Manure Processing Technologies
3.4 Anaerobic Digestion

Mary Wicks, Kirsten Dangaran, and Steve Baertsche

The Ohio State University

What Is Anaerobic Digestion?

Anaerobic digestion (AD) is a microbial process in which organic materials, such as animal manures, are decomposed in an oxygen-free environment. Two products of anaerobic digestion are: 1) biogas, which is a mixture of primarily methane (~60%) and carbon dioxide (~40%), and 2) effluent consisting of the remaining solids and liquids. The biogas can be burned to generate heat or electricity or cleaned so that the methane can be compressed for use as a fuel in CNG vehicles or sold directly to a pipeline.

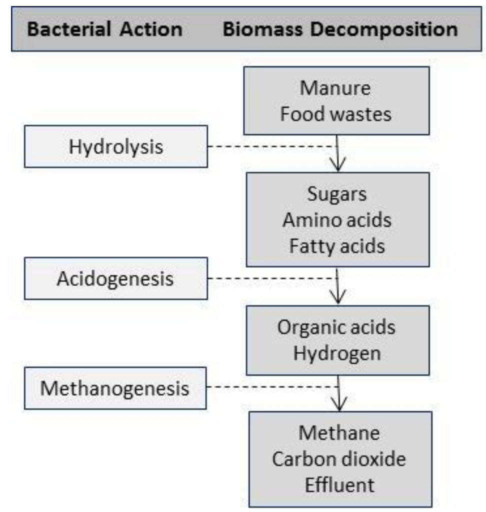

Figure 1. Diagram of microbial stages in an AD system

The digestion process occurs in a series of stages characterized by distinct types of -microbes as shown in figure 1. Management of an AD system is important to ensure a balance in nutrients so that the microbial population remains stable; otherwise, the digester can "crash" and will require cleanout. The rate at which feedstocks are broken down largely depends on the feedstock, operating parameters, and type of digester.

Feedstock characteristics

Table 1 provides the characteristics for livestock and poultry manure and the preferred range for optimal biogas production. Microbes require carbon (C) as an energy source and nitrogen (N) for proteins. The **C:N ratio** of animal manures is typically too low, but the use of organic bedding, such as straw or sawdust, will increase the carbon. If digested solids are used for bedding, they may have some effect on the carbon content depending on how much of it has been converted to methane. The **total solids** of manures will vary depending on the species and manure handling practices, and the preferred range will vary for different digester types. Enough moisture must be present to meet microbial requirements. **Volatile solids** reflect the degradability of the feedstock, but the actual methane produced depends on specific components as some decompose more quickly than others. Although the volatile solid content of manure is relatively high, microbial degradation is low. Therefore, co-digestion of food processing wastes with manure may be desirable to increase biogas production and provide an additional source of revenue.

Table 1. Comparison of manure and preferred range for AD feedstocks.

Characteristic	Animal Manures	Preferred Range
C:N ratio	6-8[a]	20-25[b]
Total solids	8-25%[c]	3-15%
Volatile solids	80-90%[c]	
pH	6.8-7.4[a]	6.8-8.5[b]

[a] Keener, 2010; [b] Burke, 2001; [c] Bulletin 604, 2006

If the feedstock characteristics fall outside preferred ranges, the rate of biogas production can be expected to decrease and the risk of a system crash will increase. Thus, it is important to have a laboratory analysis of all feedstocks when considering AD technology. It is also possible to have the methane potential of the manure evaluated to be used as a screening tool; however, the evaluation should not be relied upon solely for designing a system (Favoir and Kirk, 2011) without considering other feedstock characteristics. Use of disinfectants or other additives that could be toxic to the microbes should be avoided (Burke, 2001).

Products of AD

Biogas. The biogas produced is a mixture of approximately 60% methane (CH_4) and 40% carbon dioxide (CO_2) with small amounts of water and hydrogen sulfide (H_2S). In a Cornell study, analysis of different feedstocks found the methane potential varied with the feedstock (Table 3). Although the volume of biogas produced per ton of animal manures is relatively small, manure provides a stable environment for the bacteria, reducing the risk of a system crash. Adding feedstocks with higher potential can increase biogas production.

Table 3. Biogas potential of feedstocks (Labatut, 2010)

Feedstock	Methane Yield (mL CH_4 / g VS_{added})
Dairy manure	243
Cabbage	256
Corn silage	296
Potatoes (whole)	334
Cheese whey	424
Ice cream	649

Biogas can be burned directly for heating a boiler or generating electricity, although typically the water and H_2S are removed first to reduce equipment maintenance needs. Most farms generate more heat than can be used on the farm, especially during summer months. Unless additional uses for the heat exist such as evaporating digester effluent or drying grain, a portion of the biogas may be wasted (McDonald, 2012). Similarly, more electricity is usually produced from the biogas than can be used on the farm. Although the excess electricity can be sold to the power grid, the price per Kwh produced tends to be low and obtaining a power purchase agreement with the utility is often a long and expensive process (Furrer, 2012; McDonald, 2012).

Biogas may be further processed to remove CO_2 leaving only the CH_4, which can be sold to a natural gas pipeline or compressed (CNG) for use as a vehicle fuel. The cost effectiveness of upgrading biogas to pipeline quality depends on the price of natural gas, which tends to be highly variable. A Cornell study found that for a 500-cow dairy, the processed gas would need to sell for $12-14/MBtu, depending on whether additional pipeline construction was required; whereas, for a 1,000-cow day, it would need to sell for $8-10/MBtu (Fiesinger, 2006). Cleaning and compressing biogas for use as a vehicle fuel has been effective in Sweden where, in 2006, 54% of all natural gas vehicle fuel was from biogas; however, infrastructure is a key for distribution (Paersson, 2007). In the U.S. a 9,000-head California dairy cleans and compresses its biogas, using it as a replacement for expensive diesel in milk and pickup trucks (McDonald, 2012).

Effluent. There is little reduction in volume and nutrient value (NPK) of the feedstocks; thus, it is critical to have a plan to utilize the effluent. A Cornell study found that the decrease in the mass of nitrogen (N) and phosphorus (P) was less than 5%, but there was a shift from organic to inorganic forms, with ammonia increasing by 37% and ortho-P increasing by 26% (Aldrich, 2005), which are in more readily available forms for crop uptake. The effluent can be used as a fertilizer; however, an adequate land base must be available and best practices used during application to reduce the risk of runoff. Testing effluent is necessary to determine application rates.

For dairies, the solids are often separated from the liquids and may be composted, creating a value-added product. Composted solids may be sold as a soil amendment or for using in potting media in the nursery industry. The solids can also be reused as bedding, before or after composting. The separated liquid can be used for irrigation, but unless the suspended solids have been removed, most of the phosphorus will remain in the liquid so application rates will depend on P soil levels.

Operating temperatures

The anaerobic digestion of manures takes less time at higher temperatures, but as the temperature increases, the system becomes less stable. Most digesters are designed to operate within a specific temperature range:

- **Psychrophilic**: 35-68 °F. Covered manure storage lagoons are the most common psychrophilic system and operate at ambient temperatures, eliminating heating costs. However, biogas production is low and varies with seasonal temperature changes (Reis and Engel, 2003). These systems may be used more for odor control than energy production.
- **Mesophilic**: 95-105 °F. Processing time is longer and a larger tank is required. However, it is a more stable process due to a larger community of bacteria.
- **Thermophilic**: 120-140 °F. High temperatures increase microbial activity thus the processing time is shorter allowing for a smaller tank (25-40% of a mesophilic tank). However, fewer species of bacteria and fluctuating temperatures, cause these digesters to be less stable and, thus, require more careful monitoring.

Types of digesters

There are three basic AD system designs typically used for livestock manure. These designs vary in the type of vessel and operation as described below and summarized in Table 2.

Covered lagoon: Covered lagoons (Figure 2) are a low technology system that can be added to pre-existing manure handling systems. They have been used most often with flushed dairy and swine manure, which have a total solids content of 0.5%-3%. The system consists of at least one storage cell that can be in-ground, earth or lined but multiple storage cell systems also exist. The lagoon has a flexible gas-tight cover usually made from HDPE for capturing the biogas. If a single cell system is used, it must be large enough for 3-6 months of manure storage plus excess rainfall, run-off and freeboard. The benefit of a multiple cell system is that wastewater and excess rainfall can be stored in one cell and later used for flush water. Overtime, manure solids and organic material can settle into a sludge and can remain in the AD for years. This sludge can temporarily capture and reduce N, P, and K loads in the effluent wastewater but these nutrients will eventually have to be managed when the covered lagoon is emptied. Covered lagoon ADs are not heated by an external source so biogas production will be affected by temperature and climate. They may be more suited for warmer climates where higher temperatures will allow for continuous and efficient biogas production. Secondary system considerations for covered lagoons are related to maintenance. Rainwater may accumulate on the flexible cover and will have to be removed using pumps.

Figure 2. Newly installed flexible cover on ½ lagoon at 700-cow dairy in Ohio.

Plug flow: Plug flow digesters (Figure 3) are another example of a low technology system that is better suited for operations that collect manure using mechanical methods such as scraping. The total solids of the manure entering a plug flow digester is typically in the range of 10-15% solids but some in-field data has shown successful operation with as high as 20% solids. The higher solids percentage is needed to keep particles suspended as the manure flows through the digester since mechanical stirring or agitation may not be part of the system design. Most plug flow digesters are made of a horizontal, rectangular concrete tank that has a footprint 5 times longer than it is wide. The manure tank will be designed with a straight or U-shaped flow pattern and will have a typical retention time in the digester of 15-30 days. The digester is sealed with either a concrete (fixed) or polypropylene (flexible) cover for biogas recovery. The hard top is a higher capital investment but has a longer life and better insulation. The flexible top is less expensive and allows for more gas storage. Plug flow digesters are heated to 90-95°F using circulated hot water that flows through pipes along the concrete tank. In-field data has suggested plug-flow digesters could be run as high as 100°F for improved gas production. While horizontal plug-flow digesters are most common, vertical tanks with conical bottom also exist. This latter design may be good for sand-laden dairy manure.

Figure 3. Plug flow digester with flexible cover at a 650-cow dairy in New York.

Complete mix: Complete mix digesters are more expensive systems to finance and operate than plug flow and covered lagoons; however, it is a robust system that allows for thorough mixing during the process and are well-suited for multiple types of feedstocks. The input to a complete mix digester is typically in the range of 3-10% solids, and it has been used more with flushed swine, and in a few cases, poultry waste. The system is made of an above ground, heated tank that is insulated. The system is heated with a spiral flow heat exchanger. Complete mix digesters can be operated in either the 90-95°F (mesophilic) or 140-145°F (thermophilic) range. To prevent settling of solids within the tank, complete mix digesters use mechanical agitation or recirculating pumps. It is a continuous process with a retention time of 20-30 days.

Figure 2. Complete mix digester at the OSU/OARDC campus in Wooster, OH.

Solid-state: Solid-state digesters can utilize feedstocks that are over 15% total solids. Although solid-state systems are used in Europe for digestion of crop residues, such as corn stover and cobs, there are

Table 2. AD System Characteristics

Characteristics	Covered Lagoon	Plug Flow	Complete Mix
Digestion vessel	Deep lagoon	Rectangular in-ground	Any, above/-in ground
Level of technology	Low	Low	Medium
Supplemental heat	No	Yes	Yes
Total solids	0.5 – 3%	11 – 13%	3 – 10%
Feedstock particles	Fine	Coarse	Coarse
Retention time	40 – 60 days	15+ days	15+ days
Optimum climate	Temperate/warm	All	All

Source: http://www.epa.gov/agstar/documents/chapter1.pdf (Accessed 5/23/12) no commercial scale systems operating in the U.S. However, a solid-state digester is currently being built in Indiana and will use duck offal from a processing facility, corn silage, and other feedstocks (Vandenack, 2013). The effectiveness of solid-state digestion of livestock manure has not yet been demonstrated.

<u>Daily Management of AD systems</u>
Although much of the system monitoring, such as flow rates and temperature, will be automated and recorded with data loggers, it is recommended that flow meter totalizers for feedstock, effluent, and biogas and tank temperature be manually observed once a week to verify accuracy. Temperature, flow rates of inputs and outputs, gas production, and pH should be monitored daily and the operator needs to interpret the readings in order to make necessary system adjustments. Additional testing and data as well as maintenance activities should be scheduled weekly or monthly (Katers, 2011).

The time required to operate, monitor, and maintain an AD system will vary depending on the digester type, size, feedstocks, and biogas and effluent utilization. As the number and variety of feedstocks increases, the risk of an imbalance in nutrients increases, thus more time is required to monitor the system. Some reports that as little as 15-30 minutes are needed for daily monitoring with more time for weekly and monthly testing and maintenance (James, 2006: UC Davis), while others report the need for up to 3 full-time employees (AgTown, 2011).

What are the System Components for AD?

The components of an on-farm AD system will vary mainly depending on feedstock handling,digester configuration and how the biogas and effluent are used. Table 4 lists the key components.

Table 4. AD system components

	Process Step	**Component or Purpose**
Manure Handling	Manure collection at farm	Storage pit, directly to digester
	Manure transport to digester	Tanker, pipeline, other
	Feedstock mixing at digester	Holding/mixing tank, grinder[1]
Digester System	Digester	Covered lagoon, plug flow, complete mix
	Computer system	Required for system monitoring & operations
	Biogas flare	Required for safety and reduce GHG emissions (i.e., methane)
	Effluent storage	Size varies with volume and use
	Analytical equipment[2]	pH meter, drying oven, VFA titration, spectrophotometer (COD), thermometer, gas analyzer, etc.
Biogas Utilization[2]	Biogas cleaning and conditioning	H_2S removal, CO_2 separation
	Heat generation	Boiler, heat exchanger
	Electricity generation	Use on farm or connect to grid
	Methane compression	Distribute to pipeline, compress (CNG) for auto fuel
Effluent Utilization[2]	Land application	Tanker, injection
	Solid liquid separation	Screw press, screens, centrifuge
	Effluent/liquid transportation	Tanker

[1] May be required if additional feedstocks are used. [2] Third party, or optional depending on system.

What are the Benefits and Limitations of AD?

Although AD has the potential to generate energy from manure and to reduce odors, other factors need to be considered for each farm to determine if it is a viable system. Table 5 provides a summary of the benefits and limitations of factors that need to be considered.

Table 5. Benefits and limitations of AD systems

CRITERIA	BENEFITS	LIMITATIONS
Feedstocks		
Dairy manure	Consistent feedstock characteristics and volume. Rumen bacteria in manure act as inoculant. Reduces odor. Nutrients remain in effluent for use on cropland.	Recommend > 500 head to be economical.[a] Relatively low biogas yield (Table 2)
Swine manure	Consistent feedstock characteristics and volume. Reduces odor. Nutrients remain in effluent for use on cropland.	Typically > 2,000 head to be economical.[a] Relatively low biogas yield (Table 2)
Poultry litter	Technically viable if diluted to <6% total solids.[b] Reduces odor.	Low pH, ammonia toxicity, need bacteria adapted to high NH_4 levels, need for digester designed specifically for poultry litter.[b]
Food wastes	Increased biogas yield. Income from tipping fees possible.	Variations in feedstock characteristics and volume may decrease stability of system. Transportation may be an issue.
System and operations		
Footprint of digester	Relatively small. Must consider options for effluent storage.	Distance from manure source or storage.
Pretreatment of feedstocks	Not required for manure.	Grinding and mixing may be needed if other feedstocks are used.
Energy required	Electricity generated from biogas can be used for system operations. Heat required for digestion may be generated by burning biogas (boiler) or capturing waste heat from electricity generation.	Energy needed to maintain mesophilic (95-105^{o}F) or thermophilic (120-140^{o}F) anaerobic digestion. Heat generated/ captured may be wasted during summer.
Time required	May be able to utilize existing labor pool.	Ranges from 2-8 hours/day, depending on feedstock deliveries and preparation (e.g., sand removal, grinding), effluent management, routine maintenance, and system downtime.
System reliability	Overall, a known and tested technology, but reliability may vary with different companies/systems. Covered lagoon and plug flow have few, if any, moving parts within the digester.	Variation in feedstock feeding rate or imbalance in nutrients may cause system crash, requiring at least partial clean out and time for restart.
Operator training	Training in operations and fundamental principles reduces system failure or crash.	Required.
Biogas uses		
Heating	Usually used to heat water (boiler) which can be used to maintain digester temperature or heat buildings.	Must have use for heat, even in the summer.

Electricity	Can reduce on-farm electricity costs. May generate income from sale to electrical grid.	High cost for generation system. If not used on-farm, the price for selling to the electric company is usually low, thus not economical.
CNG for vehicle fuel or pipeline gas	May offset vehicle and farm equipment fuel costs. May generate an income from sale to pipeline.	Biogas must be cleaned and compressed, which is an added cost. Vehicle conversion and delivery system are added costs. Natural gas prices are highly variable.
Effluent		
Volume	None	No reduction.
Moisture content	None	No reduction.
Odor	Reduced odor compared to raw manure.	May have some odor, especially if not completely digested.
P content	More plant available form.	Does not reduce amount of P.
N content	More plant available form.	Does not reduce amount of N.
Additional processing	None if land base for nutrients is available and/or transport economically feasible.	Remove N and/or P may be required. Added costs for separator and/or flocculants.
Environmental impacts		
Odor control	Reduces odor as the digester is totally contained.	Odors may exist where manure and other feedstocks are handled before feeding into reactor.
Pathogen reduction	High temperatures can reduce the number of pathogens.	All pathogens may not be destroyed and there may be re-growth in effluent.
Weed seed reduction	Mesophilic and thermophilic systems can destroy weed seeds.	Some seeds may survive.
Economics		
Capital costs	EQIP cost share or grant funding may be available.	High capital costs, typically >$1,500 per cow if herd size 500-2,000 cows. [c]
Operating costs	Can utilize heat to maintain digester temperature by using biogas to heat water or capturing heat during electrical generation.	Additional labor and maintenance costs.

[a] AgSTAR. http://www.epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf (Accessed 5/22/12)
[b] Singh et al., 2010
[c] Frear and Yorgey, 2011

What is the Income Potential of AD?

The variety of AD systems, feedstocks, and biogas and effluent use makes it difficult to provide a generalized estimate of income. For example, in addition to differences in costs between AD types and manufacturers, site preparation and local construction costs will affect capital costs. The information below provides a guideline for estimating capital costs and an on-farm case study that illustrates the variations in operating costs and revenue.

IMPORTANT: If you are considering anaerobic digestion on your farm, it is critical that a comprehensive feasibility study be conducted to provide a better estimate of the costs and income potential.

Capital costs of digestion system:
The cost of an anaerobic digester varies with the volume of inputs and the type of system used.

Although the total capital cost will increase as the number of cows increase, the capital cost per cow will actually decrease as illustrated in Figure 5. In evaluating the economics of anaerobic digestion systems, the following "big picture" factors should be considered:

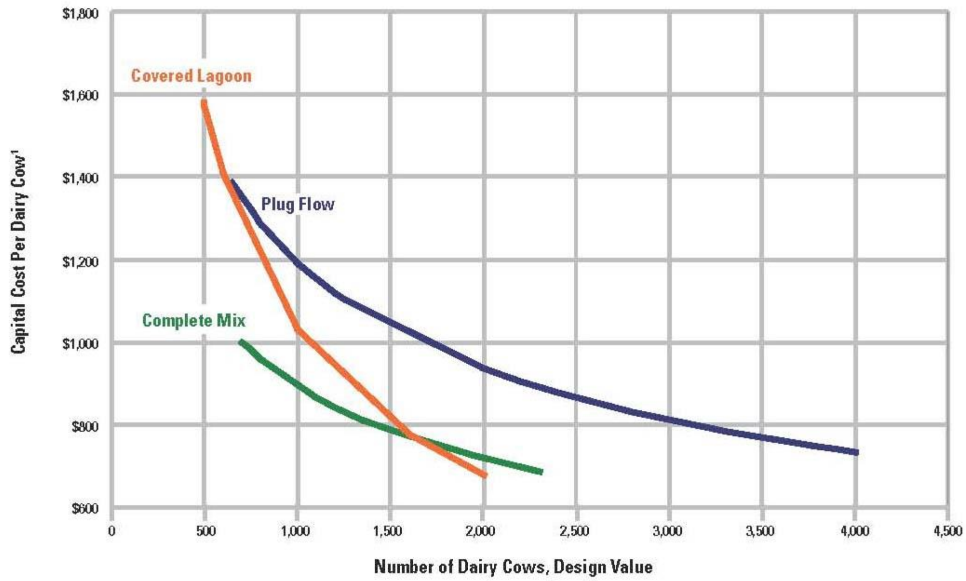

Figure 3. Capital cost per dairy cow for complete mix, plug flow, and covered lagoon AD systems. (AgSTAR, 2010)

- Community/cooperatively owned digester systems may reduce initial capital costs/cow for each farm. However, if relying on transport of liquid manure from a 'scrape' or 'flush' system(s) by truck, there will be increased handling and fuel costs. Most cooperatively owned digester systems that are operating profitably utilize some type of pipeline transport system to move the manure stream to the centrally owned digester.

- Site location and design construction should consider flexibility of receiving other available organic waste streams for co-digestion. Recent economic comparisons of farm based digesters suggest higher annual net returns when co-product markets can be developed with nearby food processors and other food retail service providers. Note that as more alternative energy markets are developed within a region, the demand for organic rich solids/liquids could reduce tipping fee potential thereby reducing income flow. (Bishop et al. 2011) Long term (1-2 year) contractual relationships with the providers of co-substrate products is highly recommended for improved cash flow and more efficient digester performance.

- Continued development of other co-products from the digester effluent that can be marketed efficiently off the farm or can offset on farm costs will be important to assist the digester's economic sustainability. Potential renewable energy credits, solids used for bedding free stalls or retail soil amendment products are examples of value-added products which can improve the economic return on investment from a digester.

<u>Operating costs and revenue streams</u>:
Anaerobic digester operating costs may not differ significantly from other manure management practices; however, revenues, including offset costs such as electricity or heat, and expenses need to be evaluated for each facility. Revenues will vary depending on how the biogas and digestate are used. Biogas used for heat or electricity may be sold directly to utilities or used on-farm and thus offset operating costs. Similarly, digestate can be land applied, offsetting fertilizer costs, and/or the solids can be separated and used for bedding, offsetting that cost.

Table 6 provides an example of the typical anaerobic digester operating costs and revenues for one year. The modified plug-flow digester was constructed in Lynden, Washington in 2004. The digester was sized to accept about 4,414 cu. ft./day of feedstocks, which is equal to 3½ 1,000-bushel semi-trucks, and capital costs were $1,136,364. Feedstocks were manure from 500 dairy cows and food wastes, including salmon carcasses, cheese whey, and inedible eggs.

Table 6. Revenues and operating costs for AD with manure and food wastes. (Bishop et al., 2010)

Source	($/year)
Revenues	
Electricity sales	97,088
Tax credit	38,835
Avoided bedding costs	18,000
Tipping fees	111,767
High value fiber	6,319
Carbon credit	14,527
Total revenue	**286,536**
Operating Costs	
Manure delivery	32,778
Building repairs	3,500
Engine repairs	11,569
Equipment repairs	29,000
Oil	24,991
Utilities	6,000
Legal fees	751
Other professional services	8,011
Miscellaneous	4,297
Total operating expenses	**120,859**
Income above operating costs	***165,641***

It should be noted that legal costs may be significantly higher in the first year if a power purchase agreement is pursued with a local utility. The carbon credit revenue was based on prices set in 2008; however, as the U.S. has no policies to limit CO_2 emissions, carbon credits currently have minimal or no value. Additional revenues may be realized from other sources, such as waste heat used on-farm or sale/use of biogas as a vehicle fuel, but are not included as there was not enough data available (Bishop et al., 2010). A complete description of the costs and revenues for this analysis as well assumptions made can be found online at: http://csanr.wsu.edu/publications/researchreports/CFF%20Report/CSANR2010-001.Ch04.pdf (accessed 5/23/12).

How can Revenues be increased?

For on-farm digesters, combining food scraps from food processors, grocers, or restaurants with manures can increase revenue in two ways. First, the food waste usually has a higher energy potential so more biogas will be produced. In addition, as the food scraps are considered waste that requires disposal, tipping fees can be charged.

For most states, including Ohio, electric companies do not pay a premium for renewable energy, thus selling to the grid does not usually increase income. However, if all of the electricity can be used on-farm, there is the potential to significantly reduce the electrical expense for that farm.

Additional Resources

Manure to Energy through Anaerobic Digestion, OSU Extension Fact Sheet: http://ohioline.osu.edu/aex-fact/pdf/AEX-653.1-11.pdf

US EPA AgSTAR, an educational and outreach program that promotes the recovery and use of methane from animal manures: http://www.epa.gov/agstar

Biogas potential laboratory analysis, Michigan State University: http://researchgroups.msu.edu/adrec/publications/2012-laboratory-fees

Purification Technologies for Biogas: http://csanr.wsu.edu/publications/researchreports/CFF%20Report/CSANR2010-001.Ch09.pdf

Case studies from New York dairies: http://www.manuremanagement.cornell.edu/Pages/Topics/Anaerobic_Digestion/AD-

Case_Studies.html.

Lessons learned from New York anaerobic digesters on dairies:
http://www.manuremanagement.cornell.edu/Pages/Topics/Anaerobic_Digestion/AD-Lessons_Learned.html

Acknowledgement

This project was funded by the USDA-NRCS Conservation Innovation Grant program with additional financial support from the Ohio Soybean Council. The authors would like thank to thank Dr. Caixia Wan, Mississippi State University, for reading through this document and providing useful suggestions.

Disclaimer

Any specific company or process mentioned in these documents is for informational purposes only and should not be considered an endorsement.

References:

AgTown. Personal conversation with owner (NAME) during a visit to the facility on November 2, 2011.

AgSTAR. 2010. Anaerobic Digestion Capital Costs for Dairy Farms. Online at http://www.epa.gov/agstar/documents/digester_cost_fs.pdf Accessed 5/22/2012.

AgSTAR. 2012. Anaerobic Digester Database. Online at http://www.epa.gov/agstar/projects/index.html Accessed 4/16/2013.

Aldrich, B.S. 2005. Anaerobic Digestion of Dairy Manure: Implications for Nutrient Management Planning. Presented at the North East Branch of the American Society of Agronomy Annual Meeting, July 11-13, 2005, Storrs, CT. (http://www.manuremanagement.cornell.edu/Pages/General_Docs/Papers/Aldrich_AD_Dairy_Manure_Implications_for_NM_Planning_2005.pdf Accessed 4/25/2012)

Bishop, C., C Frear, R. Shumway, S. Chen. 2010. Chapter 4: Economic Evaluation of Commercial Dairy Anaerobic Digester. Climate Friendly Farming Project. Washington State University, Center for Sustaining Agriculture & Natural Resources, Research Report 2010-001. Online at http://csanr.wsu.edu/publications/researchreports/CFF%20Report/CSANR2010-001.Ch04.pdf Accessed 5/23/12.

Burke, D.A. 2001. Dairy Waste Anaerobic Digestion Handbook. Environmental Energy Company, Olympia, WA. (http://www.mrec.org/pubs/Dairy%20Waste%20Handbook.pdf Accessed 4/23/2012)

Effenberger, Matthias. Biogas Production and Utilization in Germany – Status and Outlook. (http://www.docstoc.com/docs/46681067/Biogas-Production-and-Utilization-in-Germany---Status-and-Outlook Accessed 12/12/11)

Favoir, L., D. Kirk. 2011. Statistical Verification of a Biochemical Methane Potential Test. Presented at the ASABE Conference, Paper No. 1110918. Louisville, KY, August 7-10, 2011. (http://researchgroups.msu.edu/adrec/publications/statistical-verification-biochemical-methane-potential-test Accessed 4/23/2012)

Fiesinger, T., B.D. Roloson, N.R. Scott, K. Bothi, K. Saikkonen, S. Zicari. Biogas Processing Final Report. Prepared for the NY State Energy Research and Development Authority, Agreement No. 7250. (http://www.manuremanagement.cornell.edu/Pages/Topics/General_Docs/Reports/NYSERDA_final_report_Biogas_Processing.pdf Accessed 4/30/2012)

Furrer, B. 2012. Experiences from IN: Plug Flow Digester and Goals to Improve Nutrient Management and Water Quality. Presented at the Manure Technology Workshop, Wooster, OH, March 20, 2012. (http://www.oardc.ohio-state.edu/ocamm/images/MTW2012_Furrer.pdf Accessed 4/30/2012)

Hamilton, D., D. Ciolkosz, J. Martin. 2012. Processing Biomass into Biogas. Factsheet BAE-1747, Oklahoma State University. (http://www.extension.org/pages/30313/processing-biomass-into-biogas#pH Accessed 4/23/2012)

James, R., ed. 2006. Bulletin 604: COMPLERE. 2006. Ohio Livestock Manure Management Guide. Bulletin 604, Ohio State University Extension. (http://ohioline.osu.edu/b604/index.html Accessed 5/25/12)

Katers, John. 2011. Operational Schedules, Data Collection, and Integration. Presented at the WI Anaerobic Digester Operator Training Program, Fon du Loc, Wisconsin, April 13, 2011.

Keener, H.M. 2010. Optimizing Mixing Ratios. From the Ohio Compost Operator Education Course. (http://www.oardc.ohio-state.edu/ocamm/t01_pageview2/Workshops_and_Conferences.htm . Accessed 5/9/12)

Labatut, R.A., L.T. Angenent, N.R. Scott. 2010. Biochemical methane potential and biodegradability of complex organic substrates. Bioresource Technology 102 (2011) 2255-2264.

McDonald, N. 2012. Renewable Energy from Agriculture. Presented at the Manure Technology Workshop, Wooster, OH, March 20, 2012. (http://www.oardc.ohio-state.edu/ocamm/images/MTW2012_McDonald.pdf Accessed 4/30/2012)

Persson, M. 2007. Biogas upgrading and utilization as vehicle fuel. Presented at the European Biogas Workshop: The future of Biogas in Europe III. June 14, 2007 (http://www.ramiran.net/doc07/Biogas%20III/Margareta_Persson.pdf Accessed April 30, 2012)

Reis, A. and R. Engel. 2003. Feasiblity study on implementing anaerobic digestion technology on Humboldt County Dairy Farms. Report issued to the Humboldt County Economic Development Office by the Schatz Energy Research Center, Humboldt State University. (http://www.docstoc.com/docs/37124568/FEASIBILITY-STUDY-ON-IMPLEMENTING-ANAEROBIC-DIGESTION Accessed May 13, 2013)

Singh, K., K.Lee, J.Worley, L.M.Risse, K.C. Das. 2010. Anaerobic Digestion of Poultry Litter: A Review. Applied Engineering in Agriculture, ASABE, Vol. 26(4): 677-688.

Vandenack, T. 2013. Offal will help fuel Middlebury duck farm. The Elkhart Truth (http://www.elkharttruth.com/article/20120817/NEWS01/708179993 Accessed May 13, 2013)