Colorado Agriculture IOF Technology Assessments: Anaerobic Digestion

Prepared for:
State of Colorado
Governor's Office of Energy Conservation and Management
225 E. 16th Avenue, Suite 650
Denver, CO 80203

Prepared by:
McNeil Technologies, Inc.
143 Union Blvd. Suite 900
Lakewood CO 80228
Under State Purchase Order # 01-336

September 30, 2005

DISCLAIMER

This report was prepared as an account of work partially sponsored by an agency of the State of Colorado and the United States Government. Neither the U.S Government, State of Colorado, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S Government, State of Colorado or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the State of Colorado or any agency thereof.

ACKNOWLEDGMENTS

The State of Colorado, Governor's Office of Energy Management and Conservation (OEMC) funded this study. At the OEMC, Mr. Joe Lambert, Mr. Ed Lewis and Ms. Olga Erlich played an integral role in supporting the project from its inception.

The authors wish to thank several people and organizations for their efforts in support of this project. The National Biodiesel Board, American Coalition for Ethanol, USDA NRCS, Mr. Dan Manternach of the Biobased Manufacturers Association, John Long of Blue Sun Biodiesel, Dan Strachan of National Petroleum Refiners Association, Kansas Corn Commission, Ralph Overend of NREL. Special thanks to Colorado State University Cooperative Extension, especially to Raj Khosla, HR Duke, and Gary Peterson.

Finally, despite our best efforts at editing and revisions, mistakes may still remain within this document. Any mistakes or omissions are the sole responsibility of the authors. Any questions or comments should be addressed to McNeil Technologies Inc., 143 Union Blvd. Suite 900 Lakewood CO 80228. McNeil staff who worked on this project included

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Acronyms

°F....................degrees Fahrenheit
$.......................U.S. Dollars
AD...................Anaerobic Digestion
BOD ....Biological Oxygen Demand
Btu...................British thermal unit
CDPHE ....Colorado Department of Public Health and the Environment
cf ....cubic feet
COD ....Chemical Oxygen Demand
EPA ....Environmental Protection Agency
ESCO ....energy services company
ESPC ....energy savings performance contracting
ft ....feet
ft^3.....................cubic feet
gal....................gallon
H_2S ....hydrogen sulfide
HP ....horsepower
HRT.................hydraulic retention time
kW...................kilowatt
kWh.................kilowatt-hour
lbf ....pounds force
MMBtu............million British thermal units
MBtuh ....MBtu per hour
Mcf .... thousand cubic feet, a volume measure for natural gas. Equal to 1 MMBtu assuming that 1 cubic foot of natural gas has 1,000 Btu. The Btu content of a cubic foot of natural gas may vary.
MW ....megawatt
MWh ....megawatt-hour
OEMC ....Colorado Governor's Office of Energy Management and Conservation
tpd…………...tons per day
U.S. ....United States of America
USDA..............United States Department of Agriculture
WRBEP...........Western Regional Biomass Energy Program (U.S. Department of Energy)

1 INTRODUCTION

The overall objective of this project is to expand the existing Colorado state IOF program to include agriculture. Technology assessments were conducted to identify new markets and assess barriers and opportunities for state industry to deploy new energy, water, waste management and biobased product manufacturing technologies.

The goal of Colorado's agriculture IOF is to deliver near-term, cost-effective solutions that address the day-to-day operational realities facing the industry, while simultaneously laying the groundwork to develop future technologies and markets. OEMC seeks to develop a program that not only creates new market opportunities for biofuels and biobased products, but will also work to make the existing industry as efficient as possible in terms of energy use and production, water consumption, waste generation and overall environmental impact. Maximizing the performance of today's industry will improve long-term economic opportunities for developing and deploying new technologies and markets. The OEMC strongly feels that the state IOF must be cross-cutting and include both crop-based as well as livestock-based industries. Both of these sectors are important to the Colorado economy, and both sectors offer opportunities for integrated deployment of new energy, biobased product and waste management technologies. In terms of economic impact on the state's economy, livestock has more than twice the revenue of crop-based products. One of our primary interests in working with livestock operations is to see whether they can serve as niche markets for biofuels, biolubricants and biofertilizers.

Project Approach

Both novel and commercially available technologies were evaluated for their ability to meet industry needs. Technology areas evaluated include:

- Biobased Products
- Liquid Fuels
- Anaerobic Digestion
- Compost
- Wind Farms
- Precision Agriculture
- Precision Irrigation
- Integrated Pest Management
- Soil Conservation
- Cropping Systems
- Operations Management Improvement
- Energy Efficiency Improvements & Audits
- Solar Applications in Agriculture

All of these technologies/practices have the potential to reduce direct energy use or embodied energy use in all sectors of the state's agricultural industries. For example, biobased products and biodiesel can widen available manufacturing opportunities, create jobs, and improve rural economies. State livestock producers can be encouraged to switch to biodiesel for their back-up generators and lubricants thereby creating new niche markets for those products and improving operational efficiency and renewable energy balances. The technology focus areas were based on input from the steering committee and workshops.

Structure of Report

There is one overall report including all 13 technology assessments. Furthermore, there are individual break out reports for each assessment. The results will be incorporated into the Colorado IOF Program Internet web site, providing pictures and data illustrating technology applications for stakeholders.

Technology assessments include a general introduction, current status of technology, benefits, and technology barriers. Some assessments did not fall into the aforementioned categories and are written up with an introduction and applicable subject areas. Where appropriate, assessments include a comparison between conventional technology and new technologies. For example, total embodied energy use, nitrate and phosphate runoff potential and cost factors for the use of compost will be compared with commercial fertilizer use. Where possible, assessments include information on capital and operating costs.

2 TECHNOLOGY ASSESSMENT AND OVERVIEW

2.1 Anaerobic Digestion

Anaerobic Digestion is the natural, biological degradation of organic matter in absence of oxygen yielding biogas. Volatile solids in organic matter are converted to biogas consisting of methane, carbon dioxide and trace amounts of other gases. Biogas is capable of operating in nearly all devices intended for natural gas with minimal adjustments to account for lower Btu content. This section will focus on AD of livestock manure as ample resources are available in Colorado. This is an effective manure management technique with great potential for energy generation at Colorado CAFOs.

The degradation and conversion process occurs in four steps with different classes of bacteria responsible for each phase. In manure digestion, hydrolysis is often the rate-limiting step due to lignin's' resistance to degradation. Figure 1 illustrates the microbial process where the first two steps are facultative and the latter two are strictly anaerobic.

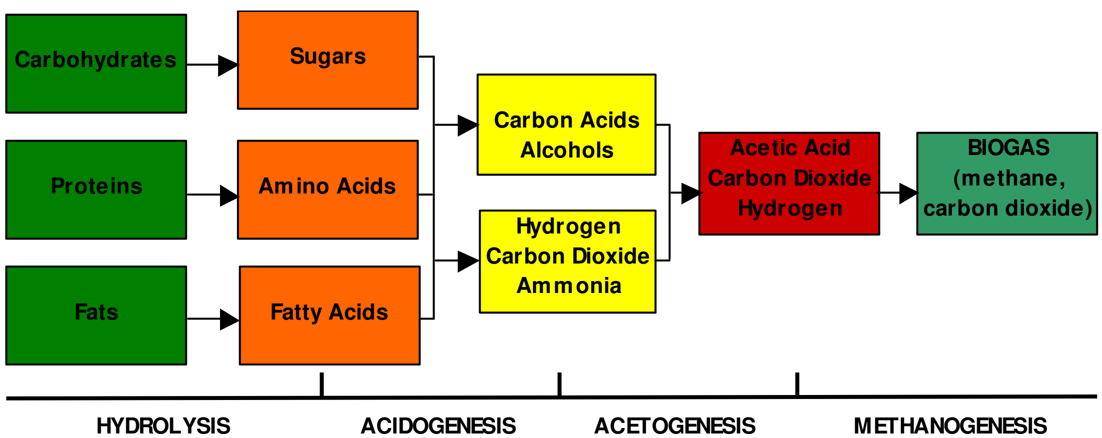


Figure 1: Anaerobic digestion process

There are several potential utilization options for biogas such as generation of electricity or heat. A portion of generated biogas is required to maintain temperature and provide energy for other functions of the digestion process. Remaining energy is available for electricity generation or direct combustion for heating purposes or use in farm equipment. There is also the potential to connect and export excess energy to the grid if a favorable power purchase agreement can be arranged with the local utility.

As of March 24, 2004, EPA AgStar reports 49 animal manure anaerobic digesters producing biogas in the United States.[1] One complete mix digester is in operation at a

---

[1] K. Roos, *Status of Existing and Emerging Biogas Production and Utilization Systems*, EPA Agstar, March 2004

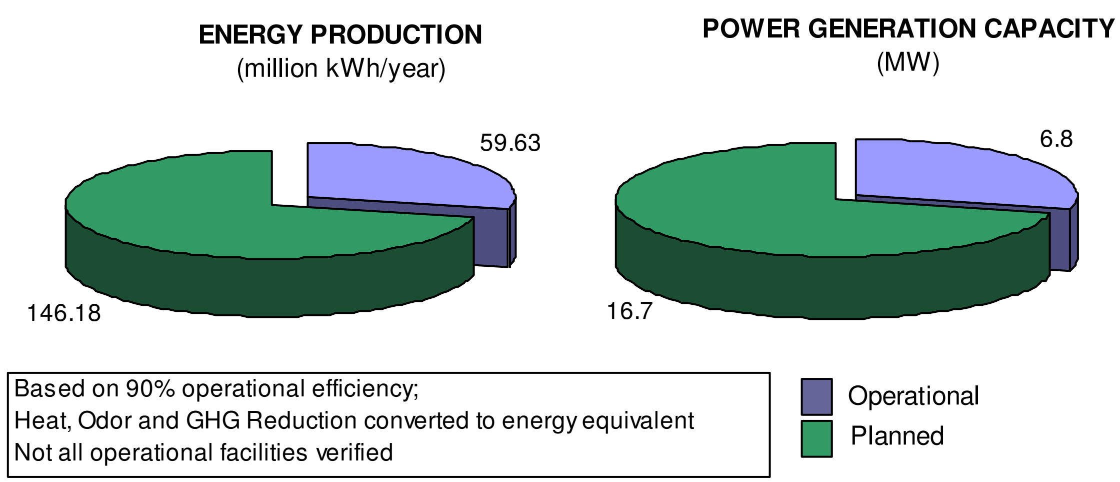
large swine facility in Fort Lupton, CO. The same report identifies 57 more digesters in planning or building phase. Digesters are used for energy generation, odor control and green house gas emission reductions. Table 1 identifies operational and planned digester types.

Table 1: Farm-based anaerobic digesters in the United States

Digester Type	Operational	Planned
Mesophilic Plug Flow	19	31
Mesophilic Complete Mix	15	8
Unheated Covered Lagoon	10	9
Centralized	4	5
Unheated Attached Media	1	
Mesophilic Attached Media		1
Other		3
TOTAL	49	57

source: K. Roos, *Status of Existing and Emerging Biogas Production and Utilization Systems*, EPA Agstar, March 2004

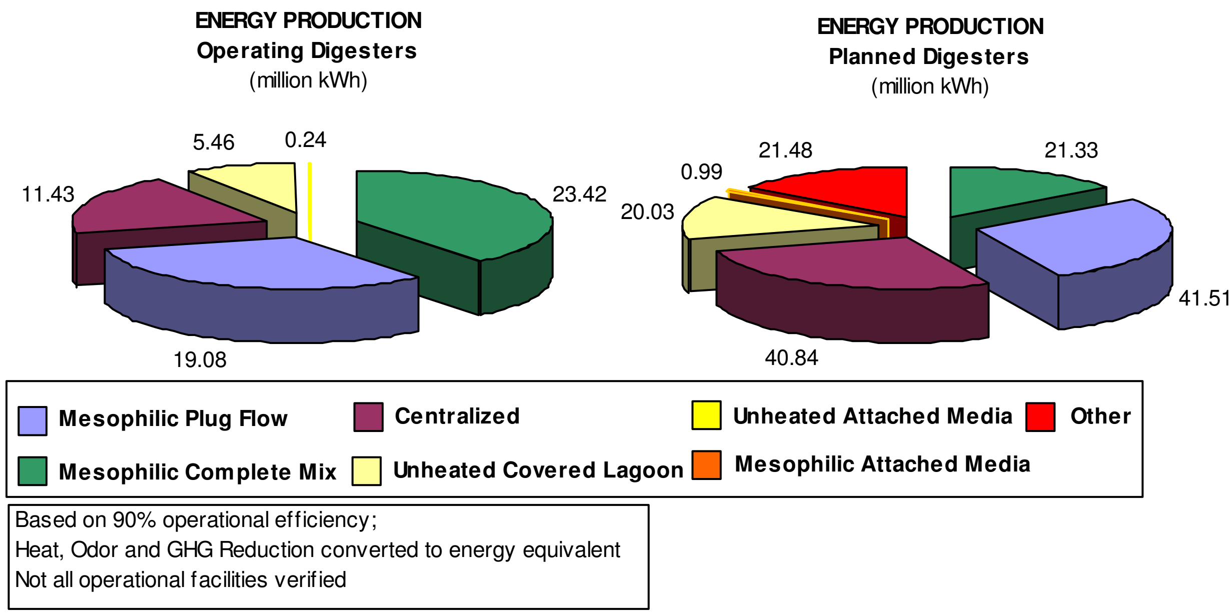
The majority of operational and planned digesters are mesophilic plug flows. This digester type is designed to digest scrapped dairy manure. It has lower capital and operating costs when compared with mesophilic complete mix and can operate in warm or cold climates. Figure 2 identifies the energy generation from operating digesters and expected generation from planned digesters.



source: source: K. Roos, *Status of Existing and Emerging Biogas Production and Utilization Systems*, EPA Agstar, March 2004

Figure 2: Energy production capacity of operating and planned manure digesters

Biogas composition and methane quantity is a function of manure type, method of manure removal and digester technology. Biogas is generally comprised of 55-70% methane and 30-45% carbon dioxide with trace amounts of other gases. Figure 3 details the energy or energy equivalent obtained from each type of digester. Energy production from planned digesters is based on the assumption that each will be built and operate at planned output.



source: source: K. Roos, *Status of Existing and Emerging Biogas Production and Utilization Systems*, EPA Agstar, March 2004

Figure 3: Energy production capacity by digester technology

2.1.1 Current Status of Technology

AD technologies are commercially available and 49 farm-based digesters are currently in operation nationwide. The USDA NRCS in conjunction with the EPA developed 'Conservation Practice Standards for Methane Recovery' from anaerobic digesters. The NRCS recognizes three digester technologies: unheated covered lagoon, plug-flow and complete mix. These standards can be viewed and printed at http://www.epa.gov/agstar/pdf/handbook/appendixf.pdf. Other types of anaerobic digesters, such as attached media filters and sludge blankets, may serve to provide technical and economic benefits in future installations.

The EPA *AgSTAR Handbook: A Manual for Developing Biogas Systems at Commercial Farms in the United States* is a comprehensive guide for evaluating the feasibility of on-farm manure biogas generation. This handbook and software to determine economic viability are available online at http://www.epa.gov/agstar/resources/handbook.html. AgStar estimates that cost effective methane collection could be achieved at 3000 US livestock farming operations.[2]

A lagoon digester is the simplest and lowest cost method to capture methane from manure. A lagoon manure pool can be transformed into a lagoon digester by adding a floating cover. An industrial strength cover rests on solid floats on the lagoon surface. Methane is trapped under the cover and collected by a perforated pipe located near the sealed end of the lagoon (Figure 4).

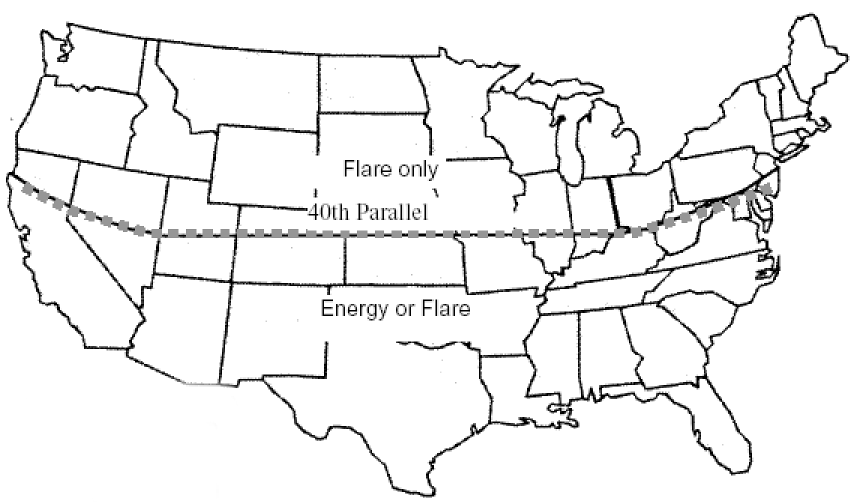
---

[2] J. Balsam, *Anaerobic Digestion of Animal Wastes: Factors to Consider*, ATTRA, October 2002.

Considerations for anaerobic lagoon methane recovery:

- Economic biogas recovery in warm climates only (Figure 5)
- Lagoon is unheated and biogas production varies seasonally
- Ideal for hydraulic flushing manure systems due to low solids (2-3%)
- Typically takes 1-2 years to achieve steady state for economic methane recovery
- Requires significant land
- Not appropriate for geographic regions with high water table due to potential for ground water contamination

Figure 4: Example of anaerobic covered lagoon and biogas recovery



Source: EPA. (July 1997). AgStar Handbook: A Manual for Developing Biogas Systems at Commercial Farms in the United States. EPA 430-B-97-015. pp. 4-12

Figure 5: 40th Parallel: climate limitation for biogas energy recovery from lagoons

The plug-flow is another NCRS approved anaerobic digester. Plug-flows are long, linear troughs usually sited above ground. Fresh manure is added daily and this action pushes previous days' plugs of manure through the trough. The AD process occurs as the plugs of manure move through the length of the trough. An airtight, expandable cover captures the methane. A photo shows this digester type in Figure 6.

Information for plug flow digesters:

- Ideal for dairy farms that mechanically remove manure (scrapping)
- Length of the digester is determined by daily manure volume
- Dimensions of height to width are typically 1:5
- Requires mix pit with volume of daily manure load to ensure solids of 11-13%
- Digester operates in the mesophilic temperature range (90-110°F)
- Waste heat from engine and cooling systems or generated biogas heat the digester
- Hot water pipes through the length of the trough maintain temperature
- Typically takes 6 months to achieve steady state for economic methane recovery

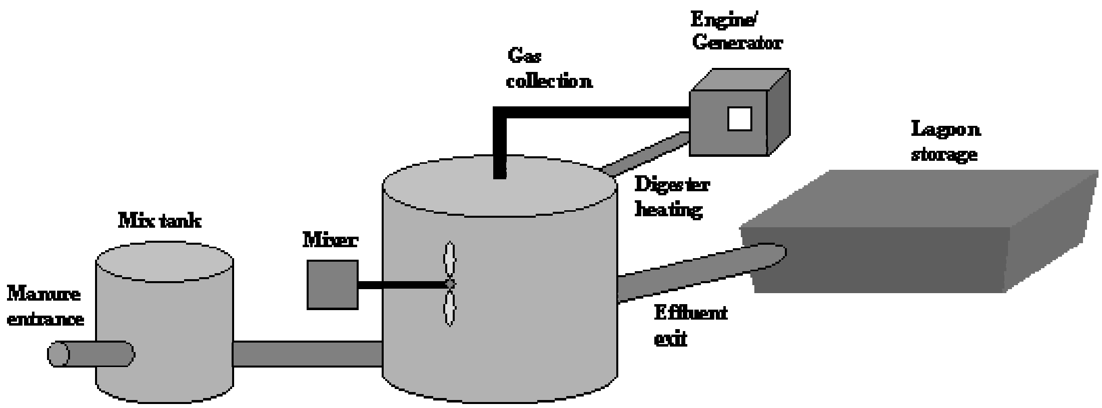
courtesy of RCM Digesters, Inc. http://64.225.36.90/Default.htm

Figure 6: Stencil Dairy plug flow digester for 1200 cows

Complete mix digesters consist of a large above or below ground steel or concrete reactor. Waste is mechanically mixed providing good contact between microbes and volatile solids leading to efficient biogas production. The mixing also provides a homogenous effluent useful as a fertilizer or soil conditioner. Figure 7 is a schematic of this digester type.

Considerations for complete mix digesters:

- Best suited for large farming operations that remove manure by washing
- Volumes range from 3500- 70000 ft^3 with capacity of 25,000-500,000 gallons manure
- Operate in mesophilic (90-110°F) or thermophilic (120-140°F) temperature range
- Installation and heat exchangers maintain temperature from biogas or waste heat recovered from engine exhaust and cooling systems
- Typically takes 5-6 months to achieve steady state for economic methane recovery
- Sewage sludge from a waste water plant is initially placed in digester for establishment of microbes prior to loading manure



Source: EPA. (February 1997). AgStar Technical Series: Complete Mix Digesters – A Methane Recovery Option for All Climates. EPA 430-F-97-004. Washington,

Figure 7: Complete Mix Digester Schematic

There is also a variation of complete mix termed temperature-phased anaerobic digester (TPAD). This two reactor digester design was developed by Iowa State University to separate microbial processes in order to optimize parameters for both. Research has demonstrated that a two-stage reactor design leads to higher biogas and methane yields although dual reactors increase construction and materials costs. Table 2 offers a comparison of the three anaerobic digesters recognized by NCRS.

Table 2: Comparison of NCRS Recognized Digesters

	Lagoon	Plug Flow	Complete Mix
Total Solids Concentration	>3%	11-13%	3-10%
Animal Manure Type	Any	Dairy	Any
Hydraulic Retention Time	>60 days	20-30 days	>10 days
Operating Temperature	Ambient	Mesophilic	Mesophilic or Thermophilic
Orientation	Horizontal	Horizontal	Vertical
Operation & Maintenance	Simple	Moderate	Complex
Capital Costs	Low	Moderate	High

source: www.biogasworks.com

Attached media, or anaerobic filters, are another type of digester technology. There is one unheated attached media digester operating in Florida . Microbes responsible for the digestion process are immobilized in a filter (often plastic) and do not leave the digester with the effluent as in other technologies. Retaining microbes reduces the size of the digester because time to treat wastes is greatly reduced to 2-6 days.[3] The capital costs are high and maintenance may occasionally require for periodic removal of solids accumulation in the filter.

[3] AgStar Digest, EPA, Winter 2003, table 1 Operating US Digesters as of October 2002.
online at: http://www.epa.gov/agstar/pdf/2002digest.pdf

Utah State University has developed an upflow anaerobic sludge blanket (UASB). A blanket of bacteria digests manure and biogas is released. This system reduces the time to treat waste because the microbes remain in the digester rather than leaving with the effluent. The anaerobic sludge blanket digester is also an attractive alternative because installation costs are lower than those of plug flow and complete mix. A UASB may be built in Fort Morgan to handle slightly more waste than the Utah State University research digester.[4]

Microgy, a subsidiary of Environmental Power Cooperation, has licensed a digester technology from Europe that significantly increases biogas production by heating a complete mix digester to thermophilic temperatures. Construction has begun on digesters at two dairy farms in Wisconsin each digesting manure from 1000 cows to drive a 775kW generator. The digesters will be owned by each farmer whereas the generation equipment will be owned by Dairy Land Power Corporation, a power company with customers in five Midwestern states.

There are several important control parameters that require monitoring to ensure methane production. Table 3 lists the most important parameters.

Table 3: Control Parameters for Anaerobic Digesters

Parameter	Acceptable Range	Other Information
pH	6.5-7.5	self regulating by anaerobic microbes; methanogens unlikely to grow <6.5
Alkalinity	.133 ounce/gallon	self regulating by converting hydrogen ions in waste to biocarbonate ions
VFA	<.013 ounce/gallon	high concentration will inhibit acetate production directly and greatly reduce biogas generation
Acidity to Alkalinity Ratio	.3 to .5	Easier to measure than alkalinity or VFA
COD/BOD of Manure and Effluent	Effluent 10% of Manure	COD (chemical oxygen demand) and BOD (biological oxygen demand) can measure the efficiency of the digester to convert volatile solids to methane

source: Biomass Course, Loughborough University, Fall 2003

It is essential to standardize the organic loading rate (manure volatile solids) to a digester to optimize methane production and minimize risk of a system shutdown. Overloading a digester with organic materials will shock the system resulting in reduced or discontinued digestion and methane production. A farm should consider constructing a manure holding tank or pond in order to regulate flow into the digester.

The cost to install and operate a farm-based digester is dependent on technology used. EPA AgStar provides estimated installation costs and operational output in kW for

---

[4] Telephone conversation with Jon Euwing of Environmental Systems and Solutions, LLC July 15, 2004

digesters producing electricity. These figures do not include the value of hot water or heat produced from biogas. Digesters serve other purposes that are not monetarily quantified including manure management and odor and leachate control. Digesters flaring biogas spent an average of $191,750 per installation without gaining any benefit from energy or heat generation. Table 4 details costs associated with each digester type.

Table 4: Comparison of Digester Costs

Digester Type	Approximate Installed Cost($)	Operational Output (kWh)	Average Cost per kWh ($)	Average Cost per Animal Unit ($)
Lagoon	$220,000-290,000	25-41	$7,727	$119/swine
Plug-Flow	$125,000-1,800,000	28-500	$3,475	$379/cow
Complete Mix	$325,000-1,400,000	33-425	$4,045	$500/cow, $98/swine

source: *AgStar Digest*, EPA, Winter 2003, table 1.

The 2002 Farm Bill section 9006 provides cost sharing grants through the USDA Rural Development Program to purchase renewable energy systems for agricultural producers. Funding is available in amounts between $2500-500,000 through 2007 and can help reduce farmers' cost to purchase and install anaerobic digesters.

Building a digester as a cooperative can mitigate initial capital costs. A community digester enables economies of scale, more financing opportunities and an increased likelihood of establishing a power purchase agreement with the local utility. Another cost reduction method is to co-digest food production wastes or other wastes compatible with manure. As an example, Matlink Dairy Farm in Clymer, New York profits $240,000 annually from their plug flow digester by accepting wastes from nearby food processing facilities and selling heat to an on-site food drying operation.[5]

There are several end uses for biogas produced through AD. Electricity generation with an internal combustion engine is the most common end-use of biogas. Minimal adjustments to the carburetion and ignition systems of an internal combustion engine are necessary due to the lower Btu value of biogas. Heat exchangers collect steam from the engine's exhaust and cooling systems to provide hot water or heat. Waste heat recovery systems can recover up to 7000 Btu/hour for each installed kW increasing overall system efficiency by 40-50%.[6]

Minimal adjustments to the carburetion and ignition systems of an internal combustion engine are necessary prior to burning biogas because it has a lower Btu value then natural gas. Most internal combustion engines with capacity of less than 200kW achieve conversion efficiencies of biogas to electricity less than 25%.[7] The remaining 75% of

---

[5] S. Inglis, P. Wright, *An Economic Comparison of Two Anaerobic Digestion Systems on Dairy Farms*, Cornell University, July 2003, table 1.

[6] T. Rooney, S. Haase, *Assessment of Biogas-to-Energy Generation Opportunities at Commercial Swine Operations in Colorado*, State of Colorado OEMC, Nov 1, 2000, chapter 4.

[7] Energy and Anaerobic Digestion, Biogas Works online at: http://www.biogasworks.com/Index/Energy%20&%20AD.htm

energy results in waste heat that can be used to heat mesophilic and thermophilic digesters or provide hot water or space heating.

Biogas can be directly combusted in boilers or furnaces to provide heat for on-farm use. Boiler modifications must be made to enlarge jets and alter the fuel to air ratio to burn low energy biogas. Direct combustion in furnaces requires extensive biogas clean up to remove hydrogen sulfide to prevent corrosion. Further processing to remove carbon dioxide, hydrogen sulfide and water allows biogas to be used as a compressed alternative fuel. However, this is a limited market as there are only a few thousand vehicles designed to operate on compressed natural gas (CNG).

2.1.2 Benefits

AD of animal manure offers extensive benefits over other manure management systems. As livestock farms grow in size and become more geographically concentrated, anaerobic digesters provide an excellent way to address manure handling regulations, odor issues and environmental contamination concerns.

Benefits include:

- Waste Treatment Benefits
  - Natural waste treatment process
  - Low land requirements
  - Reduces waste volumes
  - Effluent provides nutrient rich compost and fertilizer
- Environmental Benefits
  - Odor reduction
  - Reduces leachate risk
  - Destroys most weed seeds and pathogens
  - Immense reductions of carbon dioxide and methane
- Energy Benefits
  - Results in net energy gain
  - Biogas has numerous end uses

Animal wastes are an increasing problem on U.S. farms as all manure cannot be spread on land. Over application of raw manure elevates the risk of nutrients leaching and water contamination. Manure odor is a considerable issue as residential development expands to rural areas. AD reduces odor and environmental risks through enclosed digesters and the anaerobic conversion process. Methane is a significant green house gas, trapping over 21 more times more heat per molecule than carbon dioxide. In 2002, farm based anaerobic digesters reduced methane emissions by 112,945 tons carbon equivalent.[8] AD is the only waste management system that captures biogas for energy production. On-site

[8] AgStar Digest, EPA, Winter 2003, table 1 Operating US Digesters as of October 2002. online at: http://www.epa.gov/agstar/pdf/2002digest.pdf

energy generation can serve to reduce farm dependence on fossil fuels and costs to purchase heat and electricity.

The effluent of AD consists of biosolids and wastewater. The wastewater can be recycled back into manure flushing systems or spread through irrigation systems as a liquid fertilizer. AD processes increase concentrations of nitrogen, phosphorous, potassium and other trace elements. Additionally, effluent nitrogen is in mineralized form, same as commercial fertilizer, thus increasing availability to plants when compared with composted or raw organic nitrogen. Biosolids can be composted for use as a soil amendment.

There is potential future financial benefit to farmers in carbon trading. Carbon trading or sequestering is an emissions reduction method where companies exceeding green house gas emissions compensate farmers that use techniques that keep carbon in the soil or otherwise reduce emissions. One such qualifying practice is to capture and use biogas from AD of animal manure. More information on carbon sequestering is available at http://www.fb.com/news/fbn/html/agriculture_s.html

2.1.3 Technology Barriers

There are several issues to consider for anaerobic digester including:

- Cost of digester and biogas recovery equipment
- Digester operation
- System reliability

Building a digester and energy generation system requires considerable capital. These costs can be mitigated by applying for a USDA cost-sharing grant and by maximizing the sales of all usable products: electricity, biosolids/fertilizer and heat. In some cases, large farming operations with significant biogas generation can sell excess electricity to the grid with an acceptable power purchase agreement. Many utilities are interested in earning credits for green house gas emission reductions and may be willing to pay farmers a fair price to prevent federal legislation mandating such practices.

Digesters require regular monitoring for proper operation. Temperature and organic loading rate are the most important parameters to ensure optimal digestion and biogas production. It is also necessary to separate manure wastes from other wastes such as copper sulfate and other parlor washing chemicals. A farming operation must establish a management plan to monitor critical digestion parameters in order to identify and repair potential problems.

System reliability is important as many early anaerobic digester designs failed on U.S. farms. It is essential to select a qualified contractor and quality equipment and monitor the digester at regular intervals. The reliability of systems should improve with newer installations utilizing updated digester designs and control systems.

2.1.4 Comparison with other Manure Management Systems

Other manure management methods have high installation costs and do not offer the benefit of electrical or fertilizer sales potential associated with anaerobic digesters. They are simply absorbed expenses and Table 5 illustrates the costs associated with other manure management systems.

Table 5: Comparison of manure management systems costs

Manure Management System	Cost Range ($/1000 lbs live weight)
Covered Lagoon Digester with open storage pond	150-400
Heated Digester (plug flow or complete mix) with open storage tanks	200-400
Aerated lagoons with open storage pond*	200-450
2-cell separate treatment lagoon and storage pond	200-400
Storage ponds and tanks	50-500

source: *Managing Manure with Biogas Recovery Systems: Improved Performance at Competitive Costs*, EPA AgSTAR, 2002, Program. 8 p. (no O&M costs included)
*aerated lagoons require energy costing $35-50 per 1000 lbs live weight

In 1999, manure management systems were the eighth largest emitter of greenhouse gases in all industrial sectors in Colorado.[9] Emissions of methane were 43,049 tons with nearly 50% coming from cattle operations. Lagoon manure management systems accounted for 15,273 tons accounting for 37% of total manure methane emissions. Such emissions could be significantly reduced by covering, collecting and using biogas generated in lagoon manure management systems. Methane is a significant green house gas as it traps over 21 times more heat per molecule than carbon dioxide. In 2002, farm based anaerobic digesters reduced methane emissions by 123,961 tons carbon equivalent.[10]

AD offers a manure management solution with the added benefit of energy generation for CAFO's facing new requirements. Recent legislation regulates and limits use and application of raw manure on fields in an effort to decrease risk of environmental contamination.

---

[9] *2000 Colorado Emissions Update to Chapter Three of the 1998 Climate Change Report*, Colorado Department of Public Health and the Environment, November 2000.

[10] AgStar Digest, EPA, Winter 2003, table 1 Operating US Digesters as of October 2002.