Colorado State University

NRCS
Natural
Resources
Conservation
Service

Guide for Assessing Feasibility of On-Farm AD at Cattle Operations in Colorado

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1. Advantages of Anaerobic Digestion

Anaerobic Digestion (AD) offers a proven, time tested process for managing agricultural residues. Hundreds of case studies have shown that properly managed AD projects which are integrated into animal waste management system have proven to be viable solutions [1]. Benefits of AD include providing a source of renewable energy, reducing greenhouse gas emissions, decreasing odor, improvement of non-point source pollution concerns, and production of end products (liquid and solid) that can be land applied. In addition, energy generation from AD has the potential to decrease operational costs, or even provide revenue providing producers with the ability to respond to ever increasing regulations and public pressure. Today there are more than 150 electrical generating AD projects operating in the United States with an expected exponential growth curve [2]. With the recent rise of renewable energy initiatives culminating in a push to replace fossil fuels, AD offers a great potential as a source for consistent electricity and heat.

2. Using this Guidance Document

This document outlines standard practices for existing and potential AD projects for processing wastes from dairy and feedlot farms in Colorado. Every farm and every situation is different, and the guidance provided here will by no means apply to every farm. Thus, the purpose of this document is to provide widely applicable guidance based on commonalities found among animal feeding operations in the state of Colorado. The intention is to empower producers through the decision making process by providing them with knowledge on technical and economic feasibility of AD. Of note is that this document was developed to support the web based On-Farm Anaerobic Digestion Decision Tool (OFADT; http://erams.colostate.edu/AD_feasibility) and information provided in this document supplements information provided on the website and helps with interpretation of results provided by the web based tool. In addition, this guidance document serves as a more thorough review of on-farm AD in Colorado than provided within the web based tool and can be utilized to obtain general information on AD. The guidance provided herein is by no means exhaustive and it is important to note that AD projects require design and approval by a licensed consulting firm before implementation can begin. This document is organized in steps, starting with the first step one should take if interested in AD and following on with the appropriate subsequent steps:

1.) Understand the basics of AD

2.) Understand and apply technical considerations for an onsite AD system

3.) Estimate the Energy potential at your site

4.) Determine the Economic Feasibility for an AD system

5.) Select the Appropriate AD Technology

6.) Select AD Technology Provider

7.) Understand the operations and maintenance required

It is recommended that each of the steps be reviewed in detail before moving to the next step in the planning stages. It is stressed throughout this document that although AD is proven and a relatively simple technology, there are situations where it is not a good fit. Feasibility must be very carefully considered. In addition, the importance of health and safety should not be underestimated and management must always consider safety as important as all other issues. Installation of an AD system will require a high level of maintenance and management. Therefore, the process and its requirements should be well understood prior to AD installation.

3. Step 1: Understanding AD

AD is the process by which organic materials in an enclosed vessel are broken down by microorganisms, in the absence of oxygen. The biogas produced via AD consists primarily of methane, carbon dioxide and hydrogen sulfide. AD systems are also often referred to as "biogas systems or biomass systems”. Depending on the system design, biogas can be combusted in a generator producing electricity and heat (Figure 1). This is called a co-generation system or combined heat and power (CHP). Other options for use of biogas include burning in a boiler or furnace, or purification for supply to natural gas lines (Figure 1). The AD process produces a liquid effluent called digestate that contains water, all the nutrients and approximately half of the carbon from the incoming materials.

Notable advantages of AD include:

- Reduction of odor and pathogens in manure
- Reduction of greenhouse gas emissions
- Production of renewable energy
- Potential to process food byproducts and other waste products
- Use of end product as fertilizer

Because AD is a closed system, emissions of various constituents including methane and ammonia, can be reduced from that observed with conventional waste management processes. With regulation of greenhouse gases and ammonia on the horizon, AD will likely be used as a mitigation strategy for reducing these emissions.

AD requires that feed material be less than 17% solids by weight. Typically, manure collected on a dry lot in Colorado has much higher solids content than 17%. Microorganisms that convert organic materials into methane are very sensitive, requiring a pH near 7 and temperatures around 95^{o}F (or 35^{o}C) for optimal performance.

Configurations of AD systems vary greatly from farm to farm, but generally include manure collection, pre-treatment processing, biogas generation, biogas purification (H_2S removal), biogas utilization (electricity generation or gas use) and byproduct disposal (Figure 1).

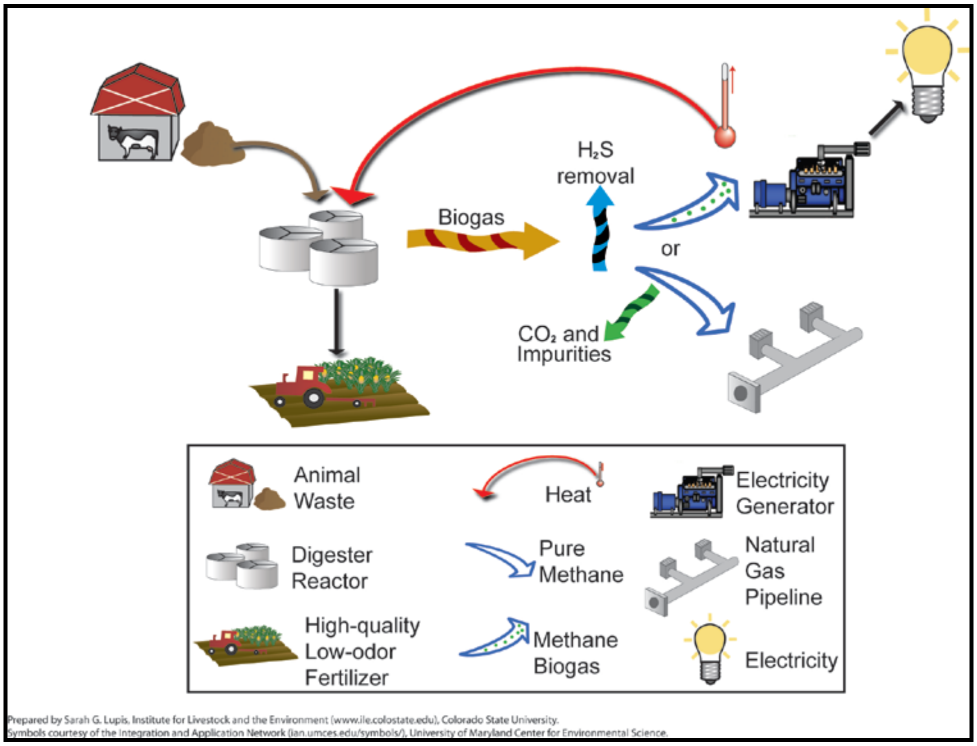

Figure 1: AD System Configuration

Biogas generated by AD typically contains between 60-70% methane (CH_4). The other primary constituent is carbon dioxide (CO_2) and small amounts of hydrogen sulfide, ammonia, water and trace organics (hydrocarbons) are also present.

3.1 Scale of AD Systems

There are two distinct scales in which AD operates including farm and centralized. The main difference between the two scales is that farm scale involves one farm, while the centralized scale involves collection of waste from multiple locations.

Farm Scale

Onsite AD systems for the "farm scale" are designed to fit the needs of a single entity or producer. The farm scale is defined by having personal ownership of the AD system. Farm scale AD systems typically only accept the waste produced for that site and offset the owner's electricity use or can add electricity to the grid when supplemental energy is produced by the system. Farm scale systems are smaller, more commonly implemented and also tend to be lower cost than centralized systems[17]. Farm scale AD systems use lower cost components and often involve a lower level of control or complexity, thus decreasing overall costs. Some farm-scale systems can accept off-farm input materials such as commercial food processing byproducts or slaughter house effluent, however this can lead to regulation difficulties and should be thoroughly considered before pursuing. Farm scale AD systems are economically viable when there are on-site uses for the biogas such as heat or power for the farm or use to compress refrigerant lines [17].

Centralized System Scale

Centralized AD systems are predominantly found throughout Europe. Material from multiple farms, food processing plants and industrial waste streams is hauled to a centralized facility through a high biosecurity hauling process. Other materials, such as source-separated organic municipal waste, are often added to boost gas production. Often the digestate is immediately transferred to remote field storage to allow for easier handling for land application. In many instances, heat from the centralized AD system is used nearby by either a commercial facility or for heating residences.

3.2 Uses for Biogas Generated from AD

The use of biogas and natural gas is rapidly growing. With ever decreasing sources of oil and the need for a more independent energy plan, the United States is adopting practices which increase the use of natural gas. Increasing infrastructure for the use of natural gas improves the capacity to make use of biogas generated through AD. Some of the potential uses of biogas include conversion to electricity, compression to natural gas and compression to liquid methane.

Conversion to Electricity

Biogas can be directly supplied to a generator and converted into electricity (Figure 2). Electricity can then be used on-site or excess electricity can be sold to a utility. Biogas generated from AD of animal waste contains hydrogen sulfide, which is corrosive to generator parts. Successful generator operation depends on removal of hydrogen sulfide from biogas which can be done by passing biogas through iron filings prior to introduction to the generator.

Figure 2: A generator for conversion of biogas to electricity at a hog farm (photo by Catherine Keske, Colorado State University

Purification to Compressed Natural Gas

Biogas can be purified and compressed to be injected into natural gas lines (Figure 3). This requires an extensive cleanup of the biogas resulting in gas containing 93-99% methane. Carbon dioxide, water, and hydrogen sulfide must be removed from the biogas. Methane can be directly injected into natural gas pipelines (with quality control) or transported to an injection facility. Vehicles can be retrofitted to use compressed natural gas.

Figure 3: Biogas Purification Station (*Source: Gas Technology Institute*)

Conversion of Compressed Natural Gas to Liquid Natural Gas

After biogas is purified to compressed natural gas, it can be converted to liquid natural gas rather than injected into natural gas pipelines. Compressed natural gas is cooled to -260^{o}F and stored as a cryogenic liquid in insulated storage vessels at 50-150 psi. Liquid natural gas has a lower storage volume than compressed natural gas, so natural gas is often liquefied when it will be transported long distances.

3.3 *Operational Temperature for AD*

Deciphering which temperature to operate an AD system can be difficult, since operation at varying temperatures has multiple benefits and considerations. The appropriate temperature setting depends on the type of AD system, the purpose, and overall goals of the project. Given the wide variety of parameters, it is best to first consult with a professional before making a final decision. The possible temperatures to run an AD system are psychrophilic, mesophilic and thermophilic.

Psychrophilic (15 ^{o}C or 60 ^{o}F)

In cases where it is desired to keep AD systems simple, they may be operated without heating. In cold climates, an unheated AD system may operate at temperatures as low as 15^{o}C (60^{o}F). These AD systems operate with very long retention times ranging from 50-150 days. Such systems are stable, easy to manage and require very little energy inputs, but produce very little biogas and in colder climates are susceptible to bacteria upsets. They require large volume and would require additional processes to achieve pathogen removal if the end product is to be land applied. These systems are most desirable when gas production is a secondary concern and the primary purpose of the system is to achieve odor reduction, greenhouse gas emission reduction, or organic and solids removal at low cost.

Mesophilic (35 ^{o}C or 100 ^{o}F)

Mesophilic require hydraulic retention times of at least 20–30 days generally required. These systems are reported to be more robust when considering bacterial upsets in comparison to thermophilic systems and are the most common application for on-farm AD. Mesophilic AD systems require larger tank volumes than thermophilic, produce less biogas and in cases where higher quality effluent is desired, may need a secondary treatment step. Mesophilic systems in general can handle a more varied or inconsistent co-digestion sources than thermophilic AD systems.

Thermophilic (55 ^{o}C or 130 ^{o}F)

Thermophilic AD operates at the highest temperature of all AD technologies. Microorganisms rapidly break down organic matter and produce large volumes of biogas. The quick breakdown means that the AD system volume can be smaller reducing the hydraulic retention time to 12-20 days. The high temperature lends itself to improved pathogen removal, thus providing a more valuable residual effluent compared to operation under mesophilic or psychrophlic conditions. Heat exchangers can be utilized in thermophilic system for general space heating or as return energy back into the AD system. Greater insulation is necessary to maintain the optimum temperature range. Thermophilic AD systems require high energy input and extensive monitoring. While the energy required to maintain thermophilic conditions can be provided by biogas generated from the AD system, it must be considered that AD heating will be an additional drain on energy produced by the system, potentially leaving less energy for other onsite uses. These systems are very sensitive to nitrogen concentration and pH. Additional monitoring of incoming materials is required and chemical additions may be necessary. It is generally recommended that thermophilic systems not be installed above the 40^{o} longitudinal line unless proper considerations are taken.

4. Step 2: Understand and Apply Technical Considerations for an Onsite AD System

AD is not a good fit for all animal feeding operations. Care should be taken to ensure that AD is feasible at an operation before installation. While typical management practices in the arid west do create challenges for installation of AD technology, there are technologies that can be a good fit. After you have determined that AD may be both technically and economically feasible at your facility, you will need to become informed on types of AD system technologies and which of those may be the best fit at your site. AD technologies include covered lagoons, plug flow, complete mix, upflow sludge blanket, and fixed film reactors. Guidance is required to select appropriate technologies. The OFADT can be utilized to determine feasibility at your site and determine most appropriate technologies for application <http://www.erams.colostate.edu/AD_feasability/ >

4.1 Dry Wastes in the Arid West

In arid climates, collected animal wastes can have very high solids content. Dairies are typically thought to be a good fit for installation of AD technology. However, waste management methods applied at dairies located in the arid west differ from other parts of the United States. As a result of water scarcity, water is not often utilized to flush dairy barns as is done in areas where water is plentiful. Instead, manure is often scraped from concrete floors or dry lots. While dairy waste has a solids content of 10-14% as excreted, solids content has been measured as high as 90% on dry lots in Colorado. For wastes containing more than 17% solids, substantial quantities of water may be required for AD. This can add to the cost of operating the AD system. As an example, at a dairy facility where manure is collected on a dry lot containing 65% solids (typical in Colorado), 12 gallons of water per animal per day would be required to achieve 10% solids (i.e. for a 2000 head dairy, this would be 24,000 gallons per day). Of note is that the OFADT provides estimates for water requirements under different waste management scenarios for different AD technologies (http://www.erams.colostate.edu/AD_feasability/). It must also be considered that when clean water is added to an AD system, it will adsorb nutrients and pathogens and become a nuisance. Dilution of waste with water is most practical when there is an available source of wastewater (domestic or food processing) to utilize.

4.2 High Inorganic Content

When manure is collected from dry lots, the collected waste is often dry with high inorganic content consisting of rocks and soil particles. Rocks and soil particles cause major operational problems for AD systems and must be removed before the waste is processed. This has been one of the most prominent causes for failure of on-farm AD and thus is very important to consider. Sand in bedding can also be a problem for AD if it ends up in the waste material supplied to the system. Removal of rocks, soil, and sand is possible, but typically involves addition of water to the waste and subsequent settling of the particles. Such processes add complexity, capital cost, and additional maintenance for an AD system.

4.3 Biogas Handling

Methane in a concentration of 6% to 15% with air is an explosive mixture. Since it is lighter than air, it will collect under rooftops and other enclosed areas. It is relatively odorless, and detection may be difficult. Extreme caution and special safety features are necessary in the AD system design and storage tank, especially if the gas is compressed.

4.4 Corrosive Biogas

The biogas generated from AD contains highly corrosive hydrogen sulfide. Sulfides must be removed prior to supplying the biogas to a generator. A simple, low cost method for removal of sulfides from biogas is passage through iron particles. Sulfides attach to the solid surfaces and are removed from the gas. The iron particles must be replaced every six to twelve months.

4.5 Co-Digestion

Combining animal feeding operation wastes with wastewater generated onsite or by nearby facilities such as food processing plants or municipal wastewater treatment plants can be beneficial by both increasing water content and increasing methane production capacity. This is typically referred to as co-digestion and is gaining popularity. The ability to combine manure with other wastes must be carefully evaluated prior to AD system installation/operation. In particular, it is recommended that waste streams are not varied seasonally or daily, but rather that a consistent waste is supplied to the AD system at all times. The microorganisms in an AD system are very sensitive and when the waste source is changed, it can take a long time (up to three months) for them to adjust and begin producing methane. Therefore, when the waste stream is changed on a daily or seasonal basis, the organisms do not have enough time to recover. If you are considering adding a waste in addition to manure into the AD system, you need to make sure that the waste will be available on a daily basis throughout the year to add into your system. Care should be taken to address the high content of fats oil and grease in paunch. While these components can be converted to methane biogas, they also can result in buildup if not managed appropriately.

Some of the most common sources for co-digestion are from the following sectors:

- Agricultural Food Crop Wastes- examples include sugar beet waste and corn silage. These high in sugar materials are excellent for adding to an AD system, but pre-processing requirements and solids content should be carefully considered.
- Food Processing Wastes – Many food processing facilities generate wastes which are highly digestible and contribute to biogas production. Examples include sugar manufacturing residues, dog food processing effluent, whey (a byproduct of milk, cheese and yogurt production) and paunch (a byproduct of slaughter houses). Such wastes also can yield high revenues from tipping fees (refer to Section 6.1 “Economic Feasibility” for more information).

- Industrial by-products – Waste streams from industries, such as ethanol and biodiesel production are common candidates for AD.
- Municipal Wastewater - The wastewater from residential or commercial facilities is also a possible waste stream for an AD system. Biosolids from nearby municipal wastewater treatment plants can also be added to an on-farm AD system.

4.6 Handling of End Products

AD effluent must be handled properly. One common misconception about AD is it will reduce the quantity of manure and the amount of nutrients that remain for utilization or disposal. Sometimes the volume of material handled from an AD system increases because of required dilution water for satisfactory pumping or AD system operation. It is important to understand that roughly 4% - 30% of the total solids are converted to biogas[3]. This means that a farm loading 1000 lb. per day into an AD system can expect to have anywhere from 300 to 960 lb. of material to store and ultimately handle.

AD effluent is slurry, containing 1-15% solids, depending on the solids content of the waste which is input to the system. The effluent leaves the AD system as a stable, nutrient rich, weed seed free, reduced or pathogen free and nearly odorless product [3].The processed material containing solids can be applied by a honey wagon, or solids can be separated for composting and subsequent land application by a manure spreader. The weight of the processed slurry material containing liquid and solids (5-15% solids) may be too expensive to transport large distances. Solids separation in combination with composting can result in a lower weight product which can be transported at lower costs compared to slurry for land application. Utilizing the nutrient rich liquid component for irrigation is referred to as fertigation or chemigation and is regulated in most states. When fertigation systems are connected to a freshwater source, appropriate measures must be taken to avoid contamination of the freshwater source such as inclusion of a backflow preventer and shutoff valve. Fertigation systems must adhere to state and local regulations. If land application is not an option, you will need to find another method for AD effluent reuse or disposal.

4.7 Summary of Criteria for AD Technical Feasibility

A technical feasibility study will be needed in order to completely asses the complexity and cost for even a small on-farm AD project. You can use the OFADT to conduct a preliminary feasibility assessment for AD installation (http://www.erams.colostate.edu/AD_feasability/). There are several criteria which can be applied to begin thinking critically about an AD project and whether the opportunity presents itself as reasonable. There are several factors which will typically determine feasibility:

- *Manure is collected from concrete by scraping or flushing:* Manure collection methods that are most feasible for AD application are collection from concrete by scraping or flushing. If manure is collected from dry lots, a reliable source of wastewater is present either from the lagoon or other outside source must be supplied. See the discussion on Dry Waste in the Arid West (Section 4.1)

- *If co-digestion is considered, a reliable source of wastewater exists:* See discussion on co-digestion (Section 4.5).

- *Sustainable outlet for effluent*: See discussion on Handling of End-products (Section 4.6).

- *Uses of biogas for either heat and/or electricity:* Determine what current uses your farm may have for electricity or heat production. Identify how steady the sources are, if they require the same energy during the day as night. Having consistent outlets for biogas production will minimize flaring and increase overall profitability. Information on estimating energy generation potential is provided in Section 5. If AD will be applied to generate heat or electricity, consider hiring a specialist to conduct an energy audit.

- *Size and location of plant:* AD systems can require substantial area and need to be located in an area that is not too far from manure production to minimize transport of manure. Take advantage of slopes, where gravity could be used to assist in the flow of manure. Additionally, if you are considering expanding current operations, look for areas where the AD system can be installed without impacting future growth. This is critical as installation of AD technology often allows for a greater cow density.

- *Staffing concerns including additional training and proper work loading:* Ensuring that the necessary staff and personnel are on hand is critical for when operational problems occur. The staff must be high skill level and be trained on the AD system in place. Operation of an AD system can require an additional 1-2 full time employees, depending on the size of the facility and complexity of the system. Generator downtimes can substantially impact economic viability of a project. Timely repairs are critical when you are reliant for energy generated either on-farm or for selling off-site. Take into consideration that larger AD systems may require a full time staff member to monitor and perform maintenance for the system.

5. Step 3: Estimating Energy Generation Potential

Biogas generated by AD typically contains between 60-70% methane. The predicted energy production for different types of animal wastes is shown in Table 1. To put the energy value of animal waste into perspective, a well-insulated, three-bedroom home takes about 32 kilowatt hours (kWh), or 110,000 BTU, per day for heating during cold weather. If 50% of the biogas goes back into maintaining the necessary temperature of the AD system, it would take the manure from approximately 21 cows to produce enough biogas to heat an average home during winter months. This assumes an efficiency of 65% for a furnace using biogas.

Table 1: Energy value for various animal wastes based on a 1000lb animal

	Volatile Solids (lb/day/1,000 lb)	Methane Production (ft^3/animal/day)	Energy Value (kWh/animal/day)
Dairy cattle	8	17	4.7
Beef cattle	6	13	3.5
Swine	5	18	5.0

The steps to estimate energy generation from animal waste at your facility and associated cost savings are outlined below.

1. Calculate the energy production per day (EPD) in kWh/day

$$\text{EPD}\left(\frac{\text{kWh}}{\text{da}}\right) = \text{Number of animals} \times \frac{\text{kWh}}{\text{animal}\cdot\text{day}} \times \frac{\text{Typical weight per animal (lb)}}{1000}$$

Note: kWh/ animal/day is the energy value available in the third column of Table 1.

2. Estimate savings associated with use of biogas for on-site heating.

   a. You will first need to determine the available energy after biogas is utilized for heating the AD system (AEB). A conservative estimate is that 50% of the produced biogas will be used to meet the heating requirement:

   $$\text{AEB (kWh/day)} = \text{EPD} \times 0.50$$

   b. Determine your daily on-site natural gas demand (ONGD). ONGD can be estimated by looking at your utility bill over the last year. Most utilities can provide one year of records upon request.

   c. If AEB is less than ONGD, the following equation can be used to estimate cost savings (assuming 65% efficiency for use of biogas as a fuel):

   $$\text{Cost Savings (\$/day)} = \text{AEB} \times 0.65\ \text{Efficiency} \times \text{Cost of Energy}$$

Note: The cost of energy should be in units of dollars per kWh. Gas bills often report energy in BTU. There are 3412 BTU in 1 kWh.

If the AEB is in excess of the on-site natural gas demand, then ONGD should be used in place of AEB:

$$\text{Cost Savings (\$/day)} = \text{ONGD} \times 0.65\ \text{Efficiency} \times \text{Cost of Energy}$$

Note: The cost of energy should be in units of dollars per kWh

3. If you are considering a generator for on-site use of electricity and/or selling the electricity to a utility, you will need to determine your daily on-site electricity demand (OED). OED can be estimated by looking at your utility bill over the last year. Most utilities can provide one year of records upon request. Energy in excess of the OED can be sold to the utility if the local utility is amenable to purchasing the electricity. You will need to research this possibility if you are interested in selling generated energy to the utility.

    d. Determine electricity available (EA) from the generator kWh/day (assuming a typical efficiency of 35% for use of biogas in a generator):

    $$\text{EA (kWh/day)} = \text{EPD} \times 0.35\ \text{Efficiency}$$

    e. Estimate savings from on-site use of energy. If the EA is lower than OED, than only EA, rather than the total OED, should be used for calculation of cost savings.

    $$\text{Cost Savings (\$/day)} = \text{OED} \times \text{Cost of Energy}$$

    Note: The cost of energy should be in units of dollars per kWh

    f. If the EA exceeds OED, then some energy may be sold to the local utility. You must determine whether the utility is willing to buy the energy and also the price they are willing to pay (P) in dollars per kWh. P is the wholesale rate of electricity, not the retail you are charged from the utility to purchase electricity. In Colorado, P is often 0.01-0.03 dollars per kWh (1-3 cents per kWh), but can be as high as 0.10 dollars per kWh (10 cents per kWh) in other states. More information on energy buy-back is included in Section 6. After you have determined P, you can estimate revenue from electricity sales (RE):

    $$\text{RE (\$/day)} = (\text{EA} - \text{OED}) \times \text{P}$$

6. Step 4: Determining Economic Feasibility for an AD System

If AD appears to be technically feasible and you have estimated the energy generation potential, it is important to consider whether the project would be economically feasible. You can use the OFADT to find more information on and evaluate the economic feasibility of AD at your facility <http://www.erams.colostate.edu/AD_feasability/ >

On-farm AD units typically cost at least $1.5 million when there are more than 1500 animals (including fees for consulting and design). Some of these costs can be offset by federal or state grants, or loans. Costs could also increase, depending upon the size of the unit, design, and features. Annual operation and maintenance costs (like maintenance, repairs, parts, labor, and insurance), must also be recovered. Of note is that installation of an AD system may require hiring 1 to 2 additional employees for routine maintenance, depending on the size of the operation.

You will need to determine whether AD costs can be offset by generating revenues or reducing expenditures on energy over the life of the AD system. The typical life of a system is estimated to be 10-20 years. However, a system can last for up to 30 years when properly maintained. Most AD systems are semi-customized by the technology provider, so the capital outlay and operating/maintenance costs will vary. The U.S. Department of Agriculture AgSTAR website provides a good overview of expected costs and revenues: <http://www.epa.gov/agstar/index.html>. The website is frequently updated with information about federal and state funding opportunities for AD projects.

Producers should be wary of relying on AD to generate revenues from utility energy buy-back. Some states have "net metering" policies, where small energy generators (like those with an AD system), can provide surplus energy to the utility, in order to offset their energy consumption. For example, Colorado recently implemented a net metering policy in 2009. However, the price per kWh received for net metering is relatively low. While this varies according to utility company, operators should expect a buy-back price of approximately $0.02 per kWh. You will need to work with your local utility to develop a net metering or purchase agreement. To increase profitability, producers should focus on reducing operation and maintenance costs, as well as offsetting on-farm energy usage with the AD system.

During the process of selecting a technology provider, you should outline some of the expected costs and revenues over the life of the system. Once a technology provider is contacted, more detailed information can be obtained and if necessary a consultant should compute costs.

6.1 Indicators of Economic Feasibility

Although it is important to actually crunch the numbers, there are five indicators that AD might be economically feasible on-farm. These indicators can help determine whether you should pursue a comprehensive feasibility study for your operation. These criteria have been selected based upon studies conducted in the intermountain west [17], [18] . If an operation meets ***at least two*** of the criteria, a more detailed analysis for you facility is recomended. The indicators are as follows:

1. *Operation meets the definition of a Confined Animal Feeding Operation (CAFO):* Before considering economic feasibility, determine if your operation meets the definition of a CAFO. CAFOs must comply with state and federal laws governing waste management practices. An AD system might complement a CAFO's plan for air emissions, nutrient, or waste management.

2. *There is potential for co-digestion:* In other words a waste stream exists that could be combined with the waste stream of another operation or business (see Section 6.2). When agricultural producers and other industries producing high organic waste products are located nearby, there are typically efficiencies that can improve the economic viability of a project. Feasibility studies have shown that co-digestion projects might be economically viable in the intermountain west [17],[19],[20]. If you or your community has an interest in a co-digestion project, it is suggested that you review reports in the reference section for more information.

3. *Operation receives frequent and/or credible complaints about odor:* AD units can provide a measurable reduction in odor, which can help to improve neighbor relations and mitigate nuisance lawsuits. The financial risk associated with an odor-related nuisance lawsuit can be difficult to estimate because information about damage awards is not readily available. The majority of cases are settled outside of court and insurance companies typically pay a portion of the settlements. Most verdicts and settlements are not publicly reported. A summary of some recent settlements is provided in Table 2, which was originally presented in Keske (2009)[17]. The take-home message of this table is that the awards associated with odor nuisance can be high, and thus can render mitigation of odor by installation of an AD system economically viable.

4. *Operation produces swine or chickens:* Many odor nuisance claims involve swine or poultry operations (Table 2). These operations have also involved high punitive damage awards. The exact cause leading up to these nuisance lawsuits is not clearly established; however, it is likely related to the strength and persistence of odor. This history may encourage swine and poultry producers to consider adoption of AD units as a management practice to reduce the risk of nuisance claims even when odor complaints have not been received. The history of nuisance lawsuits involving swine and poultry operations indicates that even operations located in rural communities with very few neighbors could still be vulnerable to a lawsuit. An anaerobic digester could be used for conflict mitigation

Table 2: Summary of Financial Awards from Agricultural Nuisance Suits

Claims Awarded in Nuisance Suits				
Year	**State**	**Award**	**Plaintiff/Case**	**Operation**
1991	NE	$375,600	Kopecky v. National Farms, Inc.	Swine
1996	KS	$12,100	Settlement—plaintiff/respondent both undisclosed in news article.	Swine
1998	KS	> $15,000	Twietmeyer v. Blocker	Beef feedlot
1999	MO	$5,200,000	Vernon Hanes et al. v. Continental Grain Company	Swine
2001	OH	$19,182,483	Seelke et al. v. Buckeye Egg Farm, LLC and Pohlman	Egg/Poultry
2002	IA	$33,065,000	Blass, McKnight, Henrickson, and Langbein v. Iowa Select Farms	Swine
2004	OH	$50,000,000	Bear et al. v. Buckeye Egg Farm, Anton Pohlman and Croton Farms, LLC	Egg/Poultry
2006	AL	$100,000	Sierra Club, Jones, and Ivey v. Whitaker and Sons LLC	Swine
2006	MO	$4,500,000	Turner v. Premium Standard Farms Inc.; Contigroup Co., Inc.	Swine
2007	IL	$27,000	State of Illinois (Plaintiff). Respondent undisclosed.	Swine

5. *Operation incurs more than $5,000 in average energy expenditures per month:* In the intermountain west, electricity costs are generally lower than the eastern United States. This is primarily due to relatively inexpensive coal and hydroelectric resources that are available for electricity generation. While the environmental damages resulting from burning coal could be factored into future energy policy, the current price per KWh of electricity is low compared to other regions of the country [17],[19]. Low energy costs make it more difficult to justify an AD system investment. This is because operations current energy expenses are relatively lower than in other parts of the country and the value of selling excess energy produced is also lower. In the intermountain west, a good rule of thumb is an average of $5,000 in energy costs to offset costs of installing and maintaining an AD system.

   Direct on-farm use of biogas to supplement natural gas demands is the most cost-effective means for using the energy from the AD system. Avoiding energy costs will yield a higher net economic impact compared to any potential revenues that might be generated from supplying electricity to the grid (Keske, 2009). A generator is required to convert methane gas into electricity, making it more expensive to operate. In addition to the extra capital outlay for a generator, operations will need to plan on maintenance, labor costs, and back-up electricity resources. An operation that strictly uses biogas would likely incur fewer expenses. If your operation incurs at least $5,000 in energy costs per month, it has the potential to offset many of these costs with an AD system and it will be worthwhile to conduct an individualized economic feasibility analysis.

6.2 Other Considerations for Economic Feasibility

The intermountain west presents unique environmental issues that might affect economic feasibility for an AD system. For example, low humidity and scarce water resources result in low water and high solids content in manure. This means that rocks and other inorganic solids could cause AD system maintenance expenses if not managed properly. Likewise, it may be expensive to add water necessary for microbial function. Most AD feasibility studies that are currently available are relevant to the eastern United States, where electricity prices are relatively higher and water resources are more readily available.

An important consideration for economic feasibility of AD is transporting manure to the digester. Whenever possible, take advantage of slopes and gravity feed systems as this will greatly reduce operation and maintenance costs. Pumping for high solids materials is typically done with rotating screw augers. Although these augers have higher capital costs when compared to positive displacement pumps, they will last longer and require less maintenance. Sometimes manure may need to be transported by truck. A general rule of thumb for transportation costs is to try and stay under $1/per ton of manure per mile[4]. This is typically the range at which AD system projects can begin to dip into the red for operational costs. Avoid transporting water as much as possible.

As follows are additional considerations for analysis of economics:

1. Include the cost of water when water must be supplied to the system.
2. Do not count on revenues from greenhouse gas offsets to fund the system. These markets are voluntary in the United States and have shown considerable price volatility and low prices in recent years.
3. Review state guidelines to determine waste transport policies for on- or off-site locations, before calculating potential tipping fees.
4. Account for maintenance and labor costs, in addition to the capital outlay of an electricity generator. You may need to hire 1-2 additional full time personnel to manage the system.
5. Include the costs of energy back-ups, in the event that the system is down for maintenance.
6. Understand state and utility company’s policies about net metering and energy buy-back programs.
7. Be sure to consider all of the costs associated with building, storing and transporting manure. The cost to tie into the grid, for example, can be high depending on the operation’s proximity to the utility infrastructure.
8. Estimate methane generation potential and maintain a realistic perspective of energy costs that might be able to offset.
9. Factor in risk. Prices can vary considerably. Be sure to look at the most likely, and the worst case scenarios.

7. Step 5: Selecting an Appropriate AD Technology

Several technologies are available for AD including; covered lagoons, plug flow, complete mix, upflow sludge blanket, and fixed film reactors. Technology selection is highly dependent on waste solids content (Table 3). Swine waste is generally in the form of a slurry (<15% solids) and thus amenable to conventional AD system technology while cattle waste collected from dry lots can be very high in total solids (TS) content (>50%). Dairy manure collected on concrete (by scraping) generally has a total solids content between 10-17%, while flushed manure can have a TS content less than 3%, but can vary substantially depending on the amount of water used for flushing manure. Use the web based OFADT for additional guidance on technology selection based on current waste management methods <http://www.erams.colostate.edu/AD_feasability/> . Of note is that while plug flow is generally the most applicable technology for Colorado feeding operations due its ability to handle high solids (Table 3), other technologies can be considered if additional wastewater is added (see Section 4.5 Co-Digestion).

Table 3: Recommended Waste Solids Content for AD Technologies

Technology	Recommended Waste Solids Content
Plug Flow	11-17%
Complete Mix	5-10%
Upflow Sludge Blanket	1-5%
Covered Lagoon	<3%
Fixed Film	<1%

7.1 Covered Lagoons

Covered lagoons are one of the lowest capital investment and simplest AD technologies available. AD and subsequent production of methane takes place naturally in lagoons which contain manure wastewater. A synthetic cover, typically plastic or rubber is used to trap and store the biogas. Covered lagoons are difficult to heat and they are only recommended in warm climates where freezing temperatures are rarely observed. Too little methane is generated by covered lagoons during cold winter months in Colorado to justify installation of biogas capture and use equipment.

Figure 4: Image of Covered Lagoon (Photo taken by Catherine Keske at Colorado State University)

Covered Lagoon Advantages:

- Low cost
- Covering of lagoon can quickly mitigate odor concerns
- Advancements in HDPE (high density polyethylene) have increased durability and lowered cost of covers

Covered Lagoon Considerations:

- Retention times are long resulting in a large required area
- Lagoons need to be excavated or cleaned routinely and covers add an additional layer of complexity to this process
- Biogas production is inconsistent since it varies greatly with temperature
- Covered lagoons become increasingly impractical in cold climates
- Little to no economic return on biogas recovery and use

7.2 Plug Flow

Plug flow AD systems are a low tech AD technology for treatment of high solids content waste. Of note is that while plug flow is generally the most applicable technology for Colorado feeding operations due its ability to handle high solids (Table 3), other technologies can be considered if additional wastewater is added (see Section 4.5 Co-Digestion).

Table 3The thick, high solids content waste travels down the AD system in a “plug,” as a continuous mass. Plug flow AD systems can be a good fit with the high solids content waste generated by animal feeding operations in the arid west.

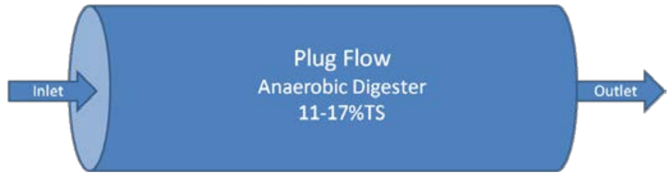

Figure 5: Plug Flow Technology (figure developed by Luke Loetscher at Colorado State University)

Plug Flow Advantages:

- Able to handle high solids content waste (11-17% TS)
- Substantially lower operations and maintenance compared to complete mix AD
- Reliable and tested technology
- Minimal upsets or downtimes
- Low capital costs

Plug Flow Considerations:

- Issues with stratification can lead to decrease in efficiency
- Inconsistent bacterial concentrations cause variability in gas production
- Sensitive to variations in waste input
- Low volatile solids destruction rates

7.3 Complete Mix

Complete mix reactors are large, often cylindrical, tanks which have a mechanism to keep the reactor completely stirred. The stirring mechanism can be injected biogas, or a motorized paddle. Mixing produces an ideal environment for anaerobic microorganisms by spreading the nutrients evenly throughout the reactor, while simultaneously helping to dampen shock loads of toxins which may enter the system since influent is instantaneously diluted through mixing. Complete mix reactors operate best when solids content is between 5-10%. Because solids content of waste produced at most intermountain west cattle feeding operations (open lot and concrete scrape) is higher than 5-10%, complete mix reactors are often not a good fit unless an external source of water or wastewater is readily available. Complete mix reactors are suitable for flush dairies.

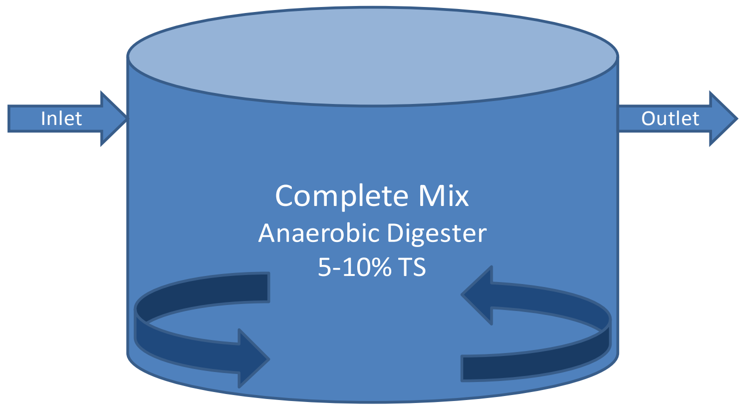

Figure 6: Complete Mix Technology (figure developed by Luke Loetscher at Colorado State University).

Complete Mix Advantages:

- Allows for variability in substrate
- Works over a wide range of solids content
- More consistent and reliable methane production compared to plug flow or covered lagoon

Complete Mix Considerations:

- Requires a large hydraulic retention time (volume), or settling and recycling of solids
- Large energy required for mechanical mixing
- High capital cost compared to other technologies

7.4 Upflow Sludge Blanket

In an upflow sludge blanket AD system, settling of solids is encouraged so that a sludge blanket is formed, maintaining biomass within the system, thus reducing the required holding time. These reactors are highly efficient and have been successfully up-scaled for commercial application. In general, waste generated at intermountain west open lot animal feeding operations is too high in solids for application of an upflow sludge blanket reactor.

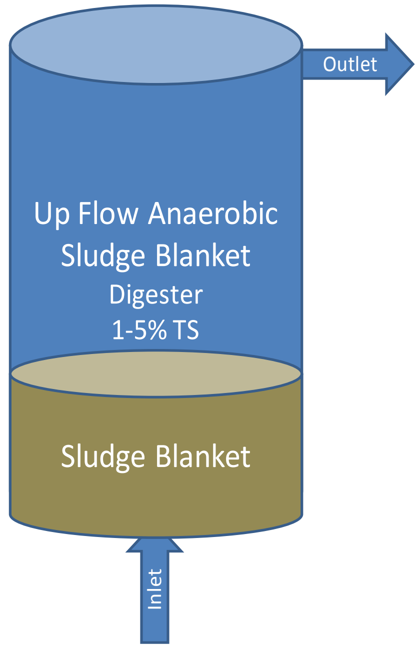

Figure 7: Upflow Anaerobic Sludge Blanket (figure developed by Luke Loetscher at Colorado State University).

Upflow Sludge Blanket Advantages:

- High destruction of volatile solids
- Lower solids output
- Low volume requirement
- High methane and biogas yields

Upflow Sludge Blanket Considerations

- High probability of upsets and downtimes
- Longer start up periods and difficult bacterial recovery

7.5 Fixed Film AD systems

In a fixed film AD system, bacteria colonize a support structure within the reactor. This support structure is a high surface area material suitable for colonization, such as PVC pipe or shredded plastic. Fixed film reactors have successfully been implemented with low solids content dairy manure wastewaters in Florida, but are not likely to be a good fit with animal wastes produced in the arid west on open lots.

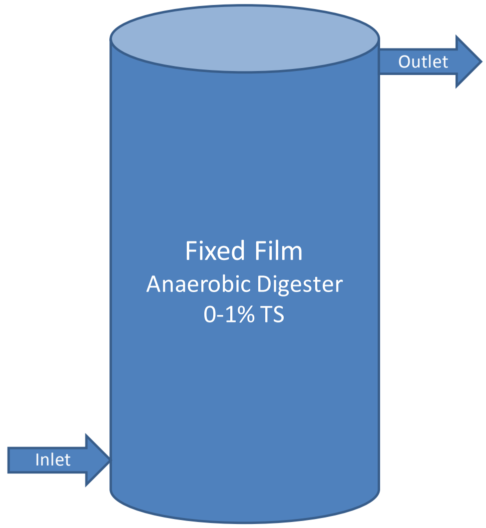

Figure 8: Fixed Film Anaerobic AD system Technology (figure developed by Luke Loetscher at Colorado State University).

Fixed Film Advantages:

- Very short Hydraulic retention times (low volume)
- High methane production

Fixed Film Considerations:

- Works only with high water content waste and solid particles must be small and therefore requires solid separation before processing manure
- Potential plugging or clogging issues

8. Step 6: AD system Technology Provider Guidance

Once an appropriate technology has been selected for AD, you can begin contacting technology providers. You may choose to hire a consultant who will guide you through the process of technology provider selection. However, make sure that the consultant is not tied to a specific technology provider. Some technology providers may assist you with project financing, although it is also important to consider all financing options. Below follows a list of questions that should be asked of a technology provider (See Appendix: List of technology providers).

1. *How many on-farm AD systems does your company currently have in operation and where are they located?*

The advantage of going with a company that has a large number of successfully operating projects is lower risk. Some of the newer companies offer novel systems that can be advantageous compared to conventional systems, however there is more risk in investing in a newer technology provider. Newer technology providers should be considered, but make sure that technologies have been successfully demonstrated on-farm at a large scale. Ask to speak with producers who have been involved in demonstrations. Many companies will also have published case studies which they can provide.

2. *Of the operating AD systems, how many are applied for animal feeding operation manure management?*

A company that specializes in AD of manure may be a good choice. Several companies have emerged who specialize in AD of food and yard wastes collected in urban areas. Manure is very different from these urban wastes, and technologies developed for food and yard waste may not work well for manure AD.

3. *Where are successfully operating AD systems located? Are you willing to take on projects in the Mountain West region?*

Many technology providers have regions where they have had a lot of success, and may not be willing to move outside of their current service area. Companies that have experience working in the Mountain West region and are familiar with the challenges associated with working in arid climates may be a more suitable choice.

4. *What types of AD technologies does your company provide?*

Some companies may only offer one technology type (i.e. complete mix, plug flow, upflow sludge blanket, or fixed film). Work with a company that offers technologies suitable to the waste generated at your farm (see above Appendix: A "List for Technology Providers" for more information also see and the OFADT (http://www.erams.colostate.edu/AD_feasability/).

5. *What are the services your company provides?*

You need to be sure of what services the company provides, and determine if you will need to find additional support for other services.

6. *Are there case studies of your technology that you can share?*

Many technology providers have published case studies of their technology. If such publications are available, review them. This will help when comparing the performance of various technologies.

7*. Is pretreatment required?*

Some technologies will require pretreatment of waste. This can add substantial capital and maintenance costs to operation of an AD system. One example is pretreatment of waste to remove inorganics (rocks, soil, and/or sand). Make sure to understand the entire process before investing.

8. *How long are your project design, construction, and system lifetime on average?*

Often it can take up to 2-4 years for a AD system to move from initial feasibility study to gas production. Make sure you understand how long it will take to install the system and what the expected lifetime for the system is.

9. *Does your company provide a performance guarantee and/or warrant and if so what are the details?*

Different technology providers will provide different guarantees and/or warrantees and you should understand the details of those so that you can make comparisons between different companies.

10*. Does your company provide support and guidance for handling of end products?*

The end-product of AD is slurry, which can either be land applied or must be disposed of (see Section 4.6). Some technology providers do not provide support for handling of end-products. Make sure to consider how to handle the end product. The costs and maintenance of handling end products must be considered in the project feasibility study. You will need to determine how much support the technology provider or consultants you are working with can provide in this area.

11. *Will your company hire any subcontractors to complete portions of the project design/construction?*

Make sure you understand who will be the project team and that you are comfortable with the design-build process.

12*. What kind of training is provided to the client by the technology provider?*

Installation of an AD system will increase maintenance required for animal waste management compared to composting or lagoon management. You need to make sure that the technology provider you work with is clear about maintenance activities which will be required after initiation of operation.

AD system operation will be more successful if the technology provider provides a clear plan for maintenance activities and training on these activities.

13. *Will the technology provider help coordinate project financing?*

As with any large capital investment, it pays to research financing options. Numerous federal and state funding programs that provide grants, reduced interest loans, and/or tax credits for AD systems. A good place to start the research is the U.S. Environmental Protection Agency Ag Star website. This link will takes you directly to the funding programs: <http://www.epa.gov/agstar/tools/funding/index.html>

Several technology providers offer loans directly for AD projects. The technology provider may also help to navigate through the numerous federal and state grants or loan programs that are available. The technology provider might be able to connect with privately funded niche programs, including greenhouse gas mitigation programs.

Your local ag bank may be your best financial resource. While the technology provider might be able to help coordinate project financing, be sure that you fully understand the project financing package offered.

9. Step 7: Operation and Maintenance of AD systems

Operation of an AD system will require more maintenance than other manure management practices, such as composting or waste lagoon management. Installation of an AD system may require hiring 1 to 2 additional employees for routine maintenance, depending on the size of the operation. The personnel devoted to AD maintenance must be skilled and trained on operation of the system. Some AD technologies, such as upflow anaerobic sludge blanket and fixed film, require highly qualified specialists to maintain the system while other technologies (covered lagoon, fixed film, and complete mix) can be operated by on-farm personnel who have received some training on operation of the system. Be prepared to meet additional maintenance requirements if you are considering AD system installation

Depending on AD system design and operation, solids can also settle out in the bottom of the AD system and/or form a floating scum mat. Both the scum mat and the solids will eventually need to be mechanically removed from the AD system to assure desired performance. When evaluating the actual performance and operation of an AD system it is important to determine and account for the amount and type of material retained in the AD system and the cost of lost AD system volume and ultimate cleaning. Some of the common maintenance activities are listed below with the frequency requirement in parenthesis.

Sludge Removal (every 1-2 years) - An AD system must be cleaned and removed of excess sludge. In well-designed systems, this is performed automatically with very little to no downtime. Other designs require manual removal of waste.

Pump Clearing (every 3-6 months) - When pumping high solids content waste, it is important to ensure that pumps are cleared of debris regularly. Items such as cow tails (when removed for ease of milking), sand, work tools and other inorganic substances can clog pumps hindering operation of the AD system.

Iron Packing Replacement (every 6-12 months) -It is important to remove the corrosive hydrogen sulfide compounds to avoid engine replacement if biogas collected from the AD systems is being refined and used for electricity generation. This can be done by passing the biogas through iron packing material. The iron packing should be replaced at least every 12 months.

General Engine Maintenance (every week) - Just as in your car, the generator producing electricity from the AD system must be inspected for proper fluid levels.

Preventative Engine Maintenance (every month) - The electrical, fuel and air intake systems must also be inspected for each of the gen sets.

Valve Leak Checks (every 6-12 months) - To avoid safety hazards, it is recommended that the valves on the AD system be checked for leaks one to two times a year. Improperly working valves should be replaced as soon as possible.

Pipe Leak Checks (every 6-12 months) - Pipes must be checked for leaks at least once per year. It is also important that no open flames are anywhere near inflow or outflow pipe lines.

Fittings Leak Checks (every 6-12 months) - Any nonmetal fitting (i.e. ducted vents, plastic valves, rubber fittings) located on the gas or waste pipeline must be inspected.

Other maintenance activities may be required specific to the system in place. Make sure to discuss maintenance requirements with the technology provider to ensure that an adequate maintenance plan is put in place. Proper maintenance of an AD system and related components will both extend the lifetime of the system as well as save money over the long term. Successful AD system operation depends on routine maintenance activities.

Appendix

A. List of Technology Providers

This list includes technology providers who provided information on their services and/or products at the time of completion of this project (September 2011). Other technology providers may be available and it is suggested that the reader conducts a thorough search for technology providers.

Business Name	Number of employees (approximated)	Services provided	Number of Operational AD systems	Locations of AD systems	AD Technology Types	Works in Colorado/ Northwest Region
RCM AD systems	35	Full service	Larger US firm with upwards of 30+ AD systems	AD systems are located in North East of USA, with a few international projects	Plug Flow, Complete Mixed, Covered Lagoon	Not Looking to expand at the moment
Environmental Energy and Engineering Co.	16	Full service	4	California, Indiana, Washington	Complete Mix	Could potentially expand
American BioGas	10	Design, Feasibility, and consulting	1 AD system in US, Have done support for multiple projects.	Germany, USA	Complete Mixed	n/a
Andigen	5	Full Service	At least 4 operational with design assistant on more	Canada and USA	Induced Blanket Reactor (IBR)	n/a
GHD Inc.	100+	Full Service	Largest firm in US with 40+ operational AD systems	USA	Plug Flow with Linear Mixing Components	Have not yet

Avatar Energy	20-30	Full Service including feasibility studies	7 (With three more in design phase)	All in California	Plug Flow	Depends on project
Bekon	55	Full service in Europe. Does	17 (none directly in USA)	All in Germany	Dry AD system (Batch/leachate)	No
Stewart Environmental	30	Consulting only	Feasibility studies only	Work in Colorado and Northern USA	Range of systems including Complete missed and plus flow	Yes
BioFerm	40	Full service	28 (world Wide projects) BioFerm is owned by Viessman Group which does projects all over the world	Most projects in Germany several located in Wisconsin	Dry AD system (Batch/leachate)	Most project located in WI region would like to expand out to rest to country
Applied Technologies	35	Full Service	Worked on at least 100 projects in US	One of the Leading AD design firms in USA	Complete Mixed, Plug Flow and UASB	None in CO. Most located in Wisconsin, Minnesota, Illinois and Iowa
Ecovation	15-20	Full Services	Subsection of ECOlab ™ Currently have 6 AD systems	All Current AD systems are in Minnesota	UASB, Complete mixed and Fixed Film	Depends on Project
Environmental Fabrics	6	Specialized Tech	Has implemented 200 plus covers worldwide	USA / Mexico and other part of the developing world	Covered Lagoon	no case studies in Colorado

* This list does not represent a comprehensive list of all biogas technology providers and is subject to change.
* For a complete list of all biogas technology providers please visit
<http://www.epa.gov/agstar/documents/agstar_industry_directory.pdf>

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