Colorado Market Assessment of Agricultural Anaerobic Digesters

Prepared for the Colorado Energy Office

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1 Executive Summary

The purpose of this project was to conduct a market assessment for potential of anaerobic digesters (AD) in the state of Colorado, focusing primarily on dairy facilities. Main objectives included assessing success criteria and main barriers for AD projects through interviews with market participants and literature research, identifying potential market size and areas in Colorado, as well as identifying possible methods in which CEO can impact the market.

Our findings are that key barriers and success criteria for AD projects in Colorado are:

- Manure management practices in Colorado, specifically the use of dry-lot facilities, make AD systems technically difficult.
- Additional feedstock, such as food wastes, improves AD project's viability considerably. Therefore co-digestion and municipal digesters should be encouraged.
- Time and knowledge limitations on behalf of livestock operators point to the need for third-party involvement.
- Financing AD projects is challenging in the current environment.

According to our economic model, for a "typical" medium to large size on-site AD system with no organic substrates, the net present value of the AD project becomes positive at an operation size of 2,000 cows. This number is much higher than the 1,200 average herd size of Colorado dairies. However, with the inclusion of organic substrates, such as food wastes, the "break-even" herd size is 1,500 cows. For greater economic viability, it is therefore recommended to focus on co-digestion systems. We have estimated the potential number of dairies with on-site digesters in Colorado as 20, if we do not include co-digestion abilities. If we assume that dairies will engage in co-digestion, 27 sites are available in Colorado.

Our policy recommendations are for CEO to:

- Consider motivating factors behind AD system implementations.
- Act as a central information source for participants, focusing on Colorado AD successes as well as the superior economic returns of co-digestion facilities.
- Encourage dairies to implement energy efficiency initiatives.
- Broker relationships among market participants by having CEO introduce relevant parties in the industry and also act as a "seal of approval" towards financiers and/or regulators.
- Mimic successful policies implemented in other states that create an environment more conducive to AD project success, such as the California Feed-in-Tariff and new Massachusetts landfill regulations.

2 Project Overview

2.1 Introduction

Over the next 25 years, energy demand is projected to increase markedly even though the U.S. energy sector has seen a large drop in annual growth, from 9.8%/year from 1949 to 1959 to only 0.7%/year since 2000. The U.S. total electricity demand is projected to grow by 29% (0.9%/year), from 3,826 billion kilowatt hours (kWh) in 2012 to 4,954 billion kWh in 2040. According to the U.S. Energy Information Administration (EIA), most new growth will come in the form of natural gas and renewables. In addition to sources such as wind, solar, hydro, and geothermal energies, interest in waste products as a source of energy (biomass) has been steadily increasing and is projected to increase. From 2012-2040, the EIA estimates biomass energy will increase by 4.4% per year, the third largest increase in renewables behind solar (7.5%) and geothermal (5.4%) annual growth rates. (EIA, 2014)

Colorado's rapidly increasing dairy sector may contribute to energy production. Colorado's dairy industry is growing as dairies move to Colorado from other states due to the regulatory environment and enhanced business opportunities. This addition of large dairies is not only increasing overall energy usage by the sector, but volumes of animal waste are also increasing. Traditionally, due to the large volumes created by livestock operations, waste disposal issues can be problematic. The waste can create local air quality issues, increase emissions of greenhouse gases, as well as contaminate groundwater. Typical disposal methods include treatment and release into water systems (with EPA permits), retention in lagoons, or injection/misting onto sprayfields. However, a growing trend is to use the waste produced by these facilities as a feedstock for a biomass energy process called anaerobic digestion.

Anaerobic digestion (AD) is of particular interest as a renewable energy option for the agricultural sector as it could provide reductions to air emissions, greenhouse gas emissions, and energy usage. AD systems generate biogas through the breakdown of animal and food wastes. The uses of biogas include electricity generation as a boiler fuel for water or space heating, or it may be used for a variety of other uses, such as transportation. These technologies could also provide an additional source of revenue for livestock operations from a former waste stream. Revenue is generated by the sale of biogas products, such as electricity to the local utility, heat generation to adjacent properties or as a transportation fuel. The sale of co-products such as fertilizers, peat moss, tipping fees, and carbon credits may also yield revenue.

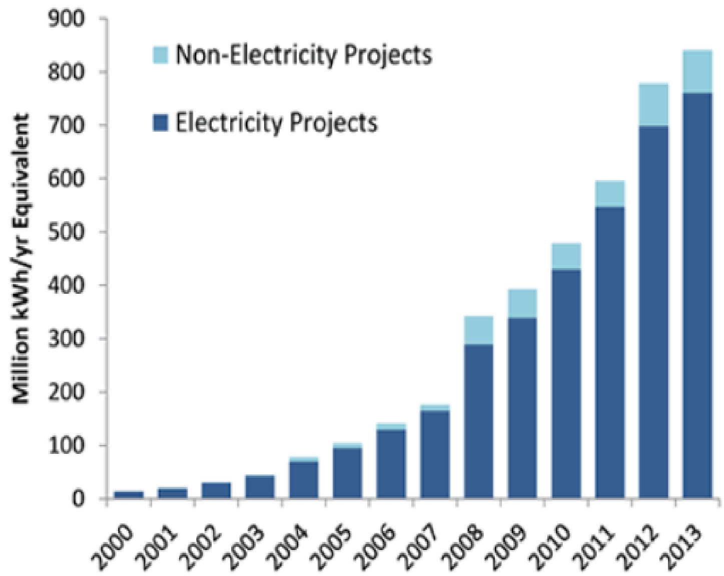

Figure 1: Equivalent energy generation in kWh generated by livestock-related AD systems from 2000-2013. (Source: EPA, 2014b)

Anaerobic digestion is a growing sector of biomass energy generation as shown in Figure 1. In 2000, approximately 20 digester projects were operating (Environmental Protection Agency (EPA), 2010a), and as of May 2014 there are 239 operating digesters in the U.S. (EPA, 2014a).

See Appendix 2 for summary statistics of the current digesters in U.S.

The EPA's AgSTAR program, which promotes the use of anaerobic digesters by the agricultural sector, estimated that approximately 840 million kilowatt hours (kWh) equivalent of energy was generated by AD systems at animal feeding operations in 2013. (EPA, 2014b)

2.2 Project Purpose

The Colorado Energy Office (CEO) requested a market assessment for anaerobic digesters and biogas production for the state of Colorado. Objectives of the study included assessing success criteria for AD projects in Colorado through interviews with market participants and literature research, identifying potential market size and areas, as well as main barriers and possible methods in which CEO can impact the market.

2.3 Data Collection Techniques

Interviews with market participants were conducted in order to gather perspectives and experiences of those who are directly participating in the AD market. A list of interviewed market participants is shown in Appendix 1. This feedback was influential in selecting the main focus points of our analysis of policy and economic variables. Primary financial data was also obtained from a number of our interview participants.

Secondary data was also extensively used to gather information about the livestock operations and anaerobic digesters in Colorado, as well as general workings of AD systems. Main sources of secondary data included EPA's AgStar Program, reports prepared by Colorado State University researchers, environmental consultancies, as well as assessments from other states, such as New York, Minnesota and Wisconsin.

There were several limitations to our assessment, especially in regards to finding data both for the U.S. and specifically for Colorado. Whenever possible we used Colorado-specific information or national averages; and in cases where neither were available, industry-wide data. For example, we did not find detailed information on manure management systems of Colorado dairies. Our information on average herd size in Colorado comes from our contact at Dairy Farmers of America. Selling price of animal bedding is based on a national average, and price for renewable energy credits (RECs) was extrapolated using national data from the Innovation Center for U.S. Dairy. We have identified our sources in this report and in the economic feasibility valuation spreadsheet provided. As more Colorado-specific data is available, valuation models can be further refined and additional potential success criteria identified. Our report focus is on on-site digesters for medium to large dairies that contain approximately 85% of Colorado cows. For possibility of on-site digesters on very small dairy facilities (<500 cows), as well as very large centralized-scale digesters, additional research is needed.

3 Anaerobic Digesters Overview

3.1 The Process of Anaerobic Digestion

Anaerobic digestion systems have been employed in the U.S. for over 30 years. They are most frequently used for manure and wastewater treatment facilities, and less commonly for food waste management. The process of anaerobic digestion involves the breakdown of organic material by microorganisms in the absence of oxygen. Organic compounds are removed as they are converted into biogas, while nutrients (nitrogen and phosphorous) remain as solids and nutrient-rich liquid, together referred to as 'digestate'. Biogas is comprised of methane (60-70%), carbon-dioxide (30-40%), and other trace gases.

Complete AD systems typically include the following activities:

- collection of organic feedstock (i.e. manure or food waste),
- a pretreatment process to remove contaminants from the feedstock,
- biogas and digestate production via anaerobic digestion,
- purification of the biogas into the pipeline-grade natural gas,
- biogas combustion to produce electricity on-site or to be sold to the local utility, or compression into vehicle fuel, and
- disposal or sale of by-products (Sharvelle and Loetscher, 2011).

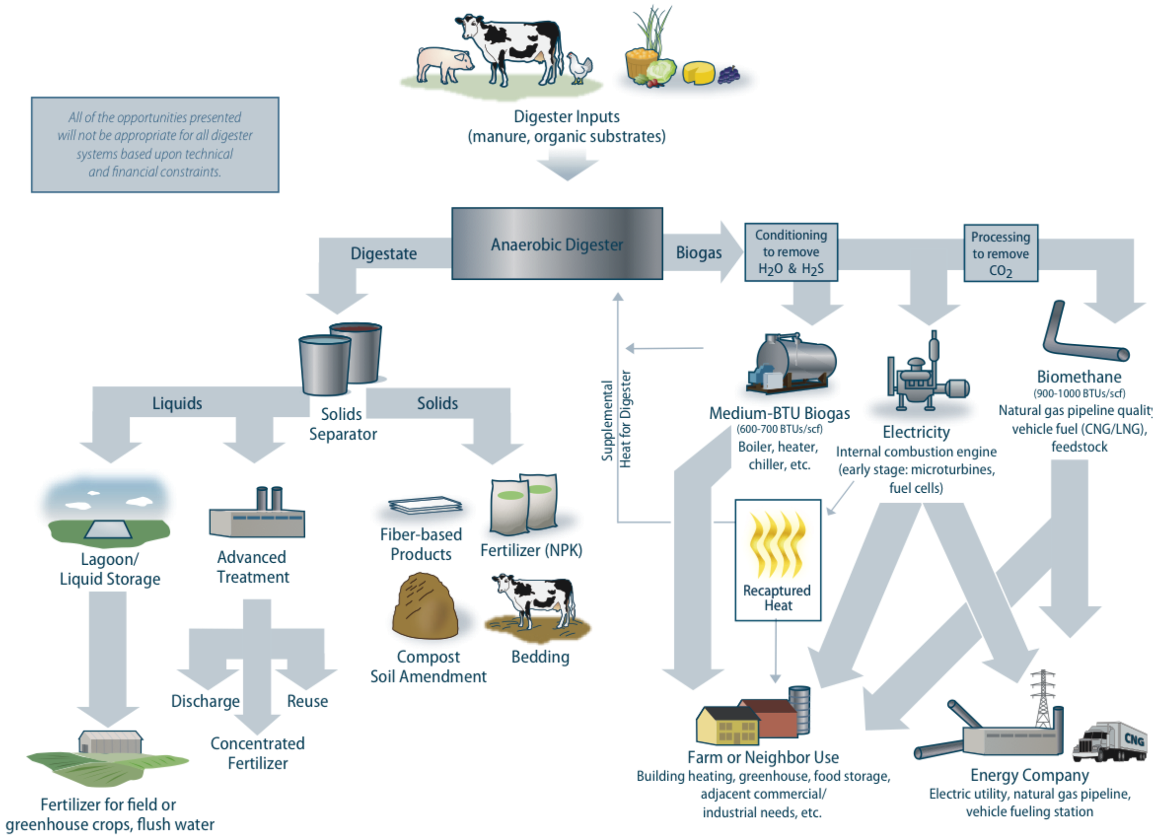

Figure 2: Basic anaerobic digester system flow diagram. (Source: EPA, 2011b)

Conversion from feedstock to biogas must be done within well-defined parameters to ensure optimal production, and minimize system downtime and costs. For example, bacteria that convert organic materials into biogas and digestate are very sensitive, requiring a pH near 7 and temperature of 95°F for optimal production. On average, about 4% of influent (inputs) is converted to biogas, while 96% leaves the digester as a nutrient-rich, pathogen-free and nearly odorless effluent. (Sharvelle et al., 2012)

3.2 Types of AD Systems for Livestock Operations

In the U.S., there is a great variety of organizational and technical choices among dairy digesters. AD systems may be

- operated on-site,
- operated on-site, but receiving additional feedstocks from other sources and/or sending its effluent to other farms,
- owned by a single animal feeding operation but operated by a digester management service, or
- centralized (community) digesters located so as to receive organic materials from several operations.

In terms of technical specifications, systems come in a variety of different styles and configurations but all have the same common environments:

- absence of oxygen,
- elevated temperatures, and
- sealed vessels.

3.2.1 Main digester types

The most prevalent dairy digester system used in the U.S. is plug flow (comprising one-third of digesters on livestock operations), followed by complete-mix system (about one-fifth of total), covered lagoon, and fixed-film reactors. Individual AD systems in the U.S. are often variations on these main four 'themes.'

Covered lagoons. The cheapest and simplest digester to install and operate is a covered lagoon, which is an earthen retention pond fitted with a synthetic cover that is used to trap and store the biogas. Digestion occurs at ambient temperatures (ideally 60° F), as the unit is not heated. Of the four types of digesters, a covered lagoon has the longest retention time and lowest gas production, and is not well-suited for Colorado's cold climate. Also, they cannot take organic substrates as feedstock and will not produce fertilizer or fiber co-products.

Figure 3: Covered lagoon system (Source: EPA)

An additional consideration is that lagoons have potential negative environmental consequences. The building of new lagoons has been banned in North Carolina.

Plug flow. Another relatively low-technology digester that can be used for high solids content waste (11-13%) is a plug flow digester. The waste enters a mixing pit (often in a long, tubular shape) where it is mixed with water. The digester is heated and the content travels down the digester as a "plug" by being pushed in by more recently added manure. Fiber produced by this type of system is known to be more usable than that produced by other digester systems. However, plug flow digesters can only be used on dairies and can accommodate limited food waste content.

Figure 4: Plug flow digester (Source: EPA)

Complete mix system. Composed of large, usually cylindrical tanks which have a mixing mechanism such as injected biogas or a mechanical paddle, complete mix systems generally handle manure with 3-10% solids. Complete mix system can be used for both cow and hog farms, and also take on more organic feedstock, hence potentially producing more energy than either covered lagoons or plug flow systems. However, the manure must be heated, requiring energy use. Additionally, the fiber from complete mix operations is of lower quality compared to that produced by plug flow systems.

Figure 5: Complete mix system (Source: EPA)

Fixed-film reactors. A less common type of digester is the fixed-film reactor, which handles only liquid feedstock, requiring the separation of solids from the liquid influent prior to digestion. Inside the digester's reactor is a high surface-area material, such as a PVC pipe or shredded plastic, which is colonized by bacteria. Such reactors have been shown to work well with low solids content in warm conditions such as Florida for example, but most likely would not be a good fit for Colorado.

3.2.2 Choosing the right digester

As can be seen from descriptions above, each AD system has distinct advantages and disadvantages in terms of

- first-time and operational costs,
- suitability to particular livestock practices,
- local climate,
- feedstock quality (particularly solids content),
- efficiency (kW produced per unit of waste),
- types of products generated, and
- ease of operations and maintenance.

Other considerations for AD system selection should include the vicinity of the livestock operation to biogas and co-products markets, as well as to additional feedstocks (for enhanced biogas and co-product generation). The appropriate technology should be chosen carefully and its feasibility studied before installation. See Appendix 3 for more complete characteristics of AD system types and requirements.

Several online and freely available resources offer more precise, analytical guidance, which should be referred to when selecting the appropriate technology. EPA's AgSTAR Handbook for example offers such guidance in form of a questionnaire, shown in Appendix 4.
The Handbook is also available on-line at: http://www.epa.gov/agstar/tools/project-dev/handbook.html

Once an appropriate technology has been chosen, a provider of such technology will need to be selected. Researchers from Colorado State University (Sharvelle et al., 2012) offer a list of about a dozen AD technology providers in their report.

3.3 Benefits of AD

The approximately 239 anaerobic digester systems operating at commercial livestock facilities in the United States (EPA, 2014b) have benefits aside from the potential to generate energy, including pollution mitigation and potential profit from a former waste stream.

3.3.1 Environmental: Pollution mitigation

AD systems have pollution mitigation impacts, such as reduction of solid waste, lowered greenhouse gas emissions, and odor reduction. Digesters are designed to capture methane emissions of livestock operations, thus allowing for the generation of biogas, electricity, and income. Methane is a potent greenhouse gas (GHG) that is 21 times more potent than CO_2, and its emissions have implications to climate change. AD has additional benefits, as it lowers other types of pollution as well, including solid waste, odors, and local air emissions of noxious gases, such as ammonia and hydrogen sulfide.

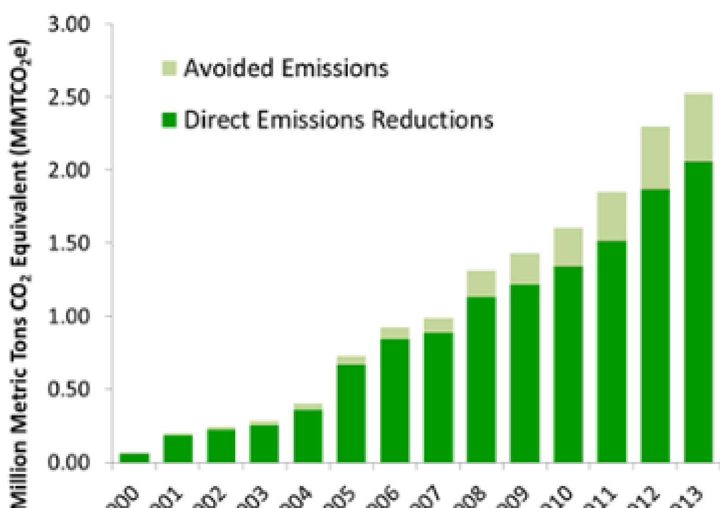

Figure 6: Avoided and reduced GHG emissions in MMT CO2 equivalents by AD systems at animal feeding operations (Source: EPA, 2014b)

Utilizing biogas as energy also results in avoided GHG emissions, as shown in Figure 6. In 2013, the EPA estimated that anaerobic digesters were responsible for avoided and reduced emissions of 2.53 million metric tons of CO_2 equivalent ($MMTCO_2e$), which is approximately 0.4% of agricultural GHG emissions (EPA, 2014a).

3.3.2 Potential for profit from a former waste stream

With anaerobic digesters, there are a variety of sources for additional income, which is partially dependent on the type of digester utilized and what additional equipment is added.

Biogas. The primary product of anaerobic digesters is biogas, which can be used for energy in various forms: electricity production, on-site heating, pipeline-quality biomethane, and compressed natural gas for vehicles. Electricity may be generated when biogas is sent through an electrical generator and either utilized on site or sent to the grid. Alternatively, biogas may be utilized as a replacement for natural gas for a boiler for heating. This practice is primarily for onsite or adjacent properties.

Salable co-products. Additionally, salable co-products from the slurry of complete-mix, fixed-film, and plug-flow digesters may also be recovered including liquid nutrients (nitrogen, potassium, and phosphorus), compost, peat moss, and bedding fiber. See Appendix 3 for a table of co-products listed by digester type. For every 1,000 kWh of electricity produced, RECs may be acquired, which may also be another source of revenue. Several technology intensive products including nano-carbon, carbon black, and bio-plastic are being created on a limited scale and could be another potential for revenue in the near future (J. Bingold, communication, Oct. 31, 2014).

Tipping Fees. Another incentive for anaerobic digesters on livestock operations is the avoided cost of waste disposal. An AD operation may also benefit from tipping fees when third parties pay to bring them waste rather than paying the cost of landfills or land applications.

3.4 Drawbacks of AD

Although there are many benefits to anaerobic digestion, there are also two primary drawbacks to anaerobic digesters that need consideration.

3.4.1 Economic Cost

Capital costs associated with AD projects can be significant, depending on the size of the system. In our analysis of medium to large-sized dairy facilities, shown in Section 5.1, we find that for a herd size of 1,200 cows, capital cost of an on-site digester, excluding generator and solids separator equipment, is about $996,000. For many livestock operations this upfront cost would prove to be prohibitive unless it is offset with grants and/or substantial revenues over the life of the project.

3.4.2 Primarily for concentrated animal feeding operations (CAFOs)

Anaerobic digesters on livestock operations are typically not considered for cow populations under 500 where manure collection is feasible with little or no soil contamination (NDSU BioEPIC, 2008). Additionally, the manure must be delivered in a slurry or liquid system for anaerobic digesters. The operations that qualify for this system are typically confined livestock facilities with either concrete or slatted flooring. (EPA, 2014c) Outdoor covered feedlots may be designed with slatted floors for collection of manure; however, free-range farms or dirt feedlots will not allow for the collection of manure without soil.

3.5 When is AD a Viable Option?

In analyses of livestock operations for which an anaerobic digester system would be economically feasible, a number of crucial factors are known to affect the viability of the system the most. The main criteria for determining AD system feasibility are the size of the operation, manure handling practices, use of collected biogas, mix and consistency of feedstock, as well as staffing and time commitment. These main criteria are summarized below.

Operation Size. As mentioned earlier, anaerobic digesters are thought to be particularly suitable for large confined animal feeding operations (CAFOs). In general, larger feedstock provides greater energy generation which may offset initial capital costs and make a project viable. Volume of feedstock is a direct result of the number of animals at the operation. EPA AgSTAR concludes that a minimum of 500 cows or 2000 pigs are considered necessary for profitability (EPA, 2011a). However, the agreed-upon minimum number of animals needed for an anaerobic digester is not a clear-cut rule in the industry. Colorado-specific studies suggest a larger number may be needed. In a study for CEO, C. Keske (2009) suggests that 3,500 to 5,000 cows is a more appropriate threshold. In 2008, Stewart Environmental Consultants found 5,000 cows as the threshold for profitability. In our 'average' AD system evaluation we find 2,000 to be the minimum number of cows for a system digesting cow manure only.

Manure handling practices. Stable manure production and collection, frequency of collection, and manure state are crucial to AD operation. Current digester systems are constructed for manure that is in a semi-solid, slurry, or liquid state. The feasibility of an AD system is also influenced by collection frequency; a minimum weekly collection maximizes the conversion of manure prior to digestion, and it is preferable if the manure is collected from a single point. Confined swine and dairy operations regularly remove manure as frequently as every few hours. For dry management systems, such as those found in other animal sectors (e.g., poultry and beef operations), typical collection is no more than three to four times per year. This infrequent collection makes an AD system on such sites a challenge.

Use of collected biogas. As a rule of thumb, on-site use of biogas is most economical, either for on-site heating or on-site electricity needs. Excess electricity can be sold to the utility at a rate negotiated between the two parties in a power purchase agreement. In Colorado studies (Lasker, 2013), this rate is usually set at about $0.02/kWh.

Feedstock mixture. The ideal mix of feedstock for anaerobic digestion contains high levels of organic components (such as crop waste or food waste) and fatty materials (such as grease). Anaerobic digesters on livestock operations that have co-digestion capabilities (ability to take feedstock from other sources) are particularly important. In addition to increasing the volume and organic component to the feedstock, this ability may add another revenue component if a tipping fee is paid to the digester by the feedstock providers.

Staff and time commitment. Like livestock operations, AD systems run 24 hours per day and require qualified personnel available for repairs and maintenance, as well as significant time and knowledge in the initial set-up stage. For large systems, a full-time staff member(s) may need to be hired for the monitoring of the AD system. An AD operator should plan for such need ahead of time.

As for the choice of appropriate technology, freely available tools exist to provide guidance on whether an AD system may work for a given dairy or not. For example:

- See Appendix 5 for the complete questionnaire from EPA's AgSTAR Handbook, available on-line at http://www.epa.gov/agstar/documents/chapter2.pdf.
- The feasibility assessment tool from Colorado State University, available at: https://erams.com/AD_feasibility_ad_tool/ and shown as a tree-diagram in Appendix 6.

4 Colorado AD Projects and Dairy Industry

Although there are a variety of waste digesters in Colorado, we will focus on two that handle animal manure. Christensen Farms is an example of an on-site digester that has been operating since 1999. Heartland Biogas is a third-party centralized digester currently (December, 2014) under construction in Weld County that will be taking large volumes of animal waste from nearby animal feeding operations.

4.1 Christensen Farms

Christensen Farms (formerly Colorado Pork), located in Lamar, is the only known anaerobic digester on an animal feeding operation in Colorado. It is currently operational and has been since 1999. The facility uses a complete mix system attached to a confined swine facility holding approximately 5,500 pigs. The produced biogas is flared full-time and currently has no receiving utility. The system designer was RCM International, LLC. The digester's primary purpose is pollution/odor mitigation and the facility's methane emissions reduction is 91.39 metric tons CH_4/year, which is equal to 1,919.18 metric tons CO_2 equivalent per year. (EPA, 2014a).

According to a report from Colorado State University (Keske, 2009), the digester has had chronic operational problems and has not been a profitable investment. Part of the problem is technical, as the chosen AD system is considered to be an early model of modern digester systems. There have been design flaws such as incompatibility between the manure holding tank with the digester, and the generator has had longer than anticipated down-time. A lower than expected amount of feedstock has also played a role in the system's difficulties causing a longer hydraulic retention time of waste. With the longer holding time, the corrosiveness of biogas led to more damage to generators, further exacerbating the system's down-time and repair costs. An EPA 2003 report investigating the project found that it had a negative annual income. The primary motivation for keeping the digester alive appears to be in compliance with state air emissions standards. At the time of the CSU research, Christensen Farms was focused on stabilizing the system and had invested $180,000 in system improvements. A maintenance worker was employed to spend 20-25 hours per week to monitor the digester's operation.

4.2 Heartland Biogas

Heartland Biogas is a multi-substrate AD facility located in LaSalle, Colorado and is currently under construction by AgEnergy. They have a covered lagoon of 8.5 million gallon capacity, which has been operational since 2013. From the operational lagoon, they produce biomethane quality gas, which they send through a connection to a main pipeline after lagoon biogas passes through upgrading stacks. The gas pipeline goes to California and the biomethane is used for renewable electricity generation there. The lagoon operation is making 180 dekatherm (dth) per day now, though the digester will serve a different function when the complete mix digester is in operation.

Figure 7: Heartland project tanks (Source: Wolton L.)

A six-tank (10.2 million gallons) complete mix digester system is also located there, but is still under construction. These tanks will need to be heated at 125°-135°F at all times and continuously have digestate as well as substrates added to the mixtures. The facility houses no animals, but contracts A1 Organics to pick up manure from nearby dairy operations on a daily basis (manure must be very fresh to retain methane). Additionally, daily deliveries of de-watered restaurant grease and food waste are added to the mix. After the waste is digested, it is spun out with large centrifuges to recover liquids and solids. The solids will be sold as peat moss (preferably) or bedding. The liquids are sent to a lagoon, which is used to feed into neighboring crop farmers. Another liquid that comes from the process of filtering the hydrogen sulfide out of the gas is a diluted form of sulfuric acid (H_2SO_4). This liquid may also be used for soil amendment.

Eventually, when the complete mix digester tanks are in operation, the 42-million-gallon AD plant is proposed to make

- 7000 dth/d of biomethane (\$10-\$13/dth in CA),
- 500 yd^3/d of peat moss (\$10/yd^3),
- nutrient effluent, and
- diluted H_2SO_4 for soil amendment.

However, there are major expenses to the facility including those for the initial build. Additionally, when operational, the largest costs for the plant will be the 12 to 15 employees needed to operate the facility and energy to supply the heaters. (J. Potter, personal communication, October 14, 2014).

4.3 Colorado Livestock Operations

In this report, we focus on dairy facilities as does the EPA in their 2011 *Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities.* A primary reason for focus on dairy cows is because lactating female cattle produce much more methane per animal than any other livestock animal. Using the crucial factors of manure management methods, operation size, and energy costs, an EPA 2011 study identified Colorado to be among the top ten states for potential electricity production on dairy operations.

As discussed above, cattle feedlots and chicken operations are typically not considered as target operations for profitable AD systems due to their manure collection methods. However, confined swine operations may be considered, but a very large number of pigs is necessary (at least 2000) as a threshold for profitability due to lower methane production per animal. Colorado has a small number of operations that this could be feasible for. The 2012 Census of Agriculture indicates that this number is a maximum of 15 (Figure 8). If swine operations were to be assessed for energy generation, they would need to be individually queried for manure collection methods.

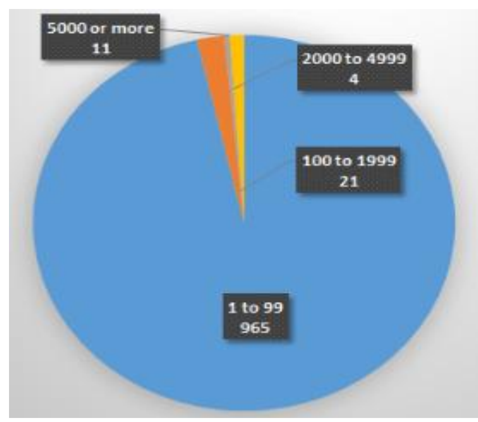

Figure 8: Number of Colorado swine operations, 2012 agriculture census (Source: USDA, 2012)

Colorado is a semi-arid area and its dairies are predominantly dry-lot facilities where cows are housed outdoors in large pens, often with no bedding material, and dry manure is collected without being flushed by water since water is scarce in Colorado. As a result, the collected manure in Colorado is often high in inorganic content and low in moisture content. Dairy waste typically contains 10-14% solids when excreted; however in Colorado's dry lots, the solids content has been measured to be near 50% even when combined with wastewater (Keske, 2009). These conditions make AD systems in Colorado challenging, making the choice of appropriate technology very important.

Newer technologies, such as two-stage digesters with better digestion of low-moisture feedstock than other digester types, may overcome this issue in the future and should be kept in mind (Keske, 2009). Multi-stage systems are much more technically complex and have higher operation maintenance requirements than single-stage digesters. The increased complexity means they have a higher capital investment (EPA, 2006). On the other hand, this process can yield up to 125% to 239% methane compared to more traditional methods (Keske, 2009). Two-stage digesters are more frequently used in the digestion of municipal wastewater than in the treatment of dairy manure. They account for a small percentage of digesters, partially because they require expensive pre-treatment of feedstock and higher heating requirements (Monnet, 2003).

4.3.1 Colorado Dairy Industry by Size

Currently there are about 143,000 milk cows and heifers in the state Colorado, which represents an increase of 27% from just four years ago when there were 116,000 (USDA, 2012). The growth comes from both existing dairy operations in Colorado that have been adding cows or building additional milking facilities, but also from dairies coming from other states.

While Colorado's dairy sector ranks 15th in the nation for overall milk production, the state yields the highest volume of milk per cow in the nation (Colorado Office of Economic Development and International Trade (OEDIT), 2014). In September 2014 for example, Colorado's milk production per cow was 2,055 pounds of milk, compared to 1,850 pounds in California, the number one state for dairy volume (Kayla, 2014). Colorado's high milk production rate is attributed to its cool and dry climate, as well as good feed and water quality.

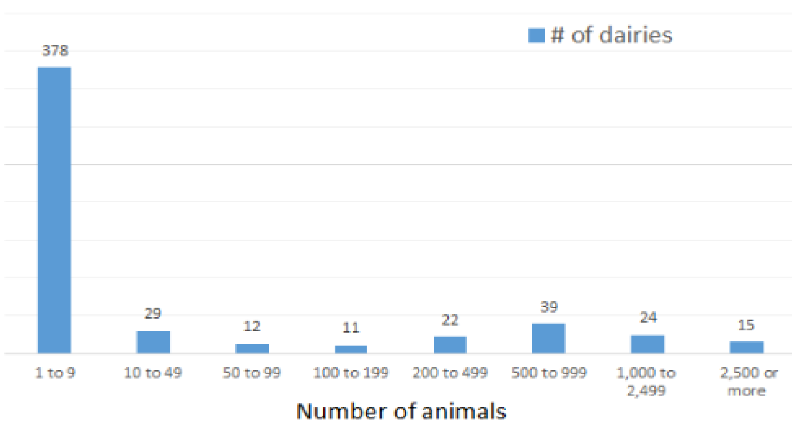

Figure 9: Number of Colorado dairy operations, 2012 agriculture census (Source: USDA, 2012)

Colorado market potential for energy-producing anaerobic digesters is limited by the animal population at the operations and the manure management practices, as discussed above. The 2012 Census of Agriculture by the USDA yields the approximate number of large facilities that *may* be suitable for biomethane production.

Figure 9 gives the number of operations with milk cows and the number at each facility. Based on profitability results from our model AD system for a typical dairy in Colorado, shown in Sections 5.1 and 5.2, we find that a potential number of dairies which could profitably install an AD system on-site is 20 for systems which will process cow manure only, and 27 for systems which will process organic substrates as well, such as fats and grease from food waste.

A 2011 EPA assessment (using 2007 census data) of the anaerobic digester market found that 54 potential sites for digesters were located in Colorado. Such sites had a minimum herd size of 500 cows, and anaerobic lagoons or a liquid slurry management system. These two criteria were deemed crucial for successful AD systems. These results indicate that there is fair potential in Colorado by number of operations alone.

Figure 10 shows EPA's mapping of manure management systems across Colorado. Note that EPA's graph shows that 87% of cow manure in Colorado is stored in anaerobic lagoons or as liquid/slurry which seems to contradict Colorado-specific studies and information provided by our contacts that Colorado's manure is mainly housed in dry lots. However, as herd size increases, solid manure storage becomes less common as larger dairies are more likely to store manure in liquid forms (CSU, 1997). And since about 60% of Colorado dairies have 1,200 cows or more (G. Harper, personal communication, Oct. 23, 2014), and are hence large dairies, their 'liquid' manure management system use probably leads to a somewhat skewed picture of manure management systems across all dairies in Colorado. We have not found any studies, other than the EPA 2011, showing what percentage of Colorado farms uses different manure management systems.

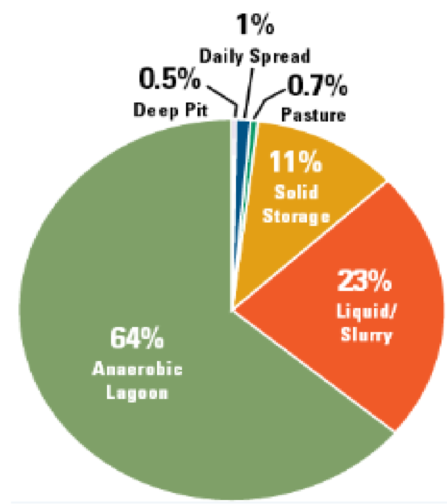

Figure 10: Dairy manure managed in each waste management system, Colorado (EPA 2011)

4.3.2 Colorado Dairy Industry by County and Potential AD Sites

The 2012 Census of Agriculture collected data by county, which is useful to highlight the areas in Colorado that may be focused on for consideration of AD system feasibility operation. Figure 11 shows that Weld County, Larimer, Morgan and Fremont have the highest populations of dairies. Weld and Morgan counties alone contain about 76% of the state's population of dairy cows. While Morgan has the highest density of cows (at 18.7 cows/mile^2 vs. Weld's density of 8.3 cows/mile^2), dairy activity in Weld County is highly concentrated in the southern and western parts of the county (Stewart Environmental, 2008). Additionally, note that much of the recent growth is concentrated in the area surrounding Greeley - in Weld, Morgan, Larimer and Adams counties, where about 90% of the state's milk production already takes place (AgProfessionals, 2014).

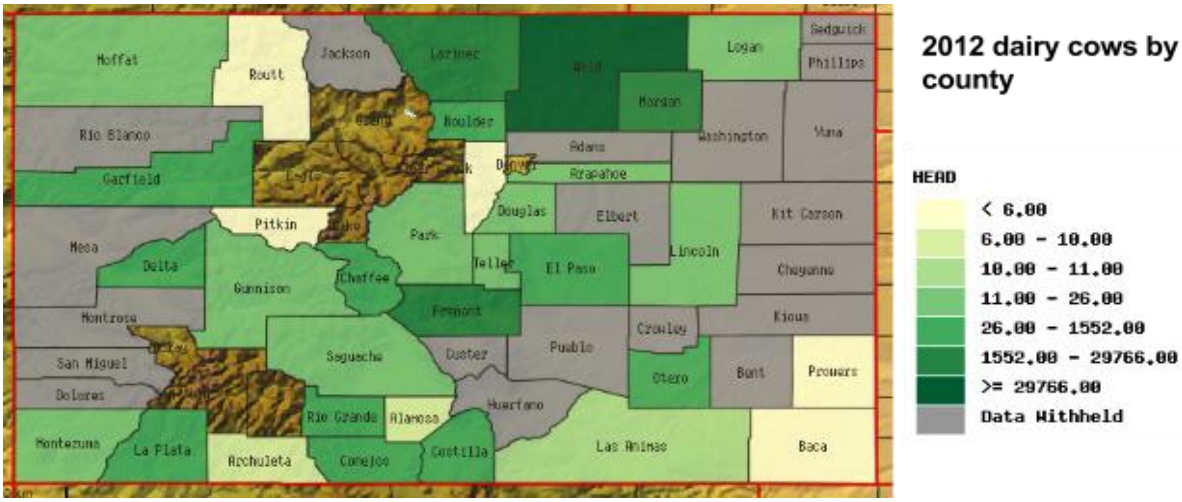

Figure 11: Dairy cows by Colorado county, 2012 agriculture census (Source: USDA, 2012)

Stewart Environmental, a consulting group, conducted a study for the Colorado Department of Agriculture in which they identified seven sites in Weld and Morgan counties suitable for regional (i.e. community-scale) anaerobic digesters. These sites have access to 5,000 dairy cows within a 2-mile radius. See Appendix 7 for the location of proposed sites and site characteristics.

As far as future growth trends are concerned, according to an article by AgProfessionals (2014), the ideal dairy sites in or near Weld will dwindle, so future growth will likely take place further to the east, near Fort Morgan and Sterling. Four large dairies (2,000-5,000 cow operations) that are currently in their financing and water-development phases will be built east of U.S. 85 and along Interstate 76.

In choosing an appropriate site for a regional digester capable of accepting feedstock from multiple diaries or food waste facilities, the following criteria should be kept in mind:

- feedstock proximity (Stewart Environmental considers a maximum of a 2-mile radius as a cut-off point due to increased transportation costs),
- adequate road or rail access to be able to accept feedstock and deliver AD products,
- proximity of markets for sale of electricity from the plant,
- proximity to communities, and
- relevant state and federal codes.

5 Economic Analysis of Colorado AD Potential

The purpose of this section is to provide an estimate of the market size of the potential anaerobic digestion systems in Colorado. We start by analyzing a single AD system and then extrapolate our results on a statewide basis by taking into account the number of dairies in different size ranges mentioned in section 4.3.1.

5.1 AD System Profitability Estimate

Economic analyses of single AD systems in the U.S. vary widely. Differences are due to many factors, but mainly the size of the dairy, type and cost of the technology employed, feedstock content (manure only or inclusion of food wastes), uses of biogas, and the prices the dairy is able to obtain for its biogas, electricity, and co-products. According to the EPA (2009a), capital cost for an on-farm anaerobic digester ranges from $400,000 to $5 million, depending on the scale and type of system used. Smaller systems are also possible, as well as much larger community-scale digesters. It is, therefore, not possible to talk about a "representative" AD system. Our goal in this section is to see how an "average" AD system in Colorado would fare from a profitability perspective, and what herd size it may need to be economically feasible. We assume that prior to its installation, the AD facility operator would undergo a feasibility assessment similar to those discussed in Section 3.5 and receive an answer that the given site is suitable for an AD system.

Note that there are freely available tools which provide very detailed economic analysis for anaerobic digestion systems, such as:

- Co-Digestion Economic Analysis Tool (CoEAT) developed by EPA to assess economic feasibility of anaerobic digesters that include food waste co-digestion. The spreadsheet is available on-line at: http://www.epa.gov/Region9/organics/coeat/index.html
- Cost of Renewable Energy Spreadsheet Tool from the National Renewable Energy Laboratory (NREL) which is available on-line at https://financere.nrel.gov/finance/content/crest-cost-energy-models
- Several universities also offer free on-line modeling spreadsheets, such as the Anaerobic Digestion Financial Decision Tool developed by Cornell University, available at http://agfinance.dyson.cornell.edu/tools.html

#	FEEDSTOCK & PRODUCTS ASSUMPTIONS ITEM	AMOUNT	UNITS
1	Animals	1200	Cows
2	Mass of Manure	112	lb/cow/day
3	Volatile Solids (VS) %	12%	
4	Concentration of Methane	60%	
5	Energy Content of Biogas	650	BTU/ft³ of biogas
6	Energy Content of Methane	923	BTU/ft³ of methane
7	Nitrogen (N) recovery rate	10	lb/ton of manure
8	Phosphorous (P) recovery rate	6	lb/ton of manure

Table 1: AD site requirements and assumptions

In this example, we assume that the digester will be operating on a dairy with 1,200 cows, which is the average herd size on a Colorado dairy (G. Harper, personal communication, Oct. 23, 2014). We assume that the technology employed will be a complete mix system. Even though the plug flow system is the most prevalent one in the U.S. (about one third of all digesters on livestock operations), the complete mix system is the second most-prevalent technology in U.S. (about one-fifth of total), and the most often used type in Colorado (both Heartland and Christensen projects use complete mix systems). We also assume that the system will operate on-site, using the dairy's manure as the only feedstock, and that the uses of biogas produced will consist of on-site heating, on-site electricity generation, sale of excess electricity to the local utility (along with associated RECs) and on-site use and sale of digestate solids as animal bedding or peat moss. Table 1 above, as well as Tables 9 and 10 in Appendix 8 show our main assumptions.

Energy Production		
Energy production	2,149,345	kWh/year

Energy Use		
AD system use	1,074,673	kWh/year
On-site biogas use (heating)	134,769	kWh/year
On-site electricity use	939,903	kWh/year
Electricity for sale	-	kWh/year

By-Products		
Animal bedding for on-site use	283	tonne/year
Animal bedding for sale	4,013	tonne/year
OR Peat moss	6,000	tonne/year

Table 2: Biogas and digestate outputs

Our model also assumes a 15-year project life, with no salvage value for the digester in the end since digesters are customized to particular locations. We assume that the capital costs will be funded with a loan bearing an interest rate of 8%, that the discount rate for the project is 8% (Wisconsin SEO, 2013), and an applicable income tax rate is 40% (Keske, 2009). We also assume that a project would qualify for the investment tax credit (ITC) which is set to 10% of the project's capital expenditures. Finally, we also take into account Colorado's sales tax incentive for renewable energy projects whereby components used in production of renewable energy, including from anaerobic digesters, are exempt from the sales tax (of about 2.9%).

Our results in Table 2 show the use of the biogas and digestate created by the anaerobic digestion process. Most of this digester's energy is used for the heating of the digester itself; 50% is the standard rate according to researchers from the Colorado State University (Sharvelle, 2011). Biogas will next be used for on-site heating, accounting for 65% efficiency of this process. The remaining biogas will be used for on-site electricity use, considering the process has 35% efficiency. The digested fiber can either be converted to animal bedding or peat moss, depending upon the profitability. In this case, animal bedding is the chosen option.

The budget for the above described project is shown in Table 3 with the associated net present value (NPV), an indication of profitability that accounts for all cash inflows and outflows over the life of the project.

Our findings indicate that this project is not profitable, having a net present value of about -$0.5 million. The revenue gained from animal bedding cost offset and sale ($104,126, or 70% of total revenue) and electricity bill savings ($44,614, or 30% of total) during the 15 years of the digester's operation is not enough to offset cash outflows created by payment on a loan to cover fixed costs ($205,846, or 68% of total costs), as well as operating and administration costs.

REVENUE (CASH INFLOWS)	
Biogas use/sale:	
Electricity bill savings (energy used on-site)	$44,614
Electricity sold to utility	$0
Renewable Energy Credits (RECs)	$0
By-products:	
Avoided animal bedding cost (digestate solid)	$60,000
Sold animal bedding cost (digestate solid)	$44,126
OR Peat moss	$42,857
Total Revenue:	$148,740
COSTS (CASH OUTFLOWS)	
Operating Costs	$48,378
Admin costs: Legal and Accounting *(yr 1 only)*	$48,378
Total Costs (excl. interest, tax):	$96,757
EBITDA	$51,984
Total Loan Payment (interest & principal)	$205,846
Depreciation	$64,504
Taxable Income	-$218,367
Income Tax	$0
Investment Tax Credit	$0
Total Costs:	$302,603
NPV:	($544,340)

Table 3: Net income and NPV

Next, we analyzed which factors would help improve the profitability of such a project, and we found the following to be most important:

Add substrate. Inclusion of organic substrates such as fats and grease from food waste radically increases the biogas production. We found that feedstock which consists of 25% food wastes and 75% cow manure (which yields ten times more biogas than cow manure alone) improves the project's NPV by about 67%, increasing it to about -$178,000.

Biogas conversion efficiency. If processes which convert biogas to heat and electricity were to improve efficiency, the NPV improves as well. For example, a 10% efficiency increase, (respectively from current 65% and 35% to 75% and 45%), the NPV improves to about +$302,000. Also, if the digester itself used less of the biogas generated, the NPV would become positive. For example, if using 25% of the total biogas generated, rather than 50%, the NPV would be about +$985,000.

Energy efficiency matters. Energy efficiency improvements at a dairy can lead to lower on-site energy use. In our example, if adjusted by 25%, energy efficiency would make this anaerobic digester's profitability improve to about +$165,000 by enabling the facility to sell increased excess electricity to the local utility. We estimate that such sales would contribute approximately $78,000 to revenues in first year alone. A recent report prepared by an energy consultancy for the CEO indicates that such efficiency improvements are within reach (BCS, 2013).

Loans decrease profitability. Not having to take on the loan to cover capital expenditure, by for example deploying one's own funds, would also improve the NPV to about +$132,000. In our estimate, we find the annual loan payment (for interest and principal) to be about $206,000. As discussed in Section 5.4, the applicability of grants should therefore be thoroughly analyzed.

Ability to extract & sell recovered N and P. Being able to sell liquid fertilizer in the form of recovered nitrogen and phosphorous would improve the NPV to about +$51,000. We estimate that the sale of such nutrients would contribute $56,876 in year one (and adjusted for inflation afterwards) to total revenues. Note, however, that while technology for recovering such nutrients exists, we have not found any cases of its successful implementation in the U.S.

Herd size. Finally, we increased the herd size until the point when the NPV became positive. This occurs at 2,000 cows, increasing the NPV to +$58,000. *However, when co-digestion is possible, which includes 25% of food wastes, the "break-even" herd size in our model falls to about 1,500 cows.*

5.2 Colorado Market Size Estimate

According to our model with no added organic substrates, for a medium to large sized on-site facility, break-even herd size is 2,000 cows, while with inclusion of organic substrates, such as food waste, the break-even herd size is 1,500 cows. From the 2012 Census of Agriculture data (USDA, 2012) in Section 4.3.1 we see that the number of dairies with 500 to 999 cows is 39, with 1,000 - 2,499 cows is 24, and with 2,500 cows or more is 15. Assuming that one third of dairies in the "1,000 - 2,499 cows" range has 2,000 cows or more (i.e. 8 out of 24), there are about 23 dairies in Colorado with 2,000 cows or more. Assuming that 87% of these 23 dairies use liquid manure management system (EPA 2011, discussed in Section 4.3.1), our range of dairies with potential economic feasibility for on-site digesters without co-digestion capabilities decreases to 20. In a different scenario, if we assume that dairies will engage in co-digestion (i.e. feedstock is food waste in addition to cow manure), and subsequently need about 1,500 cows to break-even, a larger number of sites is available: approximately 31, assuming that two thirds of dairies in the "1,000 – 2,499 cows" range have 1,500 cows or more (i.e. 16 out of 24). Applying again EPA's 87% probability of use of liquid manure management system, about 27 of such sites would be feasible for an AD system.

The tables below illustrate annual volume of production and revenues from the two scenarios.

Nb of candidate diaries	"Break-even" herd size	Avg. nb of cows/facility	Biogas Production Potential (million ft³/yr)	Methane Production Potential (million ft³/yr)	Electrical Power Output (MW)	Electricity Generation Potential (MWh/yr)
20	2000	3200	602	361	13	114,632
27	1500	2900	3921	2353	85	746,940

Nb of candidate diaries	Avg. nb of cows/facility	Electricity Sold to Utility		Animal Bedding Sale		Peat Moss Sale	
		(MWh/yr)	(million $/yr)	(tonnes/yr)	(million $/yr)	(tonnes/yr)	(million $/yr)
20	3200	-	-	214,040	6.28	320,000	2.29
27	2900	104,783	2.10	261,873	6.96	391,500	2.80

Nb of candidate diaries	Avg. nb of cows/facility	Electricity Bill Savings	Animal Bedding Savings
20	3200	$2,379,420	$3,200,000
27	2900	$3,060,855	$3,915,000

Table 4: Colorado candidate operations, annual energy production and revenues

To put the above energy generation numbers (Table 4) into perspective, the average Colorado household needs about 32 kWh per day for heating (Sharvelle et al., 2012). Assuming, that 50% of a digester's energy goes towards heating of the digester itself and that the efficiency of the biogas use for heating is 65%, then the electricity generation potential of 20 dairies without co-generation potential is enough to heat about 3,200 Colorado households, while the electricity potential of 27 co-digestion dairies is about 21,000 Colorado households. This is not very significant given that Colorado has about 2 million households (US Census Bureau, 2014).

Results also indicate that for systems without co-digestion potential, the main economic benefits come from a system's ability to offset costs (primarily of electricity and animal bedding). Co-digestion systems offer some additional revenue potential from the sale of digestate by-products (about $7 million for animal bedding) and electricity sales to a utility (about $2 million/year).

Co-digester operators may also be able to charge a tipping fee for intake of food wastes which would otherwise go to local landfills. The current landfill fee for Colorado is $49.60 per ton of waste (Clean Energy Projects, 2014). To incentivize food waste providers to separate their waste appropriately and deliver it to the digester rather than a landfill, we assumed that digesters could charge $20 per ton. Under this scenario, tipping fees could add up to approximately $6.5 million per year.

In addition to financial calculations, we quantified several of the mitigating effects provided by potential on-site digesters in Colorado. These include reductions to GHG emissions and methane reductions from the diversion of organic wastes from landfills. A summary of benefits from the potential Colorado digesters is shown in Appendix 9.

- ***GHG emissions reductions.*** A study conducted for the EPA found that anaerobic digesters result in methane reduction of 3.03 tons per cow per year on a CO_2 equivalent basis (Eastern Research Group, 2004). Using this value, we find that on-site digesters with manure as sole feedstock result in GHG emissions reductions of 194,000 tons per year, while on-site co-digesters result in reductions of approximately 237,000 tons per year.
- ***Diversion of organic wastes from landfills***. According to an Informa Economics study (2013a), diversion of 19.8 million tons of organic substrates represents a net 13 $MMTCO_2e$ methane *not* emitted into the atmosphere. Using this ratio, we estimate that 27 co-digestion systems will divert approximately 363,000 tons of food waste, resulting in mitigation of 238,000 metric tonnes CO_2e of methane. This is equivalent to removing about 50,000 passenger vehicles from the road for a year (assuming 4.75 metric tonne CO_2e emitted per vehicle per year (EPA, 2014d)).

In this report we have assessed medium- to large- sized dairies, (those with 500 to 5,000 cows), which total 85% of Colorado cows (EPA, 2011a) and those that meet the criteria for a prime target for *on-site* digesters. The identified sites do not make up the entirety of potential AD sites. There are examples in the U.S. in which smaller digesters have been installed on dairies with100 cows or more. In these smaller facilities, the cost of a digester is from $100,000 to $200,000 (USDA, 2009; Klavon, 2012). Based on data from the EPA's AgStar Operating AD Projects database, such digesters represent 15% of on-farm dairy digesters in the U.S. However, as mentioned previously, smaller dairies are more likely to use solid waste storage methods, making AD challenging. The possibility of developing systems at small dairies in Colorado warrants additional research. Likewise, centralized digesters which collect feedstock from multiple sources can be an important area of development for Colorado.

5.3 Potential Sources of Funding

As seen in our economic analyses, costs associated with anaerobic digestion projects can be quite substantial. However there are a number of sources of funding that a digester operator can access once it has been determined that an anaerobic digester is a viable option. These include grants, use of guarantees, industrial bonds, and other cost sharing agreements, and finally private funding sources (EPA, 2012b). Our contact at the Innovation Center for U.S. Dairy noted that REAP, EQIP and business and industry (B&I) guaranteed loans are particularly prevalent in this market (J. Bingold, personal communication, Oct. 31, 2014).

Grants. Several federal and state-level organizations offer grants, i.e. financing which does not require a payback, for development of anaerobic digester systems. The main sources are:

- Rural Energy for America Program (REAP). This is a federal program for funding renewable energy efficiency projects in rural areas and provides up to 25% of the project's costs as grants and up to 75% of a project's costs as loans. From 2003 to 2010, $37 million has been awarded to anaerobic digesters (Minnesota Project, 2010). Program website: http://www.rurdev.usda.gov/rbs/farmbill/
- Environmental Quality Improvement Program (EQIP). EQIP is also a federal-level program run by the Natural Resource Conservation Service (NRCS) for funding of conservation practices. EQIP's funding for 2007 alone was over $40 million (Stewart Environmental, 2008). EQIP typically provides grants of up to 75% of the upfront costs;however new operators may receive assistance for up to 90% of the costs. Grants are capped at $450,000. Program website: http://www.nrcs.usda.gov/programs/equip
- Conservation Innovation Grants (CIG). CIGs are meant to stimulate innovative conservation approaches and are funded at the federal level. Grants are available for pilot projects and conservation field trials for up to 50% of project costs. Grants are capped at $1 million. Program website: http://www.nrcs.usda.gov/technical/cig/index.html
- Some federal-level resources, such as the State Energy Program, provide grant money to states which then administer grants at the state-level.

Business and Industry (B&I) Guaranteed Loan. This loan is administered by the USDA Rural Development State Office and is a type of loan guaranteed by a federal agency, thereby significantly reducing the cost of financing. For example, a typical corporate loan interest rate for an AD project is 8%, whereas the same municipal loan would incur a 2% interest rate (Wisconsin SEO, 2013). Maximum percentage of guarantee is 80% for loans of $5 million and below, 70% for loans between $5 and $10 million, and 60% for loans exceeding $10 million, with the total amount of one loan guarantee not to exceed $10 million. Program website: http://www.rurdev.usda.gov/rbs/busp/b&i_gar.htm

Industrial Revenue Bonds. These bonds are issued by state or local entities to investors, who then provide funding for the loan. The ownership of the system (in this case the anaerobic digester) is transferred to the issuing state or local entity for the duration of the bond. Such loans typically have a lower interest rate and longer terms compared to simple bank loans. At the end of the bond term, when the AD operator repays the loan, the ownership of the digester is transferred back to him/her.

Other cost sharing agreements. In some instances, electric utilities or other companies may share the cost of the anaerobic digesters via a loan or a grant in return for a portion of the electricity generated by the system, RECs, and/or associated greenhouse gas (GHG) offset credits.

According to the Innovation Center for U.S. Dairy, even when a grant or a guaranteed loan is awarded, it usually takes about a year and a half before the funds are received (J. Bingold, personal communication, Oct. 31, 2014). Until that time, livestock operators will need to use their own resources, obtain a bridge loan from a commercial or agricultural bank, or turn to private funding sources for debt or equity financing.

- Equity financing is more common for large-scale AD projects, which attract large enterprise investors, such as energy and technology companies (EPA, 2012a). One example is the 2011 Loyd Ray Farms swine waste digester built in North Carolina and financed by Google, Duke Energy, and Duke University. In exchange for their funding, Duke Energy receives RECs and Google GHG offset credits generated by the project.
- With regards to debt financing, Dr. Keske from Colorado State University notes (2009) that the collapse of New Frontier Bank in Greeley in 2009, due to massive loan losses, has had a very negative effect on the ability of producers in Colorado to obtain capital for their projects. This sentiment is echoed in the opinions of our market contacts who noted that difficulty in obtaining financing is one of the main obstacles for anaerobic digestion projects.

6 Feedback from AD Market Participants– Key Barriers

For a thorough review of the AD market in Colorado, market participants were interviewed for their views on key barriers to the development of anaerobic digesters on livestock operations. The main barriers presented are as follows:

1) Location and Structure of Colorado Dairies. Although 60% of Colorado's dairies have populations above 1,200 cows, they are mostly dry-lot facilities, which are typically dirt with no vegetation, but may be covered with concrete. Anaerobic digestion of dry-lot manure is technically difficult. In Colorado, sand bedding is often used as well. Anaerobic digesters cannot tolerate soil, sand or other non-volatile solids well, as they take up valuable digester volume and do not contribute to biogas production (Hamilton, 2014).

Additionally, there are concerns that because Colorado is a dry, cold state and that because moisture and heat are necessary for biogas production, that it is technically not feasible. According to Eric Lane of the Colorado Agriculture Department, there is question among the sector from a technological perspective as to how anaerobic digesters can be adapted to Colorado conditions. Colorado livestock operators need to see a successful example of AD (personal communication, Oct. 23, 2014).

__2) Need Additional Feedstock.__ A recurring feedback in the interviews was that manure is a poor substrate for anaerobic digestion by itself. From the point of view of energy and co-product generation, adding more organic material (e.g., feed coming from cheese factories, crop waste, and restaurant grease) is very helpful. Figure 12 shows the relatively low methane potential of dairy manure, but also the potentials for different co-digestion products. Any addition of a co-digestion product to a digester must have a higher methane potential in order to promote biogas production (Hamilton, 2014). When new dairy farms are built in Colorado a survey should be taken for other organic wastes in the area that could be added to dairy facility's waste stream for co-digestion. Co-digestion waste streams should be available to be consistently added to the digester at all times (Sharvelle, 2011).

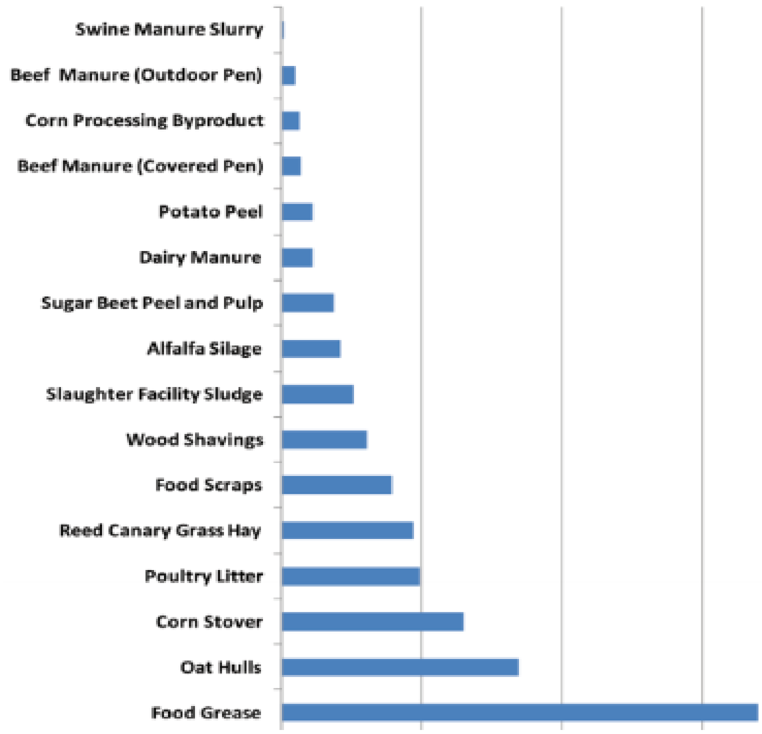

Figure 12 Wet mass methane potential of select substrates (Source: Moody et al., 2011)

__3) Time/Knowledge Limitations.__ Feedback received from nearly every participant was that dairy owners do not necessarily have the time or expertise to manage a digester at their operation. Anaerobic digesters on livestock operations that produce biogas and other co-products, like any technology, require expertise and technological knowledge. Digesters are sensitive to temperature, bacteria, condition of the feedstock, and pH. Installation and daily maintenance of a digester will require one or two additional personnel for the time commitment, as well as the technical ability (J. Potter, personal communication, October 14, 2014).

Expertise will also need to be gained to understand the specific market for co-products and biogas, if those are to be marketed. Tipping fees is another subject that needs to be understood if external sources of feedstocks will be used. According to the Wisconsin State Energy Office (2013), the most successful operations can efficiently procure and utilize non-manure feedstocks, yielding increases in two ways: 1) the production of mixed substrates greatly increases biogas production and 2) tipping profits may greatly improve AD profitability. However, it was also noted that many smaller projects, as well as some larger cases, are not aware of the availability or overall market of non-manure feedstocks (Wisconsin State Energy Office, 2013).

Third-party involvement was recommended by a number of interviewees. The success of Heartland Biogas is of interest to the agricultural community, not only as a third party operator, but also as a working example of anaerobic digestion in Colorado. Fort Collins was cited as an example of a potential site for a third-party digester because of its vicinity to dairies, restaurant grease, and food waste.

4) Difficulties in Obtaining Financing. Anaerobic digesters have significant capital outflows at the outset of an AD project. Most livestock operators do not have $1 million of freely available capital on-hand, as such funding is difficult to obtain on the market. Additionally, in recent years, fluctuating milk prices combined with record feed prices have financially strained many dairy operations.(G. Harper, personal communication, Oct. 23, 2014) However, if AD were seen as a viable market, it is likely that investors would be easier to procure.

5) Additional Barriers. Other barriers that were mentioned, but given less emphasis were nationwide issues, as well as Colorado issues. Nationwide barriers include:

- Difficulty working with utility providers, and
- Desire for incentives similar to those provided to wind and solar.

Colorado-specific barriers include:

- Relatively low cost of electricity: CO (~10¢/kWh), NY (~16¢/kWh), and
- Net-metering limits the client's production of electricity at 120% and 25 kW of the client's average annual consumption.

7 Policy Recommendations

A number of the barriers discussed by market participants are nationwide barriers and technological hurdles that cannot be solved by the Colorado Energy Office. To impact the market for anaerobic digesters on livestock facilities in Colorado, the CEO may use a mix of policy instruments. The CEO's overall mission is "to improve the effective use of all of Colorado's energy resources and the efficient consumption of energy in all economic sectors, through providing technical guidance, financial support, policy advocacy and public communications." Recommendations in this report are within the mission of the CEO and feedback from participants was incorporated into this section.

7.1 Motivations

To understand how to encourage livestock operators to install anaerobic digesters, it is also important to understand motivating factors. Environmental concerns, closer neighbors, and financial incentives are discussed briefly to be able to focus potential policy directions.

Environmental motivations including climate change mitigation may not be the largest factors for a particular livestock operation, but they may play a role. A study of Iowa farmers found that many farmers believe that climate change is occurring. The farmers were also concerned about the effects of climate change on their agricultural operations. At the same time, a substantial portion of the farmers studied did not agree with mitigation of emissions through government intervention (Arbuckle et. al., 2013). According to the Dairy Farmers of America, dairy operators see that the sector's waste is a problem and are interested in changing their environmental and social image (G. Harper, personal communication, Oct. 23, 2014).

As suburban areas grow in size and often closer to previously rural areas, dairies are finding the need to operate in a way that is less noticeable to neighbors. Livestock operators are largely exempt from nuisance complaints due to the Right-to-Farm laws. However, dairy operations anaerobic digesters are a way for them to try to be a 'good neighbor' (E. Lane, personal communication, Oct. 23, 2014).

Financial considerations are naturally important to every business. Financial incentives in the form of payments or subsidies may encourage beneficial activities or encourage an entity to avoid damaging activities. A number of grants and loans are available to digester development on livestock operations as discussed in section 5.3. One consideration is that while environmental subsidies such as those for anaerobic digesters are designed to minimize negative externalities, they are in effect promoting the continuing operation of polluting entities (EPA, 2010b).

However, as we found in our discussions with market participants, it may not make sense to focus solely on financial incentives when the current primary barriers are not related to financing issues. The first hurdle to overcome in Colorado is related to technological and expertise limitations rather than financial ones.

7.2 Future Directions

The CEO has a variety of policy options; however, the best approach would be to include a policy mix of voluntary, regulatory, and financial incentives.

1) Information Source. The CEO can play a role as an information source for potential digester operations. Much information on AD systems is already available from a number of resources, such as AgSTAR, and does not need to be repeated. Colorado-specific information is most needed on

- technical digester information specific to Colorado's climate,
- directory of local 3rd-party appraisal services,
- directory of local knowledgeable contacts,
- utility provider information and contacts,
- supply maps of local co-digestion feedstock sources, and
- energy efficiency savings potential.

There are various processes included in acting as an information source, such as gathering information, collaborating, and the promotion of successes, programs and supporting legislation.

Exchange Information. A re-occurring dialogue is important to continually assess the type and quality of information needed. The CEO could hold monthly informational sessions that are open to the public to present the basics of anaerobic digesters. Additionally, regular meetings could be held for a two-way exchange of ideas between stakeholders and the CEO.

Publicize Successes. When Heartland Biogas becomes fully functional, publicizing the success of this plant will be a useful model of a working digester system for the Colorado agriculture sector. Dispersing this information may be an important factor to changing the current beliefs that AD is not technologically suited for the Colorado climate (E. Lane, personal communication, Oct. 23, 2014).

Collaborate. As an information source, the CEO should collaborate with other Colorado government agencies to increase synergies, reach a wider audience, and avoid overlapping collection and dispersion efforts. Furthermore, several Colorado-specific studies quoted in our report have been commissioned by various Colorado agencies and should be made available from a centralized source. As an example, the studies by Sharvelle et al. (2012), Keske (2009), and Stewart Environmental (2008) should be made readily available to all agencies. The CEO, the Colorado Department of Agriculture and the Colorado EPA branch can jointly play a role in convening stakeholders in addition to information.

Promote Financial Incentives. Promoting the financial incentives that are already in place is especially important. In order to promote biogas technologies, Colorado has passed a sales tax exemption for components used in the production of renewable energy (HB14-1159 Anaerobic Digester Sales Tax Exemption), adding anaerobic digestion to the list of eligible technologies. Additionally, promotion of the CNG program that is expanding in Colorado should be publicized as a potential market for AD biogas.

Promote Energy Efficiency. Dairies use large amounts of electricity, because they operate all day, every day of the week and use energy-intensive systems, such as those for vacuum pumps, high-powered ventilation, and lighting typically for three separate areas (outdoors, the milking parlor, and in the freestalls). A report created for the Colorado Energy Office by BCS Incorporated (2013) shows that employing energy efficiency techniques could reduce dairies' energy use by 10-35%, depending on their equipment. The results in this paper's economic analysis show a significant improvement of NPV if the dairy's energy use is reduced, because more electricity becomes available for sale. Some of the recommendations in the BCS report are shown in Appendix 10.

2) Broker Relationships. CEO can broker relationships with a number of entities to improve the chances of success, as well as expedite the set-up process for a new digester. These brokering opportunities could include cultivating relationships with banks, county governments, and utility providers.

Banks. Financiers typically assess the viability of a project for an initial loan. If projects of this type could get a 'seal of approval' from CEO, the projects could be seen as more viable and would be more likely to be financed. By backing the project with feasibility documentation from assessments, as well as AgSTAR documentation, the bank is more likely to find the project lucrative.

County governments. CEO can provide verbal assurance to county governments that this is a legitimate business model and potentially be of assistance through local permitting procedures.

Utility providers. Participants in our interviews said that AD operators were having difficulty working with their utility providers. CEO can broker relationships with utility companies, easing and expediting information gathering and contractual agreements.

Relationships need to be cultivated with AD stakeholders, such as livestock facility operators, potential investors, biogas industry representatives, and restaurant associations. In order to initially cultivate these relationships, the CEO could create a coalition of these stakeholders. This information can be made available in a database to stakeholders.

3) Mimic Other States' Successful Regulatory Policies.

Massachusetts landfill regulations. With the understanding that the anaerobic digester market is competing primarily against other waste disposal costs, another incentive is to increase costs or prohibit certain waste disposal in landfills. In October 2014, a new Massachusetts regulation went into effect prohibiting commercial food waste from being disposed in landfills. Entities that dispose of at least one ton of organic material per week must re-purpose or donate the usable food. Residual food waste will be transported to an AD facility, sent to animal feeding operations or composting facilities. This ban may have been part of the motivation for increased development of anaerobic digesters in Massachusetts (G. Harper, personal communication, Oct. 23, 2014). Not only does AD look more attractive for waste reduction, but more feedstocks will be available for co-digestion, potentially with tipping fees.

According to the state's Office of Energy and Environmental Affairs (2014), in hopes of reducing their waste stream and enhancing the State's energy portfolio, Massachusetts implemented other steps in order to boost this particular policy's success. These include:

- Providing technical assistance and up to $1 million in grants to ensure that there are a sufficient number of composting or AD facilities to manage the organic material resulting from the ban.
- Starting the "RecyclingWorks in Massachusetts" program, which includes online, phone and technical assistance.
- Establishing a partnership with the Massachusetts Food Association to help 300 supermarkets implement food separation, saving each store up to $20,000 per year.

California FiT. Biogas feed-in-tariffs (FiTs) and power purchasing agreements such as California's may be helpful to promote a stable market for AD-generated electricity in Colorado. The California Renewable Market Adjusting Tariff (ReMAT) Feed-in-Tariff was designed to offer standard contracts to small renewable energy producers of up to 3 MW systems. Investment in alternative energy production is promoted by offering contracts of 10, 15 or 20 years and requiring utilities to pay a specific price per megawatt hour ($89.23/MWh as of 12/04/2014). California Senate Bill (SB) 1122, established an additional 250 megawatts (MW) bioenergy goal for investor-owned utilities, 90 MW of which are required to be from dairy anaerobic digesters. (DSIRE, 2014) Currently, the Heartland Biogas facility in LaSalle, Colorado sends their biomethane through a pipeline to California to benefit from this tariff (J. Potter, personal communication, October 14, 2014).

One final consideration with policy implementation is the need to balance encouragement for development of AD systems, while not necessarily subsidizing anaerobic digesters for CAFOs. Due to technological limitations, our report shows that confined livestock facilities with a large number of animals, CAFOs, are most likely to find on-site AD systems feasible. Additional market advantages for CAFOs could have repercussions for the viability of small farmers and those that pasture feed, which make up a large portion of Colorado's agriculture sector. One option to avoid this problem is to focus on incentives for centralized co-digesters run by third parties, rather than CAFOs.

8 Conclusion

Colorado's rapidly increasing dairy sector may contribute to the state's energy production. The industry is growing, as dairies move to Colorado from other states due to the regulatory environment and enhanced business opportunities. Anaerobic digesters are a consideration for some of the new operations due to their potential for pollution mitigation, as well as reduced energy production.

On-site anaerobic digesters at large facilities, and in particular dairies, have environmental mitigation effects and may be a source of renewable energy. Our findings indicate there are barriers to on-site digesters in Colorado, primarily manure management practices, operation size, time and knowledge limitations, financing, and the need for additional feedstock. As well as targeting the relatively small number of facilities that would find an on-site digester profitable, we suggest an additional focus on centralized digesters run by third parties, who have the time, knowledge, as well as the finances to make the endeavor profitable and efficient. For all AD systems, we encourage co-digestion and energy efficiency improvements to the facility, as a way of maximizing profits.

Our policy recommendations include that the CEO consider motivating factors behind AD system implementations when designing policies. We recommend cultivating relationships with stakeholders, as well as those that might contribute to co-digestion success, such as restaurant and grocery associations. As a central information source for participants, focus should be on Colorado-specific information, and information such as energy efficiency and co-digestion that greatly improve the success of an AD system. Regulatory policies can be mixed with these voluntary policy implementations to enhance the market in Colorado.

As anaerobic digester technologies advance, small-farm or dry-solids handling systems may emerge, allowing a more widespread use of AD systems. To this point, it is important to continue evaluating the market for potential to spread this renewable energy producing technology with so many environmental mitigation benefits. Development of bioenergy technologies such as anaerobic digesters, that produce energy from a former waste stream, are critical to Colorado's energy portfolio as well as to the environmental health of our beautiful state.

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Appendix 1

List of Market Participants Interviewed

AgEnergy USA, LLC
Jim Potter (President)
Website: http://agenergyusa.com

BioCNG, LLC
Jay S. Kemp (Engineering Manager)
Website: http://biocng.us

Colorado Department of Agriculture
Eric Lane (Division Director, Conservation Services)
Website: http://www.colorado.gov/ag

Innovation Center for U.S. Dairy
Jerry Bingold (Director - Renewable Energy)
Website: http://www.usdairy.com

Dairy Farmers of America
George Harper (Industry and Public Affairs)
Website: http://www.dfamilk.com

Appendix 2

U.S. Digesters Summary Statistics

US DAIRY DIGESTERS SUMMARY STATISTICS - Under Construction															
Status		**Animal Type**		**Location**		**Project Type**		**Population Feeding Digester**		**Installed Capacity (kW)**		**Digester Type**		**Biogas End Use(s)**	
Under Construction	**16**	**Dairy**	**12**	Top 3 states	8 (PA 4, VT 2, ID 2)	**Farm Scale**	**10**	Range	60 - 15,500	Range	300 - 7,600	Complete Mix	4	Electricity	9 (1 CNG)
		Beef	2	Other	4 (NM, NY, WI)			Average	4,527	Average	2,250	Fixed Film	3	Boiler/Furnace fuel	-
		Cattle	1					Unknown	1	Unknown	4	Modified Plug	1	Pipeline Gas	-
		Unknown	1									Unknown	2	Cogeneration	1
						Centralized/Regional	**2**	Range	1,800	Range	4,800	Complete Mix	1	Electricity	-
								Average	1,800	Average	4,800	Fixed Film	-	Boiler/Furnace fuel	-
								Unknown	1	Unknown	1	Modified Plug	-	Pipeline Gas	1
												Unknown	1	Cogeneration	1

US DAIRY DIGESTERS SUMMARY STATISTICS - Operational															
Status		**Animal Type**		**Location**		**Project Type**		**Population Feeding Digester**		**Installed Capacity (kW)**		**Digester Type**		**Biogas End Use(s)**	
Operational	**239**	**Dairy**	**190**	Top 3 states	88 (WI 33, NY 32, PA 23)	**Farm Scale**	**161**	Range	75 - 24,900	Range	20 - 6,750	Plug Flow	78	Cogeneration	76
		Swine	29	Top 5 states	118 (above + VT 15, CA 15)			Average	2,124	Average	660	Complete Mix	44	Electricity	63 (1 CNG)
		Mixed	7					Unknown	9	Unknown	20	Covered Lagoon	18	Flared	9
		Cattle	4									Fixed Film	1	Boiler/Furnace fuel	5
		Beef	3									Other	16	CHP (comb, heat & power)	2
		Other	5									Unknown	4	Unknown	6
		Unknown	1			**Centralized/Regional**	**16**	Range	1,255 - 10,000	Range	300 - 3,000	Complete Mix	11	Electricity	12 (4 CNG)
								Average	3071	Average	1,082	Plug Flow	5	Cogeneration	3
								Unknown	4	Unknown	1			Pipeline Gas	1
						Unknown	10								
						Research	3								

Table 5: U.S. digesters summary statistics (based on EPA AgStar Operating Projects database)

Appendix 3

Types of AD Systems

Characteristics	Covered Lagoon	Complete Mix Digester	Plug Flow Digester	Fixed Film
Farm Type	Dairy, Hog	Dairy, Hog	Dairy Only	Dairy, Hog
Optimum Location	Temperate and Warm Climates	All Climates	All Climates	Temperate and Warm Climates
Digestion Vessel	Deep Lagoon	Round/Square in/above Ground Tank	Rectangular In-Ground Tank	Above Ground Tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	0.5 - 3%	3 - 10%	11 - 13%	3%
Solids Characteristics	Fine	Coarse	Coarse	Very Fine
Solids Separation Prior to Digestion	Recommended	Not Necessary	Not Necessary	Required
Food Waste/Manure Mix	0%	> 25%	< 25%	[?]
HRT* (days)	40-60	15+	15+	2-3
Co-Digestion Compatible	No	Yes	Limited	Yes
Biogas Yields	Low	Medium	Medium	High

**Hydraulic Retention Time (HRT) is the average number of days a volume of manure remains in the digester.*

Table 6: Suitable digester technology matrix (Source: EPA, 2009b)

Characteristics	Covered Lagoon	Complete Mix Digester	Plug Flow Digester
Primary Products			
Electricity Production	Yes	Yes	Yes
Pipeline Quality Biomethane	Yes	Yes	Yes
CNG	Yes	Yes	Yes
Co-Products			
Recovered Nitrogen (N)	No	Yes	Yes
Recovered Phosporous (P)	No	Yes	Yes
Recovered Potassium (K)	No	Yes	Yes
Nutrient Rich Fiber	No	Yes	Yes

Table 7: Products produced by anaerobic digester type (Source: Informa Economics, 2013a)

Appendix 4

EPA AgSTAR Selection of Appropriate Technology Questionnaire

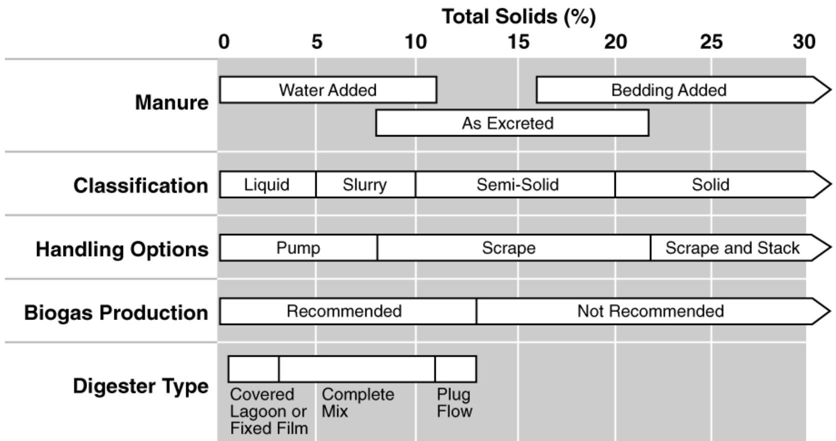


Figure 13: Appropriate manure characteristics and handling systems for specific systems (Source: EPA, 2009)

Climate†	Animal Type	Collection System	Estimated Min. Ratio of Water:Manure*	%TS	Digester Type
Moderate to Warm	Dairy	Flush	10:1	< 3%	Covered Lagoon Fixed Film
		Scrape & Parlor Wash Water	4:1 - 1.1:1	3% - 11%	Complete Mix
		Scrape - Manure Only	N/A	> 11%	Plug Flow
	Swine	Flush	10:1	< 3%	Covered Lagoon Fixed Film
		Scrape	2:1	3% - 6%	Complete Mix
		Pull Plug	5:1	< 2%	Covered Lagoon
		Managed Pull Plug	3:1	3% - 6%	Complete Mix
Cold	Dairy	Flush	10:1	< 3%	Limited possibility for Covered Lagoon
		Scrape & Parlor Wash Water	4:1 - 1.1:1	3% - 8%	Complete Mix
		Scrape - Manure Only	N/A	> 11%	Plug Flow
	Swine	Flush	10:1	< 3%	Limited possibility for Covered Lagoon
		Scrape	2:1	3% - 8%	Complete Mix
		Pull Plug	5:1	< 3%	Limited possibility for Covered Lagoon
		Managed Pull Plug	3:1	3% - 6%	Complete Mix

Table 8: Matching a digester to your facility (Source: EPA, 2009)

Appendix 5

EPA AgSTAR AD System Feasibility Questionnaire

Checklist for facility characteristics:

1.	Do you have at least 500 cows/steer or 2,000 pigs at your facility?	Yes ❑	No ❑
2.	Are these animals in confinement all year round?	Yes ❑	No ❑
3.	The average animal population does not vary by more than 20% in a year?	Yes ❑	No ❑

If the answer is **YES** to all the above questions, your facility is in good shape. Proceed to the next section. If the answer is **NO** to one or more of the above questions, the production and utilization of biogas as a fuel may not be suitable for your facility. For biogas production and utilization to succeed, a continuous and relatively consistent flow of biogas is required. However, collecting and flaring biogas can reduce odors. Therefore, also proceed to the next section if you have the need for an effective odor control strategy.

Checklist for manure management:

1.	Do you collect manure as a liquid/slurry/semi-solid?	Yes ❑	No ❑
2.	Is the manure collected and delivered to one common point?	Yes ❑	No ❑
3.	Is the manure collected daily or every other day?	Yes ❑	No ❑
4.	Is the manure sand relatively free of clumps of bedding and other material, such as rocks, stones, and straw?	Yes ❑	No ❑

If the answer is **YES** to all the above questions, manure management criterion is satisfied. If the answer is **NO**, to any of the questions, you may need to change your manure management routine. See text.

Checklist for energy use:

1.	Are there on-site uses (e.g., heating, electricity, refrigeration) for the energy recovered?	Yes ❑	No ❑
2.	Are there facilities nearby that could use the biogas?	Yes ❑	No ❑
3.	Are there electric power distribution systems in your area that could or do buy power from projects such as biogas recovery?	Yes ❑	No ❑

If the answer is **YES** to any of the above questions,
the energy use criterion is satisfied for initial screening purposes.

Checklist for management:

1. Is there a "screw driver friendly" person on the farm that can operate and maintain the technical equipment?	Yes ❑	No ❑
2. If YES, can this person spend about 30 minutes a day to manage the system and 1 to 10 hours on occasional repair and maintenance?	Yes ❑	No ❑
3. Will this person be available to make repairs during high labor use events at the farm?	Yes ❑	No ❑
4. Is technical support (access to repair parts and services) available?	Yes ❑	No ❑
5. Will the owner be overseeing system operations?	Yes ❑	No ❑

If the answers are **YES** to the above questions, the management criterion is satisfied. In general, if the owner is committed to seeing the system succeed, it will.

Initial appraisal results checklist:

1. Are there at least 500 cows/steers or 2,000 hogs in confinement at your facility year round?	Yes ❑	No ❑
2. Is your manure management compatible with biogas technology?	Yes ❑	No ❑
3. Can you use the energy?	Yes ❑	No ❑
4. Can you be a good operator?	Yes ❑	No ❑

If the answer is **YES** to all questions, there are promising options for gas recovery. Proceed to Chapter 3, where the project technical and economic feasibility will be determined. If you answered **NO** to any of the questions, you may need to make some changes. Read the relevant section, evaluate the cost of changes required, if any, before proceeding.

Figure 14: EPA AgSTAR AD system feasibility questionnaire (Source: EPA, 2009)

Appendix 6

Colorado State University AD Feasibility Assessment Tool

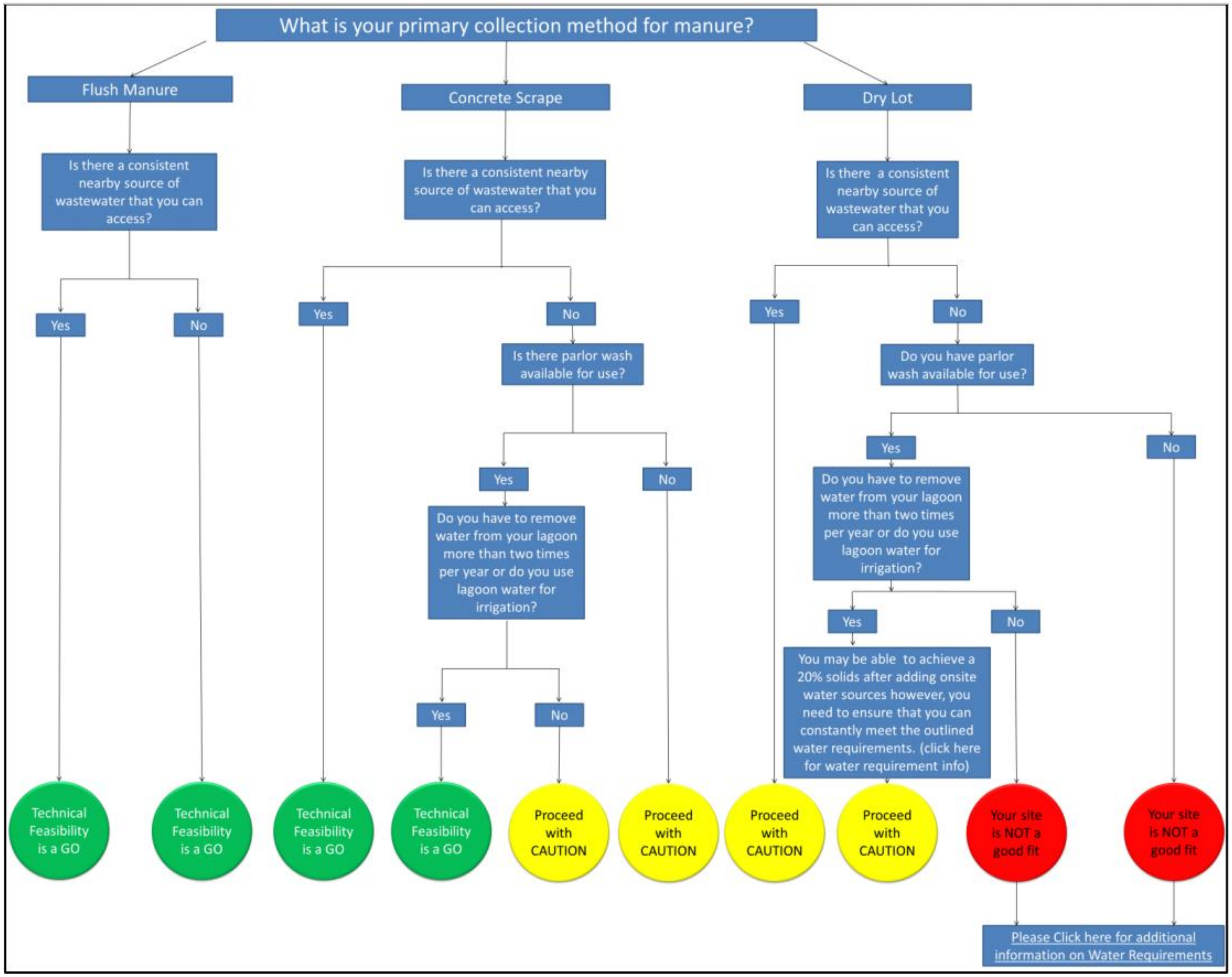
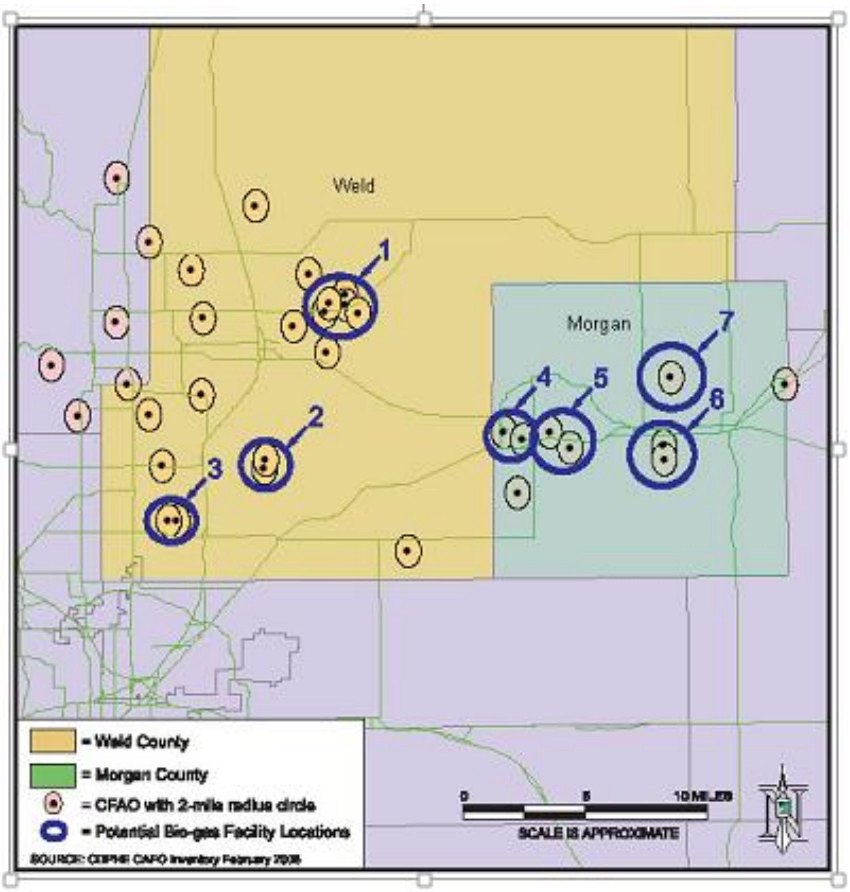


Figure 15: CSU AD feasibility assessment tool (Source: Lasker, 2013)

Appendix 7

Stewart Environmental Proposed AD Sites



Site #	County	Current Number of cows	Permitted Number of cows	Area (sq mi)	Density (cows/mi)
1	Weld	10,875	15,850	13	837
2	Weld	5,200	9,000	2.6	2,000
3	Weld	5,500	6,100	1.6	3,438
4	Morgan	9,700	12,300	5.7	1,702
5	Morgan	5,300	8,700	3.2	1,656
6	Morgan	5,872	12,935	3.2	1,835
7	Morgan	5,000	10,000	N/A	Single Farm

Figure 16: Proposed AD sites (Source: Stewart Environmental, 2008)

Appendix 8

Model AD System Assumptions

Technology type	Complete Mix	
Item	**Amount**	**Units**
Projected Biogas Production	5.75	ft^3/lb of VS
Volatile Solids Conversion Rate	33%	
Conversion of Biogas to Fuel Efficiency	65%	
Conversion of Biogas to Electricity Efficiency	35%	
Digested fiber recovery rate	7	$yard^3$/cow/yr

Table 9: Digester System Assumptions

Item	Amount	Units
Dairy Electricity Use	1,200	kWh/day
		~ 1 kWh/cow/day
Dairy Cost of Electricity	0.1071	$/kWh
Utility's Purchase Price of Electricity	0.02	$/kWh
REC price	1.00	$/MWh
Bedding Sales Price	18	$/ton of fiber
Cost of Bedding	50	$/cow/year
Amount of Bedding Needed per Cow	10	lb/cow
Peat Moss Sale Price	10	$/$yard^3$
Recovered N Price	0.25	$/lb
N coefficient	60%	
Recovered P Price	0.22	$/lb
P coefficient	80%	
Capital Cost of a Digester	996,464	$/digester
		= $563 per cow + $320,864
Generator Cost	40%	of capital cost
Solids Separation System Cost	6.4%	of capital cost
Operating Costs	5%	of capital cost
Admin. Costs	5%	of capital cost

Table 10: Revenue and Cost Assumptions

Appendix 9

Summary of Benefits from Potential AD Systems

(a) For 20 on-site digesters without co-digestion

Number of Candidate Dairies	20
Break-even Herd Size	2,000
Average Number of Cows/Facility	3,200
Biogas Production Potential	602 million ft^3/yr
Methane Production Potential	361 million ft^3/yr
Electrical Power Output	13 MW
Electricity Generation Potential	114,632 MWh/yr
Electricity Bill Savings	$2,379,420/yr
Animal Bedding Savings	$3,200,000/yr
Animal Bedding Sale	$6,275,720/yr
GHG Emissions Reduction	193,920 tons/yr

Table 11: Summary of benefits of on-site ADs without co-digestion

(b) For 27 on-site digesters with co-digestion

Number of Candidate Dairies	27
Break-even Herd Size	1,500
Average Number of Cows/Facility	2,900
Biogas Production Potential	3,921 million ft^3/yr
Methane Production Potential	2,353 million ft^3/yr
Electrical Power Output	85 MW
Electricity Generation Potential	746,940 MWh/yr
Electricity Bill Savings	$3,060,855/yr
Animal Bedding Savings	$3,915,000/yr
Animal Bedding Sale	$6,958,143/yr
Electricity Sold to Utility	104,783 MWh/yr
	$2,095,659/yr
Tipping Fee	$7,259,193/yr
Food Waste Reduction	362,960 tons/yr
GHG Emissions Reduction	237,249 tons/yr

Table 12: Summary of benefits of on-site ADs with co-digestion

Appendix 10

BCS Energy Efficiency Recommendations

Listed below are some of the potential improvements as they appear in the energy efficiency report from BCS, Incorporated, to Colorado Energy Office.

- ***Vacuum pumps***: Using lower horsepower vacuum pumps, coupled with the use of variable-speed technology, could reduce the pumps' electricity consumption by 50%–65%.

- ***Lighting:*** Switching from T-12 lamps to T-8 or T-5 fluorescent tubes for indoor lighting could save more than 20% in electricity consumption, and they will also last longer than T-12 bulbs.

Additionally, a Colorado dairy recently reported installation of an outdoor light-emitting diode (LED) light that has proven to be very effective for the operation's lighting needs; although, the dairy views the single LED light bulb as a test case for further consideration due to its high initial cost.

Other efficient lighting options include high-pressure sodium lights can be installed to replace incandescent light bulbs in barnyards. High-pressure sodium lights for barnyards are more efficient and have an expected life of about 24,000 burning hours, or six years, for photo-controlled fixtures.

- ***Ventilation fans:*** Variable speed ventilation fans with sensors that can auto-detect when conditions require that they be turned on could save electricity compared to older ventilation technologies.

In addition, new dairy facilities can be designed to completely eliminate fan loads by installing steep ceilings that will pull the hot air up quickly and out of the facility.

- ***Refrigeration:*** The installation of a refrigeration heat recovery unit can pull and recover 20%–60% of the energy in the form of heat from milk that is in the cooling process. This process typically uses a technology called a plate heat exchanger and serves to both lower refrigeration energy costs by precooling the milk and warms water that can be used for washing and providing drinking water for the herd.

- ***Renewable Energy Development.*** Installation of methane digesters and solar thermal systems are important energy opportunities for dairies.

Source: BCS, Incorporated. (2013). Colorado Agricultural Energy Market Research Phase II: Market Research Report for the Colorado Energy Office.