a retention time of 20 to 30 days. Higher “thermophilic” (125° - 135° F) temperatures could cut retention times in half and would also increase pathogen kill in the digester. It is difficult however to maintain high temperature with conventional in-ground digesters, without having manure solids “cook-on”. This is a good potential area for research. There have been successful thermophilic systems designed for chicken manures by Dr. Jason Shih at No. Carolina State University. There have also been experiments at the University of Illinois which show thermophilic digestion of cattle wastes is possible and with increased gas output and shorter retention times.[4]

A third way of decreasing retention time is to split the digestion process into 2 stages. First you would have an acid stage where the manure could go thorough the initial digestion and be heated to the temperature of the digester. Then the manure would go into the methane digester system. This would require looking closely at the microbiology and chemistry of digestion to determine the conditions needed for this to occur.

Gas Content and Use

Methane content of biogas may vary from 55% to 80% [1]. At 80% methane the biogas could be used in almost any system designed to use natural gas. Most digesters however, produce biogas with around 60% methane and many uses would need some type of conditioning of the gas. The primary other components in the gas are CO_2, H_2S and H_2O and filters vary from simple lime filters (barrel filled with lime stones) to vary complex gas separation systems. If the gas is used for heat generation in a boiler these are not be a problem. When run through an engine or fuel cell they become an issue. There is research underway to improve gas purity coming out of digesters. Both bacterial agents and surfactants that could be used to increase the BTU content of the biogas are being investigated in a number of places in the USA and around the world. Given the complexity of the work being done it is not advisable for Vermont to try and duplicate any of this research at this time.

Energy Production

Generally biogas produced on a dairy farm is utilized to produce electricity. However, any use that would burn the biogas directly is a preferred use, if it is a reasonable piping distance from the digester. Recent improvements in plastic tubing suitable for gas pipelines has changed the cost dynamic of how far away from the digester biogas can be utilized. Direct use would be areas like space heating, water heating, and possible refrigeration systems. DOE has been funding research into gas refrigeration systems and there may be available funding to add this to our pilot project.

Electricity Production

The most common way to produce electricity is through the use of an internal combustion engine. The engine itself is not very efficient but when combined with the recovery of the waste heat both from the engine and the exhaust system the efficiency rises to a reasonable level. Gas engines designed for biogas can be purchased at a reasonable price and if the oil is changed regularly at short intervals, H_2S removal from the biogas is not necessary. Diesel engines are more efficient but, require gas scrubbing to remove some of the impurities and minor modifications need to be made to the engine.

There are two new developments in the power generation picture in the last few years. One is the advent of the microturbine, a downsized more efficient version of the traditional turbine engine.

The other is the fuel cell.

Microturbines have only one moving part and could be run on multiple fuels. The combined heat and energy output is better than an internal combustion engine and with only one moving part maintenance should be simpler. There are a number of developers working on these engines and they will soon be appearing in cars. Once that happens, the cost should come down substantially. The disadvantages are the need for gas scrubbing (in current design), the input gas needs to be pressurized and they are not "load" following. This means they are designed to run at only one speed and a constant power output. Because of this constant output the generator would need to be attached to the grid in a net metering fashion.

Fuel cells are like ceramic batteries which utilize hydrogen and oxygen to produce electricity, H_2O, CO_2 and heat. Hydrogen rich fuel is fed into one side of the unit. Oxygen rich material (air) is placed into the other. The materials strip electrons from the oxygen and hydrogen producing electricity. The protons then pass through a special membrane where the H and the O combine into water and the carbon from the CH_4 and O combine into CO_2. Fuel cells have been used by NASA to power space craft and have proven themselves to be very reliable. They will run on many fuels, however they are sensitive to H_2S so biogas would need a good scrubbing system to use them. Currently they are very expensive but GE just announced a marketing agreement that may significantly reduce the cost down into the range where they may make economic sense.

Electricity Utilization

Most systems utilizing all of a farm's manure should produce electricity at a rate higher than the farm needs for it normal operation. Selling excess power back to the utility is complicated and expensive to set-up. There is little question that setting up a single farm electrical generator to sell power to the utility is not a profitable venture with current rules. In Vermont we have a Net Metering law which in very basic terms, allows farm customers producing electricity from biogas to connect to the utility grid and send power back through the farm's main electric meter, causing the meter to run backward. At the end of the month the farmer would pay the net difference if he used more power than he sent to the grid. The farmer would get credit each month for any excess power beyond what was used from the grid. At the end of each year of operation any net credit owed to the farmer would revert to the utility and the farmer would not be paid. This net metering arrangement could change the economics for farms that are generating the total volume of power they need but need to have buffering capacity for peak loads.

Solutions to uses for excess power may include cooperative manure management where a group of farmers would pool the manure to a central facility that would produce a large enough quantity of electricity to make the venture profitable or involve energy intensive enterprises (ie: greenhouse operations) to consume electricity and heat, giving a larger effective return on the electricity and heat produced.

As re-regulation progresses more states may have renewable (green) energy portfolios which require utilities to purchase a certain percentage of their power from renewable energy sources. This would increase the value of electricity produced with biogas. There also may be increases in the value of pollution credits where utilities would build and operate the generation system allowing them to claim green house gas credits for capturing the methane and not allowing it into the atmosphere. In some states consumers may be allowed to pay a premium to buy power totally produced by renewable sources.

Odors

Odors typically associated with manure are significantly reduced with anaerobic digestion. In one study[5] a group of panelests were handed a set of flasks, some of which held dairy wastes, and some of which were odorless. The panelists scored the odor on a scale of 1 to 10**.** If they could not determine which flask held the wastes it was given a score of 0. At the beginning of the manure digestion process the average score was over 6. After 20 days of digestion it was 3. Anecdotally there is even more significant reduction in odors. The first digester in the U.S. was on a pig farm and it was designed for odor control. Other studies suggest as much as a 97% odor reduction.[1]

Pathogen Reduction

Danish law was the first to specifically accept anaerobic digestion as a hygienic measure. They base their standards on one hour of treatment at 158°F.[1] This can be achieved either with a complete mix system operating at 125.6°F for 10 hours, or in a plug flow type system with pre or post treatment at 131°F for 5.5 hours in a thermophilic digester, or 7.5 hours in a mesophilic digester. Other times and temperatures are also acceptable. A complete table is shown in footnote 1 page 2-23.

Some specific bacteria time temperature relationships are shown in the following chart:

Pathogen	Temperature of Digester	Time	Reduction
E Coli	91°F	48 hours	99%[6]
	122°F	10-12 hours	99%[3]
Fecal *Streptococcus*	*91-95*°F	14-16 days	99%[3]
	127°F	2 hours	99%[3]

Salmonella typhimurium	91°F	4-6 days	99%[3]
	122°F	1.4-1.6 hours	99%[3]
Mycobacterium paratuberculosis	95°F	12 days	99%[3]
	127.4°F	1.4 hours	99%[3]
Eimeria tenella (coccidiosis in chicks)	Mesophilic	normal cycle	90-99%[7]
	Thermophilic	normal cycle	99.9%[4]
Fungal Spores	Mesophilic	normal cycle	94-98%[4]
	Thermophilic	normal cycle	99-100%[4]
Clostridium perfringens	95°F and 127.4°F	length of study	no reduction [3]

Reduction of *Listeria Monocytogenes* and *Campylobacter jejuni* vary significantly with the strains involved. In order to achieve a 99%reduction in numbers, reduction times varied from days to months.[3]

Enteroviruses including Coxsackievirus and Poliovirus were inactivated at mesophilic temperatures in between 1 and 9 days. At thermophilic temperatures all enteroviruses were at the 99% reduction in less than a day. Other non-enteroviruses had variable time requirements, but those tested were at the 99% reduction in less than a day at mesophilic temperatures. At 122°F or thermophilic conditions a 99.99999% reduction per day was achieved.[3]

There is little in the literature on *Giardia* or *Cryptosporidium* reduction however cattle nematodes are inactivated at thermophilic temperatures.[3]

Dealing with the Manure

Manure coming out of the digester is actually a better soil amendment than when it went in. The nitrogen is more available and odors and pathogens are significantly reduced. On systems with ample lands, direct land application is a simple, environmentally sound, use of manure. Digested manure could go into a conventional lagoon storage system and wait until an appropriate time for spreading. For some farms separation of the liquid and solid portion will be desirable. Solids could be taken and field stacked until an appropriate time for spreading or sold to horticultural farms with the liquid portion used back on the farms own fields. On some soil types the highest value use will be to put the solids on the farm fields. Systems could be designed to dry the solids down to a granulated form and sold to fertilizer companies as an organic fertilizer ingredient. Or a farm could start their own soil amendment company, however they would want to carefully develop a marketing plan to assure they had a good market for their products. Here is another area where a cooperative structure could be advantageous with solids going to a centralized processing and marketing facility.

Economic analysis

Since 1996 AgSTAR, an EPA initative, has provided technical assistance to two 1000 cow dairy operations installing plug flow digesters producing electricity. The average initial capital cost was approximately $250,000. Anticipated annual benefits are about $55,000.[8] On the surface this is a positive payback. Both farms had estimated annual digested fiber sales of about $26,000 and electricity offset of $27,000 per year plus hot water available for use on the farm. However, it is not feasible for very many farms to be able to achieve these kinds of sales numbers in digested solids and many farms will want some or all of the solids for use on their own fields. The electricity and hot water benefit of $28,750 per year is not a very good return on investment.

One solution is a sharing of cost for these systems. Digesters could become part of the nutrient management systems designed by NRCS and become partially funded by the same sources of NRCS (Natural Resources Conservation Service) and EQUI, (Environmental Quality Incentive Program) moneys. Other income sources could include tipping fees for composting or digesting carefully selected industrial or commercial waste. Solids could become a value added product ranging from fertilizer to burnable fuel.

Summary or "Why isn't every body doing it already?"

Problems associated with anaerobic digestion and methane production are actually quite well known. There are areas where we can search for better answers but the biggest questions come back to economics. Farmers are reluctant to commit to new management tasks that have questionable payback. The ½ hour a day it takes to run a digester is one more task for someone who is already over worked. Labor markets are tight and hired help willing to work for farm wages is getting harder to find. Until it can be shown that money can be made doing this it will continue to be an underused manure management strategy.

Potential Research

The following are areas which may affect the feasibility of digestion technology. We may be able to address these in our project:

1. Resource availability assessment to determine the total amount of manure and other potentially digestible waste products produced by county in Vermont including organic

solid wastes. The study needs to also evaluate the impact on the digestion process these solids would have.

2. Cooperative ventures. A feasibility study of the cost of hauling and digestion at a centralized facility should be performed to see what size the facility would have to be and what possible synergistic industries we have or would want in Vermont.

3. Marketing study as to the potential sales and value of effluent as-is, composted and dried either to existing fertilizer companies or direct sales.

4. Retention time reduction research - Attached growth, two stage digestion and thermophilic technologies. Also we should look at the nutrition of digestion and what can be done with the feeding of the animals, or nutritional supplements to the digester, to improve the digestion process.

5. Refrigeration systems using biogas fuel.

6. Installation of monitoring equipment to be able to do research with the existing digester in Vermont. Before this equipment is selected and installed we need to determine what variables, if monitored, would return useful information.

7. Weeds: In researching the information about anaerobic digestion there is little information published on reduction of weed seeds through the digestion process. This could be done by questioning a number of the farms using digesters on dairy farms to see what the anecdotal evidence is and if there are still questions about weed seed viability, a study could be done where manures were spread in controlled plots before and after digestion to determine the survivability of weed seeds.

References

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