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consulting engineers and scientists

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October 20, 2008

Ms. Stacy Romero
Colorado Department of Agriculture
700 Kipling Street, Suite 400
Lakewood, Colorado 80215

Subject: Report of a Feasibility Study
Project No.: 4113.001(1)

Dear Ms. Romero:

Stewart Environmental Consultants, Inc. is pleased to provide the Colorado Department of Agriculture with the enclosed Report of the Feasibility Study on Utilizing Anaerobic Digesters to Generate Biogas from Diary Cattle (Contract Routing Number (CLIN#): 08BAA00188). The report represents our research findings on this subject and offers insight into the viability of such operations in Colorado, as well as the potential next steps.

It is our sincere desire that this research information will further the development of similar renewable energy projects in the state as well as the country. We are honored to have had the opportunity to research this important subject, and it is our intention to carry this research forward to successful commercialization.

Sincerely,

STEWART ENVIRONMENTAL CONSULTANTS, INC.

Fred Porter
Project Manager

David R. Stewart, PhD, PE
President and CEO

Enc.

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Report of the Feasibility Study on Utilizing Anaerobic Digesters to Generate Biogas from Dairy Cattle

Prepared for:

Colorado Department of Agriculture
Lakewood, Colorado

Prepared by:

Stewart Environmental Consultants, Inc.
Consulting Engineers and Scientists
Fort Collins, Colorado

October 2008

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EXECUTIVE SUMMARY

Funding for this report was provided by the Colorado Department of Agriculture (CDA) through their Advancing Colorado's Renewable Energy (ACRE) Program. The CDA award the ACRE grant to Stewart Environmental Consultants, Inc., an environmental consulting firm based in Fort Collins, Colorado, to study the feasibility of building regional anaerobic digesters. This report details a business model that will support the installation of regional anaerobic digesters, which will help dairy farmers handle their manure and create energy in the process.

According to the CDA, Colorado's dairy industry is ranked fifteenth in the nation for total milk production with the highest amount of milk produced per cow in the country. Colorado has a population of approximately 115,000 dairy cows and 150 licensed dairy farms. The CDA predicts that more than $300 million worth of milk are produced a year in the state and the dairy industry contributes 8,000 jobs to the state and is responsible for nearly $1 billion in revenue to the states economy. Based on these statistics, the dairy industry is a huge contributor to the state's economy.

In an article published by the Northern Colorado Business Report in October of 2007, Mr. Greg Yandoo, chief operating officer (COO) for the Salt Lake City based Mountain Region of Dairy Farmers of America Co-op, said:

> "We lose about 5 percent of our farms each year," Yando said. "When I started in 1977 there were about 600 to 700 dairy farms in Colorado. Now there's about 150."
>
> Urban encroachment, high milk production costs and other factors have reduced those numbers," he said. "Still, Colorado is well-suited to dairying and the future for well-managed dairies appears bright," Yando added.
>
> "It's a tremendous climate for milking cows," he said. "Cows are adverse to heat, more so than cold. Cows can't manage heat and humidity very well."

Despite the reduction in number of farms, Colorado is ranked fifteenth for milk production in the United States and has the highest rate of milk production per cow. All of these facts point to more large well managed dairy farms in the state of Colorado, which bodes well for anaerobic digesters to produce green energy.

Colorado's population of dairy cattle creates environmental concerns for both the air and water in Colorado. The Department of Agricultural and Resource Economics at Colorado State University in Fort Collins, Colorado conducted a study, and they subsequently estimated that a healthy dairy cow produces 19 tons of Greenhouse Gases (GHG) equivalents[1] a year. The amount of GHG emissions released by one dairy cow a year is equivalent to burning 1,910 gallons of gasoline or the amount of CO_2 emissions produced by driving 3.5 passenger cars for a

[1] A GHG equivalent is the destructive effect of a gas released into the atmosphere as defined in a quantity of CO_2 gas emissions. As an example one metric ton of methane gas is equivalent to 19.1 metric tons of CO_2.

year. In Addition to the release of GHG on their farms, dairy farmers are also facing Colorado Regulation 61, which imposes restrictions on process water storage and requires a nutrient management plan. Additionally, Colorado's demand for additional "green" power continues to grow and electric utilities need to meet Colorado Amendment 37, which stipulates that 10 percent of their energy must come from renewable resources by 2015. Federal and state agencies, electrical power producers, and dairy farmers can work together to create feasible solutions to solve the environmental issues and meet the new regulations and laws.

Some preliminary solutions to date include distributed generation, which is a means to provide additional power locally without requiring the development of new transmission facilities, and processing cow waste – manure – through anaerobic digestion, which produces methane gas as a by product that can be used as a direct fuel source or to fuel electric generators.

Regional anaerobic digesters designed to digest dairy cow manure create renewable energy, reduce GHG emissions and benefit both farmers and electric utilities; farmers benefit by being able to treat their process water onsite, reduce the necessary onsite storage, and improve handling of nutrient liquid by-product from the process; and electric utilities benefit from the creation of a reliable renewable energy source that can provide a steady supply of electricity.

The capital costs of installing an anaerobic digester are significant, and it is unrealistic to expect all but the largest dairy farmers to be able to afford these costs alone. There are some grants and low-interest programs available through the U.S. Department of Agriculture (USDA) rural development office, which could potentially help finance a regional digester project. A viable option that should not be overlooked are cooperatives, dairies, or even complementary industries, such as food processors, that could form cooperatives with dairies to mitigate the initial cost of installing an anaerobic digester, which could benefit all parties by processing their waste. Additionally, Stewart Environmental has been contacted by several "Green Project Financiers," who are looking for projects that offset GHG. These investors are interested in constructing and operating regional anaerobic digesters based on the pay back from the electrical generation, carbon credits, and other by-products. This model of outside investors owning and operating the regional digesters is very promising. The regional digester model developed in this study produced an impressive 18 percent internal rate of return.

1.0 INTRODUCTION

Stewart Environmental Consultants, Inc. received a grant from the Colorado Department of Agriculture (CDA) through their Value-Added Development Board, which administers the Advancing Colorado's Renewable Energy (ACRE) Program to study the feasibility of regional anaerobic digesters for processing dairy cattle waste and generating renewable energy in the form of biogas. The Environmental Protection Agency (EPA) AgSTAR program estimates that there are currently "111 anaerobic digesters operating at commercial live stock facilities in the [United States]." The EPA estimated that in 2007, those facilities generated "215 [megawatt] hours equivalent of useable energy."

Stewart Environmental conducted this feasibility study to determine the appropriate technology for a regional biogas facility, the economics of the potential project, and identification of various funds to move this project forward. Data was gathered via internet searches, interviews with local dairy farmers, operators of successful anaerobic digesters, anaerobic digester vendors, power companies, and other interested parties.

2.0 PROJECT PURPOSE

The purpose of this feasibility study is to determine the feasibility of regional anaerobic digesters in Colorado servicing several local dairy farms and producing green energy in the form of biogas. The specific tasks are:

- Identify proposed facility sites
- Identify optimal anaerobic technology for the application
- Identify significant pieces of equipment
- Identify waste transport methods and requirements
- Identify the range of potential by-products including energy, nutrient removal, and solids
- Assess financing, business, and regulatory arrangements
- Assess design criteria for optimal product output quantity and quality
- Survey similar recent projects and outline their keys to success and/or failure

3.0 COLORADO DAIRY INDUSTRY

Milk production in Colorado has increased by 25 percent from 2002 to 2007 moving the state to the rank of fifteenth for milk production (volume) in the United States. Colorado is an ideal state for the dairy industry given its dry climate and moderate temperatures; dairy cows enjoy the cool, arid climate. Recently, Colorado was ranked first in milk production per cow in the United States.

3.1 Confined Animal Feeding Operation (CAFO)

In the state of Colorado, there are approximately 204 CAFOs registered with the Colorado Department of Public Health and Environment (CDPHE). These CAFOs include: poultry, cattle, hog, and dairies. Of the 204 registered CAFOs, approximately 27 are dairies, which have a total recorded population of approximately 75,000 cows and capacity for a total of 146,575 cows. The Colorado Department of Agriculture estimates that there are 115,000 dairy cows in the state. For the sake of this report, we used the CDPHE data and no further census was taken or researched.

The majority of all the dairy cows in the state are located within three counties, below is a table listing the number of cows by county.

Table 1: CAFO Dairy Cows by County

County	CAFOs	Current Number of Cows	Maximum Operating Capacity
Weld	21	33,145	65,290
Morgan	10	24,272	52,335
Larimer	3	9,000	9,500
All other counties	7	8,930	19,450

Weld and Morgan counties have 76 percent of the population of dairy cows within the state; therefore, these counties will be the area of focus for locating regional biogas facilities. A further consideration of the locations of biogas facilities is the density of the cattle per square mile. Below, is a table describing the density of dairy cattle in the three higher cattle population counties.

Table 2: Diary Cow Density

County	Area (Square Miles)	Current Number of Cows	Density of cows (Cows/Square Mile)
Weld	4,004	33,145	8.3
Morgan	1,296	24,272	18.7
Larimer	2,640	9,000	3.4

Given that Weld County is more than three times the size of Morgan County and that it has only approximately 8,800 more cows, there is no surprise that Morgan County has the highest density of dairy cows. However, all of the dairy activity in Weld County is in the southern and western portions of the county. Therefore, we have determined that there are six viable sites for regional biogas facilities based on the criteria of 5,000 dairy cows within a 2-mile radius.

On average, a 1,400 pound (lb) dairy cow produces 23 gallons of manure a day, which translates to 1,725,000 gallons of manure a day in the state of Colorado and 1,320,000 gallons of manure in Weld and Morgan counties alone. If all of the manure in these two counties was processed, it would equate to 49 million cubic feet (ft^3) of biogas a day or enough gas to generate more than 100 megawatts (MW) of electricity.

Transporting manure is costly and labor intensive, so it is critical to the success of any regional biogas facility that transportation of manure is minimized. The combined labor and fuel costs make it unfeasible to be transporting manure more than 5 miles. Therefore, sites were chosen within a 2-mile radius; however, the ideal arrangement would be to pump manure to the biogas facility eliminating the high cost of transportation.

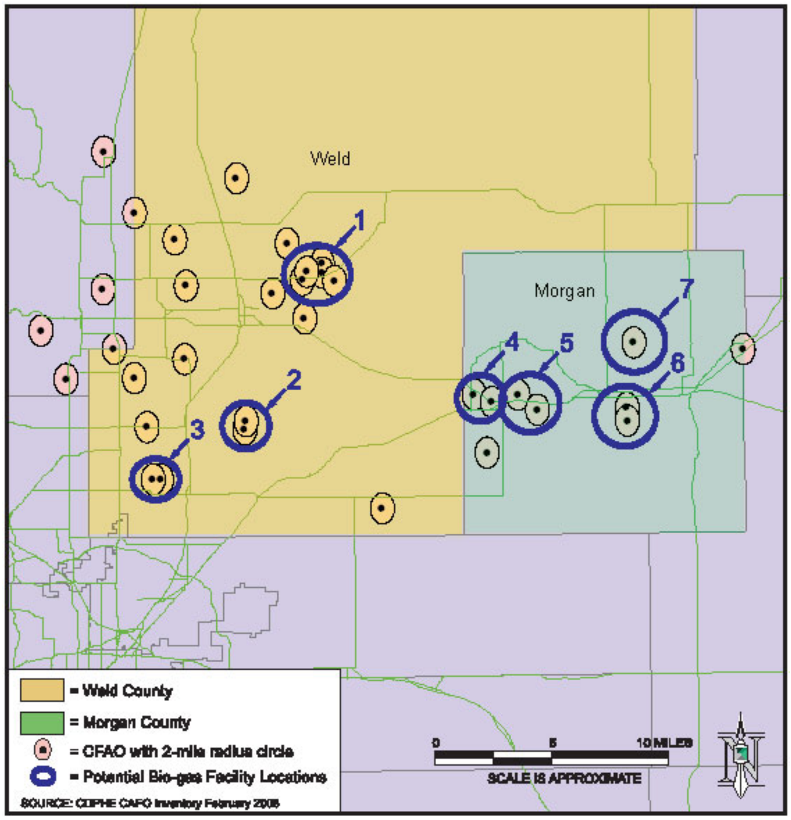


Figure 1: CAFO sites in Weld and Morgan Counties.

The figure to the right is a map of dairies based on the data supplied by CDPHE. All farms have a 2-mile diameter circle shown. There are three potential regional biogas facility sites in Weld County and three in Morgan County. One dairy farm in Morgan County has a large enough herd to support its own regional biogas facility.

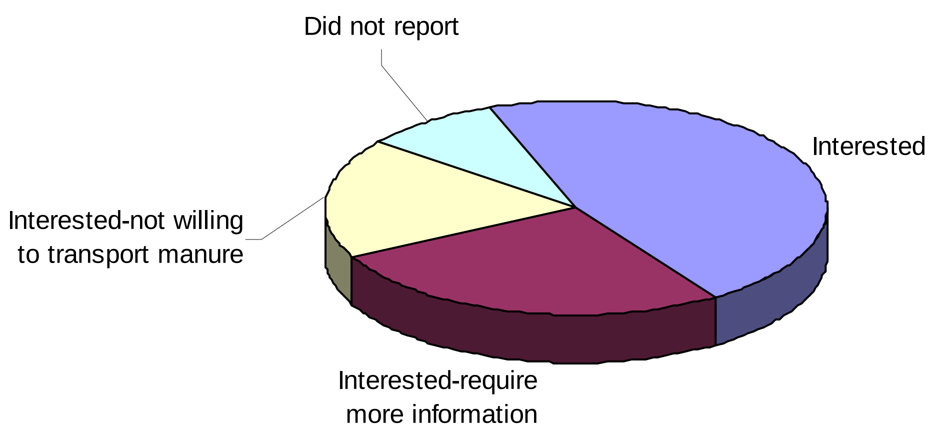
Table 3: Proposed Sites and Density of Cows

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

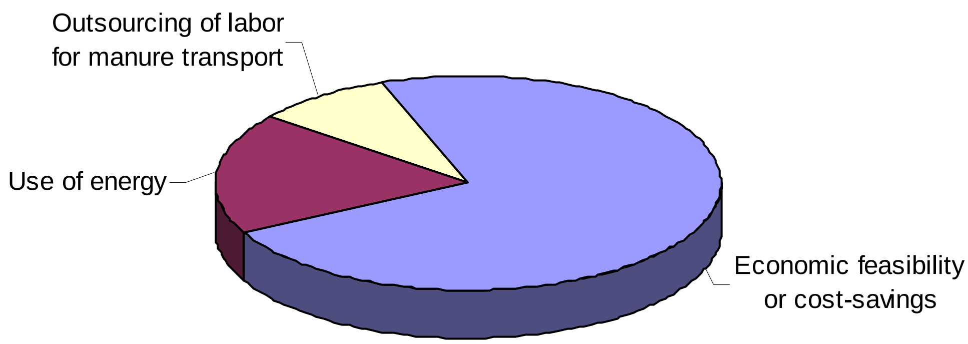
3.2 Phone Survey

Stewart Environmental conducted a phone survey to assess interest in the utilization of anaerobic digesters on CAFOs in Northern Colorado. Fourteen dairy farms registered with CDPHE in Larimer, Weld, and Morgan counties were contacted. Of these fourteen farms, two declined to partake in the phone survey because they were not interested and one declined because they were under a due diligence contract study and could not give information concerning their operations. The remaining 11 dairy farms that partook in the phone survey were asked a series of questions concerning their operation and interest. These phone surveys yielded the following results:

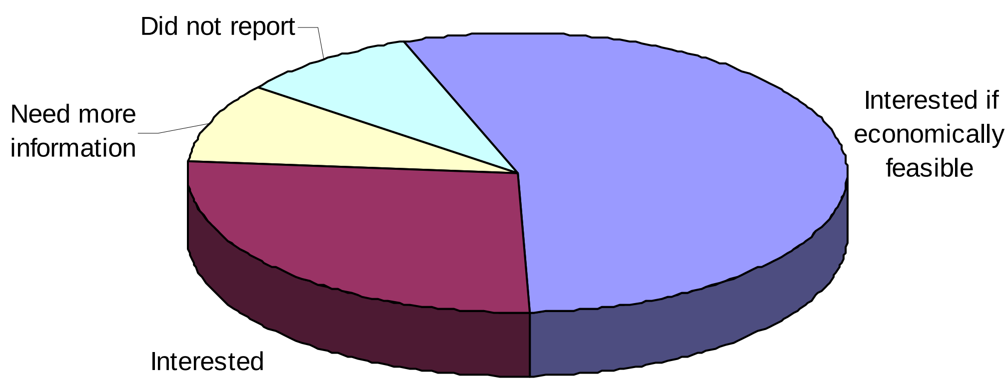
- When asked about their interest in participating in a regional digester project, the farmers responded as indicated below:
    - 46 percent were interested in participating
    - 27 percent wanted more information
    - 18 percent were interested, but were not willing to transport manure to a centralized location themselves
    - 9 percent did not report



- When asked about what would make it worthwhile to participate in a regional digester project:
  - 73 percent said for it to be economically feasible or cost saving
  - 18 percent said it would depend on the use of energy
  - 9 percent said if labor associated with transportation of manure was outsourced

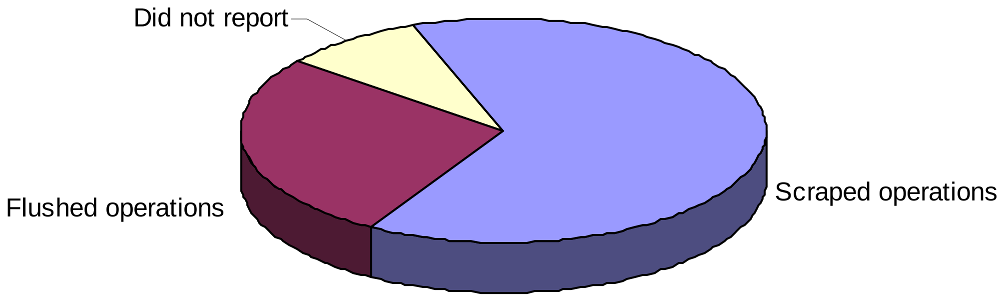


- When asked about interest in hosting a regional digester on site:
  - 55 percent said yes if economically feasible
  - 27 percent said they were interested
  - 9 percent said they needed more information
  - 9 percent did not report



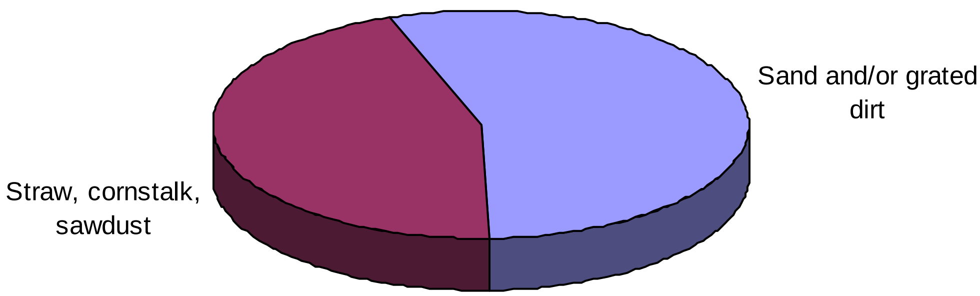
- When asked if they conducted scraped or flushed operations:

    - 64 percent scraped
    - 27 percent flushed
    - 9 percent did not report



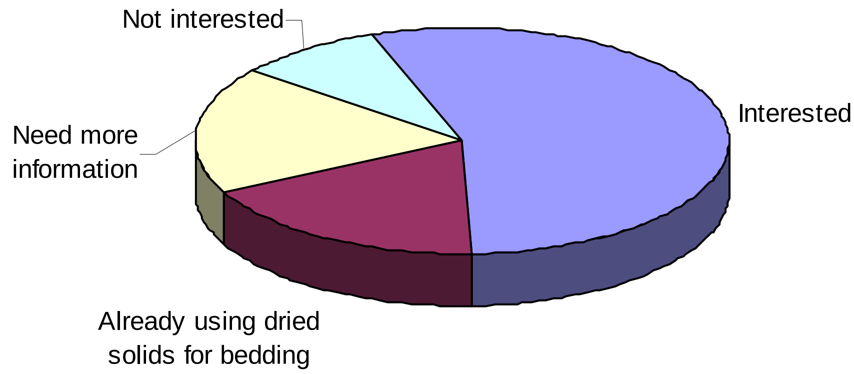
- When asked about the type of bedding used:

    - 55 percent used sand and/or grated dirt
    - 45 percent used straw, cornstalk, and/or sawdust



- When asked about the interest in dried solids as bedding:

  - 55 percent were interested
  - 18 percent already dried solids for bedding
  - 18 percent needed more information
  - 9 percent were not interested



Most of the interviewees' primary concern was the cost savings and economic feasibility of utilizing a regional digester. It is highly unlikely that any dairy farm would want to utilize a digester if it was more expensive than current costs of manure disposal.

Additionally, the labor associated with manure transport is a concern. Transportation and labor costs for manure handling can be substantial, and it is important to reduce operation and maintenance responsibilities of farmers interested in participating.

The minimization of costs can be accomplished in part by the use of organic dried solids from the digester for bedding. The dried solids are excellent bedding and organic, so when mixed with the manure and added to the digester they will degrade. However, inorganic bedding such as sand can present a problem for the anaerobic digestion process by eroding equipment and clogging the digester due to settling in the tank. Ultimately, the use of dried solids will be beneficial to the farmer by reducing their costs for bedding, and it will remove sand from the digestion process benefiting the digester operation.

4.0 FINANCING

4.1 Grants and Loan Programs

Since 2003, the USDA, who has awarded in excess of $31 million for anaerobic digester systems, is one of the major sources of funding available for these systems. However, with the cost of oil rising steadily and the poor performance of the stock market, there are many private equity funds that are interested in investing in "Green Energy" projects. Three public sources that could potentially be used to fund this project include:

- USDA Rural Development's Value-Added Producer Grants (VAPG)
- USDA Rural Development's Renewable Energy Loan and Grant Program
- EPA's Environmental Quality Incentives Program (EQIP)

These programs are described in brief below.

4.1.1 USDA Rural Development's VAPG

- *Total Amount of Funding Available*: $18.4 million

- *Amount of Funding Available per Project*: Maximum - $100,000 for Planning; $300,000 for Working Capital

- *Eligibility Criteria*: Grant program is designed to help independent producers of agricultural commodities, agriculture producer groups, farmer and rancher cooperatives, and majority-controlled producer-based business ventures develop strategies to create marketing opportunities and to help develop business plans for viable marketing opportunities regarding production of bio-based products from agricultural commodities.

- *Application Deadline*: March 31, 2008

- *Website Information*: http://www.rurdev.usda.gov/rbs/coops/vadg.htm

4.1.2 USDA Rural Development's Renewable Energy Loan and Grant Program

Funding for Fiscal Year (FY) 2008 has not yet been issued, but will be released soon. It is likely that the 2008 funding cycle will be similar to the 2007 funding cycle, so information from FY 2007 is summarized below.

- *Total Amount of Funding Available:* Approximately $11.4 million in funding for competitive grants and $176.5 million in authority for guaranteed loans.

- *Amount of Funding Available per project*:

    - Loan guarantees: loan guarantees can cover up to 50 percent of project cost

        - Not to exceed $10 million
        - Loan guarantee thresholds:
            - 85 percent guarantee for loans equal to or less than $600,000
            - 80 percent guarantee for loans equal to or less than $5 million
            - 70 percent guarantee for loans equal to or less than $10 million

        - Rural Development combined grant and guaranteed loan funding packages cannot exceed 50 percent of eligible project cost, with the grant portion not to exceed 25 percent of costs.

    - Grants:

        - Grants available for up to 25 percent of projects cost
        - Not to exceed $250,000 for energy efficiency
        - Minimum grant amount for energy efficiency is $1,500
        - Not to exceed $500,000 for renewable energy projects
        - Minimum grant amount for renewable energy projects is $2,500

- *Eligibility Criteria:* In FY 2007, eligible projects fell into two categories:

    - Installation of renewable energy systems, such as small and large wind turbines, solar, geothermal, biodiesel, ethanol, anaerobic digesters, or hydrogen.

    - Energy efficiency projects, including installing new electric motors that are more efficient, adding insulation, and improving electrical or heating and cooling systems.

- *Application Deadline:* Funding for FY 2008 has yet to be released.

- *Website information:* http://www.rurdev.usda.gov/rbs/farmbill/
  http://www.rurdev.usda.gov/co

4.1.3 EPA's EQIP

- *Total Amount of Funding for FY 2007 was $40,216,358* Current year information not available.

- *Amount of Funding Available per Project:* EQIP is summarized on the USDA's Natural Resources Conservation Service (NRCS) website as follows:

  "EQIP offers contracts with a minimum term that ends one year after the implementation of the last scheduled practices and a maximum term of ten years. These contracts provide incentive payments and cost-shares to implement conservation practices."

  It continues on to state:

  "EQIP may cost-share up to 75 percent of the costs of certain conservation practices. Incentive payments may be provided for up to three years to encourage producers to carry out management practices they may not otherwise use without the incentive. However, limited resource producers and beginning farmers and ranchers may be eligible for cost-shares up to 90 percent. Farmers and ranchers may elect to use a certified third-party provider for technical assistance. An individual or entity may not receive, directly or indirectly, cost-share or incentive payments that, in the aggregate, exceed $450,000 for all EQIP contracts entered during the term of the Farm Bill."

- *Eligibility Criteria:* Landlords, operators, tenants, and nonfederal landowners involved in livestock or agricultural production are available for this program. Producers are ineligible in any year their adjusted gross income exceeds $2.5 million, unless 75 percent of that income is derived from farming, ranching, or forestry.

- *Application Deadline:* Information not available.

- *Website Information:* http:// www.nrcs.usda.gov/programs/eqip
  http://www.epa.gov/agstar/pdf/ag_fund_doc.pdf

In addition to grants and/or loans, renewable energy investment funds and carbon trading partners could also be used to financially sustain this project. A brief overview of these funding sources can be found below.

4.1.4 Renewable Energy Investment Funds

- **Private Equity Funds**

  A number of "Green" Private Equity funds are actively looking for projects to finance, own, and operate producing renewable energy and or energy efficiency projects within the United States. They are dedicated to providing cost-effective, competitively priced clean energy for customers, and exceptional investment opportunities in the renewable energy sector.

  - *Website Information:* http://www.mmarenewableventures.com

5.0 ENVIRONMENTAL REGULATIONS

CDPHE's Water Quality Control Commission (WQCC) has water regulations specific to CAFOs; Regulation No. 81, "Animal Feeding Operations Control Regulation." We have highlighted some of the following issues of concern:

- Operation and maintenance of tanks should be conducted so as to not discharge wastewater to groundwater.
- Impoundment liners should be constructed and maintained to meet the design standards in Regulation No. 81.
- Removal of manure or wastewater should be accomplished without damaging the impoundment liner. A Standard Operating Procedure (SOP) shall be submitted to demonstrate how manure will be removed.

- Depth markers in impoundment should be installed in a way that maintains the required seepage rates and liner integrity.
- Earthen conveyance structures should be maintained and minimize ponding of wastewater. Structures should limit seepage of wastewater according to Regulation No. 81.
- Impoundments of new source CAFOs should not be located in areas outlined in Regulation No. 81.
- Establish standards for groundwater monitoring according to regulation.
- Establish standards for impoundment closure according to regulation.
- Best management practices (BMPs) should be implemented to reduce impacts on surface and ground water.

Regulation No. 61, "Colorado Discharge Permit System Regulations," includes additional CDPHE regulations requiring permitted CAFOs to create and follow a Nutrient Management Plan by February 27, 2009. The Nutrient Management Plan should address the following issues:

- Adequate storage for manure and process wastewater
- Procedures to ensure proper operations and maintenance (O&M) of tanks and impoundments
- Proper management of dead animals
- Diversion of clean water from production area
- Prevention of chemical and contaminant disposal in manure or water sources
- Conservation practices to control pollutant runoff into surface water
- Procedures to sample and test manure, wastewater, and soil
- Procedures for land application
- Records of implementation and management of minimum requirements
- BMPs to implement effluent limits

Please refer to CDPHE's Regulation No. 61 and Regulation No. 81 (available on their website at http://www.cdphe.state.co.us/regulations/index.html) for more detail.

Nutrient management is a critical issue for the dairy farmer; a small on-farm digester will not meet their management needs. Approximately 45 percent of nitrogen is volatilized with current management practices on the farm. So, for every 1,000 pounds (lbs) of nitrogen excreted, 550 lbs need to be accounted for in the nutrient management plan. Digesters will reduce the amount of nitrogen volatilized so the amount of nitrogen accounted for in the management plan will actually increase. If the manure and nitrogen are taken to a centralized facility, the nitrogen can be concentrated using filtration equipment. Participating farmers can then utilize this concentrated liquid product as needed, or it could be sold as a fertilizer and transported to other locations. By condensing the nutrients and creating a low volume high nutrient liquid fertilizer, the nutrients can easily be transported to sites other than the farm producing the waste. This will aid farmers with limited land for application of nutrients and aid in nutrient management.

Title V of the federal Clean Air Act states that any source that emits or has the potential to emit more than 100 tons of any regulated air pollutant per year is required to have an operating permit. In addition, any source that emits or has the potential to emit more than 10 tons per year of a hazardous air pollutant, or more than 25 tons per year of a combination of hazardous air pollutants, is required to have an operating permit. This includes older sources, which before were never required to obtain an air pollution permits. Operating air permits will be necessary if an internal combustion engine or boiler is used to burn bio-gas. Additionally, a permit may be necessary for the digester due to the potential of accidental release of hydrogen sulfide gas, which is listed on the EPA's list of hazardous air pollutants.

6.0 ANAEROBIC DIGESTION PROCESS

The term anaerobic means free of air; however, it is more accurate to say free of oxygen since anaerobic bacteria require an oxygen-free environment in which to thrive. Under anaerobic conditions, naturally occurring bacteria found in cow manure digest a portion of the solids and produce biogas. Biogas typically consists of 60 to 85 percent methane (CH_4) with the remaining percentage made up of carbon dioxide (CO_2), hydrogen sulfide (H_2S), and various other inconsequential gases.

Anaerobic digestion is a proven technology that is used in many different industrial and municipal applications to digest high strength wastes. The digestion of cow manure is a relatively new application, which shows great promise. The major hurdle to overcome is the digestion of cellulose, which is a component of manure in the form of volatile solids (VS). Current digester technology can accept a wide range of solids concentration; lagoons can handle a very dilute 1 to 3 percent solids while mixed and plug flow digesters can handle as high as 12 13 percent solids. In a typical mixed system, a reduction of volatile solids by 20 to 35 percent can be anticipated. On average, 15 ft^3 of biogas is produced for every pound of VS digested.

Anaerobic digestion is a three-step process involving a diverse consortium of symbiotic bacteria, which convert complex substrates to methane gas and carbon dioxide. Given the process requires several steps, it is similar in concept to a production line with each type of bacteria performing their part in the sequence, so it can only proceed as fast as the slowest member, which in this case is the methanogenic bacteria. Successful anaerobic digesters are designed to promote the rapid growth of methanogens, which have a very slow growth rate and are very sensitive to feedstock overload, pH swings, and temperature changes. Complex feedstock is broken down in three steps: hydrolysis, acetogenesis, and then methane generation. In hydrolysis, large molecules are broken down to simpler organic compounds, which are then fermented to volatile fatty acids by acetogenesis. Volatile fatty acids (VFA) consist of propionate, acetate, butyrate, etc.; these are the precursors to methanogenesis. Methanogens break down VFAs to create methane. Additionally, methanogens are slow to grow and sensitive to temperature and pH changes. If the methanogens cannot keep up with the acetogens and the VFA concentration increases too rapidly, the pH will drop and further inhibit the methanogens growth and gas production, so a very delicate balance needs to be maintained to keep a digester running well.

The three temperature ranges where anaerobic digestion can take place are: the psychrophilic (below 15 degrees Celsius), mesophilic (15 to 40 degrees Celsius), and thermophilic (40 to 70 degrees Celsius). The mesophilic and thermophilic are most suited to the operation of an anaerobic digester because of greater gas production and a higher percentage of methane in the gas produced. Experiments on thermophilic anaerobic digestion have shown that the process is faster requiring less retention time, produces more gas, and provides disinfection of the biosolids. However, there are some problems with the thermophilic process including: odor, higher energy demand, lower quality effluent, ammonia toxicity, and slower methanogenic growth rates. The mesophilic range provides a slightly reduced gas production, stable operation, reduced energy demand, and a faster growth rate of bacteria. The vast majority of functioning anaerobic digesters today operating on dairy manure operate in the mesophilic range; however, there are some large regional operations functioning successfully in the thermophilic range such as the bio gas plant located in Huckabay Ridge, Texas.

A hybrid configuration that has shown promise both experimentally and in operation is a temperature phase anaerobic digestion (TPAD), which utilizes a thermophilic digester in series with a mesophilic digester to take advantage of the benefits of both temperature ranges. This system has shown a 42 percent reduction in solids and the solids meet EPA 503 class A standards for bio-solids due to the thermophilic portion of the plant. In Egypt, there have been several studies done incorporating solar energy into a thermophilic anaerobic process. The study results show that at 50 degrees Celsius, the process produces more gas than at 60 degrees Celsius, probably due to ammonia toxicity at the higher temperature. Perhaps more interestingly, the studies also found that there is only a slight reduction in methane production (12 percent) with a 10 degree Celsius swing in temperature change. This reduction in gas production is slightly more than the parasitic loads (8 percent) for a typical system using biogas for heating the process. A system heated with solar energy would see daily temperature swings. In the Colorado environment, a blend of solar and biogas heated process would be most practical and warrants further investigation.

In the United States, there are currently at least 40 working anaerobic digesters operating on dairy manure producing biogas, which is used either to produce electrical power or as a fuel source. The majority of these are on single farms dealing with odor problems and producing small amounts of electricity (less than 300 kilowatts (kW)). Anaerobic digesters are successfully reducing odors and manure solids, capturing nutrients for reuse, and providing energy from the biogas. There have been several different types of reactors used; however, the two types with the greatest success are plug-flow and completely mixed. Completely mixed is better suited for higher methane production and a regional digester project while the plug flow is a simpler process and better suited to the single farm application.

7.0 ANAEROBIC TECHNOLOGY

Research on anaerobic technology included internet searches, literature research, and interviews with technology vendors and dairies that had operating anaerobic systems.

Anaerobic digestion has been used for decades to treat high strength industrial waste, agricultural waste, and reduce municipal sludge volumes. Feedstock is typically a high strength organic waste, such as animal waste or food and beverage processing waste. The anaerobic process is a net energy producer as opposed to aerobic treatment, which is a net energy consumer. The main by-product of the anaerobic digestion process is biogas, which contains 50 to 80 percent methane gas, the main constituent in natural gas.

Anaerobic digesters are engineered containment vessels designed to exclude air and promote the growth of anaerobic bacteria. While there are many different types of anaerobic digesters, there are only three configurations that are suitable for digesting manure: the covered lagoon, plug flow, and completely mixed. These digesters are discussed in detail below.

7.1 Covered Lagoons

The lagoon system shown to the right is located at a brewery and is part of an anaerobic and aerobic treatment plant. In the foreground, the anaerobic digester is shown with an inflatable gas hood. In the background are aerobic basins. Lagoons are a very simple system that will reduce odors and digest solids; however, typical lagoons have no temperature control and are operated at ambient temperature. Without temperature control, digestion stops during the cold winter months, so they are not well suited to gas production. The main benefit of lagoons is the reduction in odors and solids.

Figure 2: Covered lagoon at New Belgium Brewing Company, Fort Collins, Colorado.

Covered lagoons are the simplest type of anaerobic digester designed with the least amount of mechanical equipment. Generally, lagoons are not heated, so they only function well during the summer or in warmer climates. While these will function in Colorado, the winter temperatures can cause the reaction rate to decrease considerably, which will lead to seasonal fluctuations in the manure treatment and biogas production. Lagoons can handle solids in the range of 0.1 to 2.0 percent, so they function well with very dilute waste, such as waste from dairies with flush systems. Since these are the slowest rate reactors (hydraulic retention time (HRT) is 40 or more days), they require a very large volume and produce the least amount of useable methane. Another draw back to these reactors is the small amount of solids they can handle, so great care needs to be taken to prevent solids such as hay and silage fibers from entering the system otherwise a mat will form on the surface, which will reduce the biogas production and eventually plug the digester. While these are functional for digesting dairy cow manure, their temperature, solids loading, and huge volumes do not lend this type of digester to a regional system. Additionally, the biogas production is very low and fluctuates greatly.

7.2 Plug Flow Anaerobic Digester

Figure 3: Picture Courtesy of GHD, Inc. below ground plug flow digester at Gordondale farms shown.

The plug flow system is more advanced and has temperature control, so it can operate in the mesophilic and thermophilic range and provide a much greater reduction of solids and gas production. Plug flow digesters are well suited to single dairy operations and, in fact, there are many of these operating successfully. Plug flow digesters are covered concrete tanks above or in-ground; the manure is loaded into one end of the digester and travels through as a plug. The majority of functioning anaerobic digesters treating cow manure in the United States are located on individual farms and are plug flow. If properly designed, there is enough mixing as the plug flows through the digester to maintain anaerobic digestion. The hydraulic retention time is the same as the solids retention time, so the amount of solids reduction and gas production is limited. Plug flow digesters are best suited for scraped manure and will not function properly with the diluted waste from a flushed system. The simple design and operation make this ideal for individual farms that mechanically remove their manure.

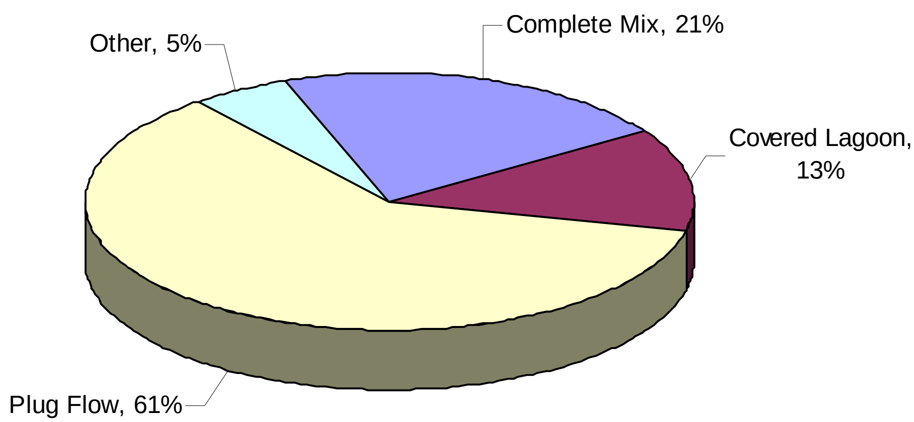
7.3 Completely Mixed Digesters

The completely mixed system is the most technologically advanced digester system and provides the best digestion of solids and, as a result, the best gas production. Because of the solids reduction and gas production, a completely mixed system is best suited for a regional digester application.

Figure 4: Completely mixed digester system.

Based on the data maintained by the EPA Agstar program, approximately 21 percent of all anaerobic digesters designed to operate on cow manure in the United States are completely mixed These are covered tanks, either rectangular or silo shaped, with heating and mechanical mixing. This design is the most expensive to install and operate; however, it provides the most process control and is resilient to changes in loading. Design solids loading is 2 to 10 percent, so these complete mixed systems can handle either scrapped or flushed manure. The completely mixed reactor would be the best choice for a regional digester since it can handle both scraped and flushed solids and provides the greatest solids reduction and the highest gas production.

Percentage of Anaerobic Digester Types in the United States



The table below provides a detailed comparison of the three types of anaerobic digesters.

Table 4: Anaerobic Digester Comparison

Variable	Covered Lagoon	Plug Flow	Complete Mix
Temperature Range	Psychrophilic (<15 C)	Mesophilic (15-40C) and Thermophilic (40-70C)	Mesophilic (15-40C) and Thermophilic (40-70C)
Operational Solids Concentration	Low 1-2%	11-13%	8-12%
Manure Handling	Flush	Scraped	Scrape and some flush
HRT	40+ days	20-30 days	20-30 days
Solids Reduction	20%	20-40%	30-50%
Methane Production	Very low	1 lb VS-15 ft^3 biogas 50% CH_4	1 lb VS-15 ft^3 biogas 60% CH_4
Capital Cost	Low	<1000 cows $1-$1.2K/cow >3,000 cows $700-800/cow	$700-$1200/cow
Parasitic Energy (required as percentage of biogas produced)	Only pumping required for draining digester	8% of biogas energy produced (< 1,000 cows) 5% of biogas energy produced (>3,000 cows)	5% of biogas produced

Variable	Covered Lagoon	Plug Flow	Complete Mix
Experience	A few operating mainly to deal with environmental issues	Several small dairy systems operating successfully	Fewer operational dairy systems, but promising for larger size projects. Majority of industrial process digesters are complete mixed.
Pathogen cleansing	Little or none	Dependant on temperature range	Dependant on temperature range
Reduction of greenhouse gases	Yes, if covered and gas recovered	Yes	Yes

Table 5: Anaerobic Digester Type Conclusions

Variable	Covered Lagoon	Plug Flow	Complete Mix
Temperature	Will not produce enough biogas to justify recovery other than to flare off for GHG reduction	Mesophilic is best for operational purposes and Colorado Climate	Mesophilic is simplest to operate and well suited for Colorado Climate. However, gas production is less than Thermophilic. Thermophilic possible; however, more difficult to operate. Highest gas production
Manure management	Flush systems not appropriate for regional digester	Scrape or vacuum	Scrape or vacuum. More flexible solids concentration range
Experience	Limited	Most successes on single farms	Limited for dairy manure; however, wealth of industrial applications
Methane production	Too low	Good	Best

8.0 DESIGN CONSIDERATIONS

The purpose of this report is to survey the feasibility of a regional biogas facility and consider several aspects such as transportation, digester technology, and the financial viability of the project. As such, design considerations are outlined below:

- *Financial Arrangement:* There are very few dairy farmers with the financial resources to be able to invest in a regional digester. As a result, the capital will need to come from other sources. There are federal and state sources of funding covered in section "4.0 Financing" as well as several investment groups with an interest in financing "Green Energy" projects covered in that section.

- *Manure Management:* Preferably scraped or vacuumed. A regional facility could handle some flushed manure; however, transportation costs for a flushed system would make it unfeasible unless it is pumped to the digester site.

- *Location:* Depending on the use of the biogas, the site will need to be near either natural gas lines or electrical service that can handle the introduction of power to the grid.

- *Facility Layout:* For the purpose of this study, a biogas facility to service 5,000 cows will require a 5-acre site. This could be reduced if all manure was pumped to the site and residual liquids were pumped back for irrigation. Given the great distances and expanses of land to be irrigated, this may not be feasible, so truck traffic has to be considered.

- *Reactor Design Parameters:*

  - Chemical Oxygen Demand (COD) – the majority of which is in the volatile manure solids
  - Inorganic Solids (sand) –will cause excessive equipment wear and can accumulate within the digester
  - HRT – the amount of time liquid stays in the digester
  - Solids Retention Time (SRT) – the amount of time biological solids are retained in the digester

- *Operating Temperature Ranges:*

  - The psychophilic range (less than 15 degrees Celsius)

    - No Pathogens killed
    - Low gas production
    - Long HRT
    - No parasitic gas load
    - Erratic gas production

  - The mesophilic temperature range (15 to 40 degrees Celsius)

    - Most pathogens killed
    - Biogas production is good
    - 5 to 8 percent parasitic load
    - Appropriate for Colorado climate
    - Most staple operation

- The thermophilic temperature range (40 to 70 degrees Celsius)

    - Pathogens killed
    - The HRT is short-smallest volume
    - Biogas production highest
    - 20 percent parasitic load
    - Difficult to operate; sensitive to changes
    - Susceptible to ammonia toxicity
    - Slow growth rate for bacteria
    - Odor problems
    - Long startup times

9.0 SIGNIFICANT EQUIPMENT

For the regional digester, cattle bedding and manure management are critical to the operation of the facility. Manure can contain many contaminants such as straw, sand, ear tags, and other debris that will not be digested in the process and must be separated from the manure before it enters the anaerobic digester. Ideally, digester solids will be used for bedding and manure will be scraped or vacuumed and transported either via pipeline or truck. Manure arriving at the facility will be delivered to a coarse bar screen for removal of large debris and then deposited into a mixed holding tank. The collection/mixing tank will be a 100,000-gallon concrete tank with warm supernatant re-circulated from the digester to maintain a constant solids concentration of approximately 8 to 10 percent. The mixture will be pumped to two parallel digester vessels that are 750,000 gallons each. Heat from the co-generation system will be recovered in heat exchangers to maintain a digester temperature of 35 to 38 degrees Fahrenheit. The nutrient rich supernatant will be pumped to two parallel screw presses for solids separation. Solids will either be composted on site or transported to the dairies for use as bedding. A portion of the remaining supernatant will be used for mixing with the incoming waste to control the solids level and the remainder of the nutrient rich liquid will be stored in the 180,000-gallon effluent holding tank for land application by the dairy farmers.

9.1 Manure Collection and Handling

Key considerations in the system design include the amount of water and inorganic solids that mix with manure during collection and handling. Flush systems will have very diluted manure, which is only well suited for low-rate anaerobic lagoon system and due to the large volume of liquid transportation is very costly. Sand bedding can erode pumps and settle in the digester consuming valuable capacity. The type of bedding used will have a significant impact on the operation of an anaerobic digester and needs to be carefully considered.

The best system for recovering manure will be either a scrape or vacuum system. Additionally, the ideal bedding will be dried solids from the digestion process. The manure will need to be trucked or pumped to the regional digester. Transportation costs will be an important consideration given the volume of manure that will need to be moved. If it is possible, a pumped system will be the most economical and environmentally friendly. A pumped system requires a holding tank and pumps. The buried pipeline will likely be the largest cost. However, given the volume of manure to transport, a pumped system will quickly pay for itself when compared to the cost of trucking manure. For a farm relying on trucking, a simple holding tank is all that is necessary. Stewart Environmental has received price quotes from $5 to $9 per inch of pipe diameter per foot of buried pipeline at a depth of 5 feet. This does not include any costs for de-watering, manure pumping equipment, or easement costs.

The Inland Empire Utilities Agency (IEUA) in Chino, California operates an anaerobic digester for dairy cow waste. Currently, they have 14 dairy farms using the facility with a combined population of approximately 30,000 dairy cows. The agency provides their own trucks to transport manure. All farms use vacuums and hold their manure in 10,000-gallon holding tanks. Additionally, all of the farms are within 2 to 5 miles of the anaerobic facility. IEUA charges the farmers a fee for the pick up, and there is a mileage charge to cover costs.

For the financial model, a fleet of 10 trailers and five trucks is included in the capital costs. The assumption is that the regional digester entity will own and operate all of the trucks, so operational costs for the fleet have been included.

Figure 5: Manure vacuum (Image courtesy of IEUA).

9.2 Pre-treatment

For a regional facility, collected manure must be screened to remove large debris, such as rocks and ear tags. After coarse screening, grit removal will be necessary to remove in-organics such as sand prior to the process. Bedding and manure management practices play a critical role in how much pre-treatment is necessary. Ideally, all contributing farms will use processed solids from the anaerobic digester for bedding, sand bedding should not be considered, as it will cause unnecessary amounts of inorganic removal and excessive wear on all pumps and process equipment. The final pre-treatment step will be mixing and holding the manure prior to introduction to the anaerobic digester. For this, a concrete or metal collection/mix tank with mixers will work well. For the financial model, a 6,000 gallon sump and a 112,000 mixing tank are included. The sump will be below ground with a coarse screen to remove large solids. Manure will be pumped up from there to a holding tank. The model does not include any inorganic solids removal.

9.3 Anaerobic Digestion

An anaerobic digester is an engineered containment vessel designed to exclude air and promote the growth of methane producing bacteria. For the purpose of a regional digester a complete mixed system will be the most versatile. Single farms may want to consider a plug flow system given the simple operation.

The configuration of the digester can be a tank, a covered lagoon, or a more complex design, such as a tank provided with internal baffles or with surfaces for attached bacterial growth. Heat exchangers can be located in the digester or externally. There are many different configurations of digesters and peripherals. For a successful project, the data gathering and design process are critical. There are many individuals and groups selling their particular digester as a "one size fits all;" this is not the case. It is imperative that a thorough evaluation of the manure/feed stock, the site characteristics, the treatment goals, and operator capabilities be evaluated before the type of digester is chosen. There are many examples of failed anaerobic digestion projects; in order for a project to be successful an independent outside consultant with experience in anaerobic digestion and no allegiance to any particular digester design should be considered as an owner's representative. The small fee for the consultant's knowledge will pay for itself many times over during the life of the digester project.

For the purpose of this study, the digester is assumed to be completely mixed similar to an Upflow Anaerobic Sludge Blanket (UASB) digester, which can be built in many different materials. For this project, the assumption is that there are two 750,000 gallon concrete anaerobic digesters. The tanks will be well mixed and operate with a solids concentration of approximately 8 percent. Gas will be recovered in a gas-tight upper chamber, solids will be removed on a daily basis, and the hydraulic retention time will be approximately 22 days.

9.4 By-product Recovery

Digested solids and liquid effluent can and should be processed to create marketable by-products. The solids can be used as cattle bedding or composted as a soil amendment, and the liquid effluent will be rich in nutrients such as nitrogen and phosphorus and should be condensed using reverse osmosis (RO) to create a highly concentrated liquid fertilizer, which will be marketable.

If the solids are to be reused for cattle bedding, precautions must be taken to ensure that there are no pathogenic organisms present in the material. Masthesis is a big concern for dairy cows. If centralized digesters are utilized, great care must be taken to ensure pathogen-free bedding is used. This can be accomplished two ways; the first is using a thermophilic digester, which will kill pathogens during the process because of the high operating temperature. The second option is to compost the solids after removal from the anaerobic digester, which will require a significant amount of space. Typically, a screw press will be used for solids recovery after anaerobic digestion. After the screw press, the solids will need to be dried further, so space will need to be provided for solids handling. The solids provide an excellent revenue source and farmers participating in a centralized digester should be strongly encouraged to use the solids as bedding. The bedding used by farmers will have a direct impact on how well the digester functions. Additionally, the digested solids will be less expensive than purchasing sand.

The treated effluent will be high in nutrients and could be land applied in the dilute form or it could be processed with RO to create a highly concentrated liquid fertilizer and a clean stream of high quality water. Storage capacity and or filtration equipment will be necessary for the liquid effluent. All CAFOs will be required to have a nutrient management plan in place by February 27, 2009 when CDPHE Regulation 61 becomes effective. Nutrient management plans will be hard for "landlocked" dairy farmers to meet with limited land on which to apply their high-nutrient waste. By utilizing a centralized biogas facility, all of the high-nutrient waste will be removed from their farm processed and contained in the effluent from the digester. This high nutrient liquid waste can be further condensed using RO to create a highly concentrated liquid fertilizer product that could easily be sold. Concentrating the liquid waste will create two liquid waste streams; a highly concentrated fertilizer product and a supply of clean water that could be directly discharged to a river or used for irrigation.

The financial model includes equipment for solids removal and air drying as well as filtration equipment for processing the liquid waste and recovering nutrients. Both the solids and liquid waste streams are sources of income accounted for in the cash flow.

9.5 Biogas Recovery and Handling

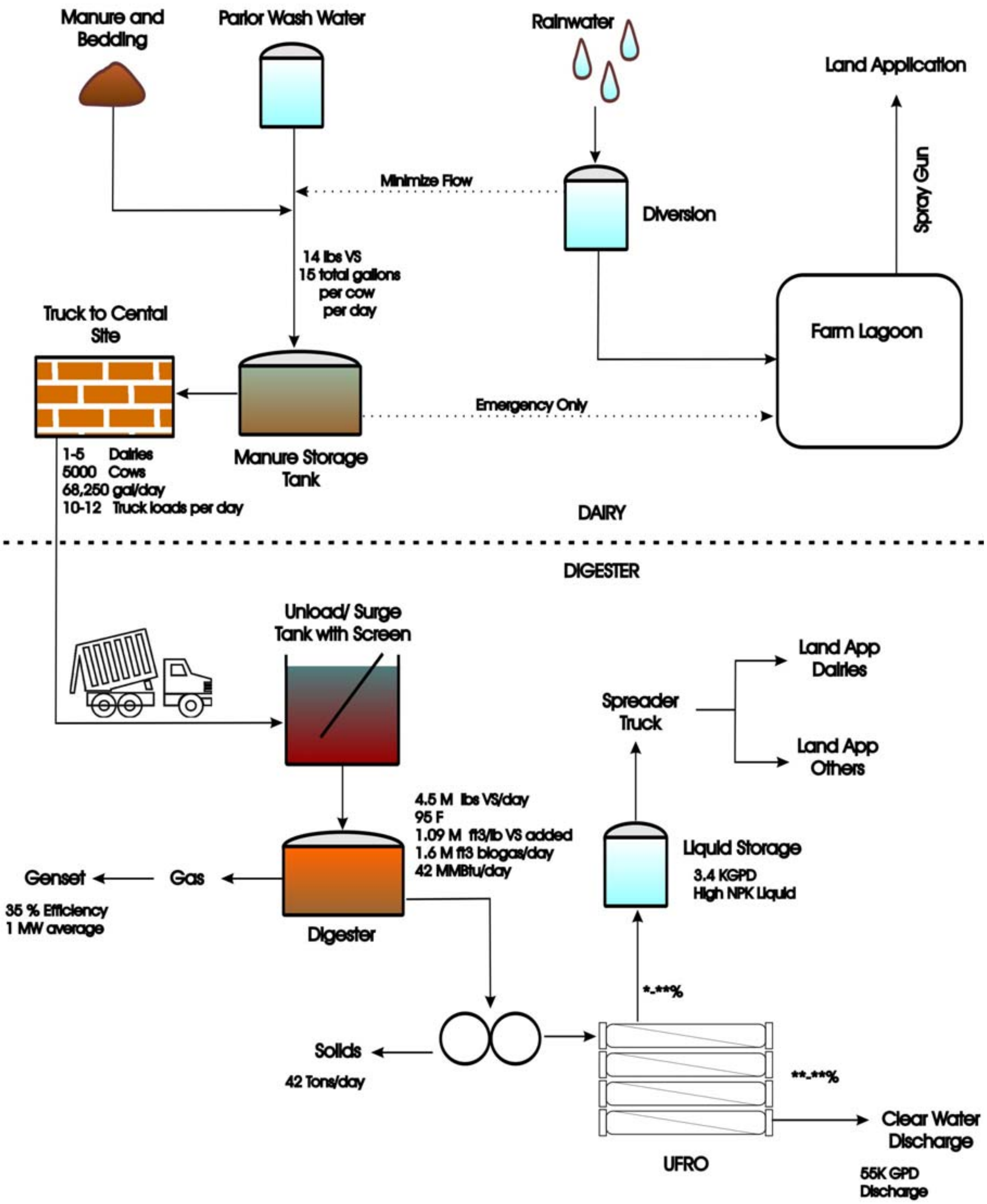
Biogas formed in the anaerobic digester will bubble up to the surface and be captured in the top of the digester where it will be removed and stored in a low-pressure system designed specifically for very moist and corrosive biogas. Biogas is comprised of 50 to 85 percent methane gas, carbon dioxide, and approximately 1 percent of other contaminants, such as hydrogen sulfide gas. Typically, biogas is saturated with moisture and extremely corrosive, so all piping and equipment in contact with the gas must be highly corrosion resistant, such as very high quality 316-stainless steel or high density polyethylene (HDPE) plastic. Gas will be stored in a low-pressure bladder and transported using low-pressure blowers. Every joule of energy put into transporting or pressurizing the gas will reduce the payback, pressurization should be avoided if possible. Additionally, raw biogas contains high amounts of moisture, hydrogen sulfide, and carbon dioxide, which can be removed using a scrubber or dryer, again the payback needs to be considered. The more energy put into pressurizing and scrubbing the gas, the lower the payback. Ultimately, the end use should be carefully considered prior to commencement of the project. The financial model assumes that the gas will be stored in a low-pressure system, moved with low-pressure blowers, and burned in specially designed co-generation engines capable of handling the moisture and hydrogen sulfide gas. Heat will be recovered from the engine to heat the process and electricity will be sold to the utility. As a safety precaution, a flare needs to be installed to burn off excess gas in emergencies.

9.6 Transportation

The financial model includes a fleet of trucks for transporting manure, residual liquid fertilizer, and waste solids for bedding or compost. The transportation costs for hauling manure need to be controlled to ensure a profitable operation. For every 5,000 cows, there will be approximately 12 truck loads of manure a day, so the transportation needs to be reliable and should be operated by the anaerobic facility operator to maintain quality control of incoming waste.

Special liquid spreader trucks should be used to accurately apply the liquid fertilizer product. For the financial model the assumption is that the liquid is condensed by RO and land applied with liquid spreader trucks at a rate of $15 per 1,000 gallons.

Figure 6: Manure Conversion Process



10.0 RECENT REGIONAL ANAEROBIC DIGESTER PROJECTS.

The EPA AgSTAR website has a wealth of information about types of anaerobic digesters, financing, and anaerobic digester projects around the country. The EPA estimates that there are 114 digesters operating at commercial live stock facilities in the United States. Of that number, there are four regional systems. The vast majority of anaerobic systems are located on farms and privately owned and operated. We were able to contact two regional facilities and discuss their operations.

10.1 IEUA

The IEUA, located in Chino, California, has three anaerobic digesters to process manure from 14 local dairy farms with an estimated population of 30,000 dairy cows. In addition to dairy manure, IEUA also processes 90 tons of food waste a day. IEUA is located on top of a huge aquifer, so their motivation is to protect the aquifer from salts, nutrients, and pathogens in an economical fashion. The project is partially funded by the California Energy Commission, USDA Natural Resources Conservation Service, U.S. Department of Energy, South Coast Air Quality Management District, and Western United Resource Development, Inc.

The IEUA operates a fleet of trucks for transporting the manure to their facility and the three anaerobic digesters. The facility had several issues to overcome in the beginning. The vacuum trucks picked up everything in the feed lanes including sand, rocks, asphalt, bailing wire/twine, ear tags, etc. All of this debris ended up in their process and caused mechanical failures and consumed valuable capacity in the anaerobic digesters. Changes they made to solve these problems included installing a coarse bar screen at the head of the plant and turning off the mixers in the mixing basins to allow the sand to settle out there and keep it out of the digesters. According to Mr. Manuel Moreno, operations supervisor, the mixing tanks are much easier to clean than shutting down a digester to remove sand. Another improvement was the design of the newer digesters, which included a system for removing sand while operating.

Their successes include:

- Generate renewable energy to power de-salter cogeneration system and other IEUA facilities
- Contribute to local energy self-sufficiency goals minimizing dependence on non-renewable fuels
- Protect Chino Groundwater Basin and downstream users from infiltration of salts and nitrogen compounds generated at dairies
- Reduce air quality pollutants, including global warming gasses, dust, and odors
- Support a sustainable agricultural industry in the Chino Basin

10.2 Microgy’s Huckabay Ridge Facility

This facility is located in Texas and is one of the largest renewable natural gas plants in the world. It is projected to generate 2,000 million British Thermal Units (btu) of renewable natural gas (RNG) a day, which will be sold to Pacific Gas and Electric. The RNG is biogas, which has been scrubbed to meet natural gas standards. Huckabay Ridge uses a mixed fuel source of dairy manure and other organic waste to generate biogas. The facility has eight thermophilic digesters and has been operational for over a year and commercially producing RNG since December of 2007. In a discussion with Mr. Mark Hall, senior vice president of Environmental Power Co. (parent company to Microgy), they have not had many operational issues with the anaerobic process; however, they have had some well documented problems with their gas scrubbing process. They use an amine-based gas purification process, which requires a consistent temperature profile. Due to either design or workmanship issues, they have been experiencing temperature swings, which have hindered the process. As a result, they are going to switch to a pressure swing absorption process for scrubbing the gas.

When asked about lessons they have learned, Mr. Hall commented that they have spent a great deal of time monitoring and gathering data to really understand the process. With an operation this size and level of sophistication, it is not something that can be handed off easily, so Microgy feels an obligation to own and operate its plants to ensure a successful outcome. Their Huckabay Ridge project showcases technology with eight 900,000 gallon digesters and a projected 2,000 Million British Thermal Units (MMBTU) of RNG produced on a daily basis; this is one of the largest biogas facilities in the world. When a process gets this large and complex, it is necessary to have very sophisticated process controls and well trained operators. In addition to the normal process parameters of temperature, pH, and flow, Microgy monitors Volatile Fatty Acids (VFA) throughout their process.

Microgy currently has about seven anaerobic facilities in operation and three more under construction, with Huckabay Ridge being their largest. The Huckabay Ridge project is a great example of the regional anaerobic digester concept, which is providing a clean renewable source of energy while removing harmful GHGs from the atmosphere and containing nutrients from cattle waste.

11.0 FACILITY ASSUMPTIONS

For the purpose of this study, a model biogas facility was developed, which could easily be scaled up or down. There are several considerations that were taken into account. First was the economy of scale. In other words, there is a base level of equipment that needs to be included in the system regardless of the number of animals involved or gas generated. The model developed for this study assumes a population of 5,000 cows within 2 miles of the facility. This does not mean that a smaller or larger project will not work. Both are possible and likely will provide substantial benefits to investors and farmers. The idea of a one size fits all for a regional biogas project is not realistic; every site and project will be slightly different and requires buy-in from all parties, detailed planning, and diligent operation by skilled operators. Location of the facility and proximity to electric power lines and/or natural gas lines will have an impact on the design of the facility. The model created here assumes that all biogas is consumed in a co-generation engine, which produces heat and electricity. The heat is critical to the digester operation, so if the biogas is to be scrubbed and sold as natural gas, adjustments will need to be made to the system. The electricity will be distributed to the grid using the local power provider's system and sold to the wholesale provider. In this case, either Tri-State Generation and Transmission Association or Xcel energy.

The intent of the model chosen for this report is to show the potential paybacks of a well planned and executed biogas facility.

The model assembled is based on a completely mixed system with concrete holding tanks and two identical anaerobic digesters. Co-generation equipment is included to generate electricity and recover heat. The capital costs are based on a turn-key system designed with a manure truck receiving station, manure transport trucks, and two liquid waste hauling trucks. Below are tables detailing the assumptions.

Table 6: Site Requirements and Assumptions

Site Requirements		
Land requirements (no cost included)	5	Acres
Biogas Facility Input Assumptions		
Description	**Amount**	**Units**
Animals	5,000	Cows
Mass of Manure	112	lb/cow/day
Volume of Manure	2	ft^3/cow/day
Volatile Solids (VS)	12	%
Volatile Solids Destruction	35	%
Projected Gas Production	12	ft^3/lb of VS
Concentration of Methane	60	%
Gas Production		
Description	**Amount**	**Units**
Biogas	279,888	Ft^3 biogas/day
Methane	167,933	ft^3 Methane/day
Energy Production		
Description	**Amount**	**Units**
Electrical Generation	0.20	kW/cow
Electrical Power Output	1.0	MW

Table 7: Process Equipment and Facility

Description	Volume		Cost
	(ft3)	(gal)	($)
Daily Volume of Manure	9,100	68,250	
Sump	800	6,000	$ 50,000.00
Screen			$ 100,000.00
Grit Removal			$ 100,000.00
Holding Tank (20'x30'x25')	15,000	112,500	$ 495,008.00
Effluent holding tank (20'x35'x35')	27,300	204,750	$ 543,494.44
Site Improvements			$ 100,000.00
Filtration for Liquid stream			$ 50,000.00
Electrical Interconnection			$ 300,000.00
Sub-total			$ 1,738,502.44
(Vendor Provided)			
Anaerobic digester (22 day HRT)	0	0	
Pumps& Mixers			
Hot water management			
Biogas Handling			
Screw Presses			
Valves & Piping			
Mechanical/ Electrical/ Plumbing			
Solids separation equipment			
Gas storage			
Co-Generation Equipment/building	4.0 MW		
Flare			
Cost per cow ($700-$1,200)	$ 1,000.00		$ 5,000,000.00
Total Process Equipment			$ 6,738,502.44

Table 8: Transportation Equipment

Equipment	Qty	Unit Cost	Total Cost
Transport Trailers	10	$ 20,000	$ 200,000
Transport Tractors	5	$ 30,000	$ 150,000
Spreader Trucks	2	$ 30,000	$ 60,000
Total Transportation Equipment			**$ 410,000**

Table 9: Capital Costs

Description	Cost
Total Process Equipment	$ 6,738,502.44
Engineering & Start up (10%)	$ 673,850.24
Total Transportation Equipment	$ 410,000.00
Project Admin & Contingency (5%)	$ 336,925.12
Total Project Cost	**$ 8,159,277.80**

11.1 Operational Assumptions

The biogas facility will be highly automated and operate on a 24–hour, seven day a week schedule. Operators will be required on a five-day a week basis. They will need to manage the process, feed manure to the system, remove and handle solids, filter and transfer liquid effluent, transfer chemicals, and perform regular maintenance. Below is a table of the assumed annual salary requirements for plant operators. There is no allowance for transportation in this table. All labor costs associated with transportation of by-products are accounted for in the transportation costs.

Table 10: Biogas Facility Operations Personnel Assumptions

Operators	# of employees	Cost factor	Annual Salary	Cost
Lead Operator	1	1.5	$80,000	$120,000
Secondary Operators	3	1.5	$40,000	$180,000
			Total Cost of Personnel	**$300,000**

11.1.1 Transportation

The model includes trucks for transportation of the manure and by-products in the capital costs as shown above in Table 8. Transportation of the manure and by-products will be critical to the successful operation of the biogas facility. The shear volume of manure that will need to be moved to the biogas facility on a daily basis requires a solid transportation system, which should be owned and managed by the biogas facility. The transportation will need to be run seven days a week to maintain operation of the process or farmers will need to provide added onsite storage capacity and the biogas facility will need to add buffering capacity to hold by-products and manure on site. Ideally, the manure will be recovered and added to the digester as soon as possible to ensure that the maximum amount of biogas is recovered since the manure immediately begins to degrade reducing the potential energy available for digestion. On the following page, is a table of transportation operational assumptions.

Table 11: Transportation Operational Assumptions

Description	Quantity	Units
Number of cows	5,000	cows
Manure Production per cow	14	gal/day
Manure production per day	68,250	gal/day
Truck loads per day	12	Loads/day
Distance per load	10	miles
Time per load	2	hours
Driver	$ 30	$/hr
Diesel fuel	$ 5.00	$/gal
mileage	5	mile/gal
Truck Maintenance	$0.50	$/mi
Cost per load	$ 75.00	
Total Daily Transportation Cost	$ 900.00	$/day
Cost of Spreading liquid	$ 15.00	$15/1000gal
Annual Cost of Spreading Liquid	$ 18,427.50	$/yr
Total Annual Transportation Costs	**$ 342,427.50**	**$/yr**

11.1.2 Operations and Maintenance

Operations and maintenance costs were estimated to be 10 percent of the capital costs. This includes utilities, preventative maintenance, and chemical additives required for the process. Operation of the filtration system for recovering nutrients from the liquid effluent were estimated to be $100,000 per year, which covers utilities, chemicals, maintenance, and membrane replacement.

The table below includes all estimated operational costs for the biogas facility:

Table 12: Operation and Maintenance Costs

Description	Cost
Operation Personnel	$ 300,000
O&M Costs (5% of Capital costs)	$ 336,925
Transportation	$ 342,427
Filtration Operation cost	$ 100,000
Total Project Cost	**$ 1,079,352**

11.2 Revenue Assumptions

The primary objective of regional biogas facilities is to provide an environmentally sensitive and cost effective means for dairy farmers to process their manure. Regional biogas facilities have the potential to accomplish this goal by capturing GHGs and producing energy and marketable by-products.

The revenue streams included in this financial analysis are: biogas used for electrical generation, carbon credits, solids for compost or bedding, and a high strength liquid nutrient fertilizer product. The table below shows all of the assumptions made for the revenue model.

Table 13: Revenue Assumptions

Description	Cost	References
Capacity Payment Rate (kW/month)	$ 20.14	Based on Tri-State rate ($20.14 kW greater than 82% load factor)
Instantaneous Average kVA*	$ 4,333	Reference "Energy Analysis"
Energy Payment Rate	$ 18.82	Based on Tri-State rate ($18.82 MWH+)
Wheeling Charge ($/kWh++)	$ 0.005	Estimated no hard data available
Conversion Methane to Carbon Dioxide	$ 21.00	Chicago Climate Exchange (CCX) ratio
CCX Rate/Ton	$ 5.50	CCX price for CO_2 credit
Renewable Energy (PTC#) ($/kwh)	$ 0.01	IRS Form 8835 (2007)
Liquid Fertilizer by Product ($/gal)	$ 0.05	Estimated value no hard data
Residual Solids ($/ton)	$ 20.00	Compost = $26.00/ton

*kVA= A measure of electrical power-kilo volt amps
+MWH = megawatt hour
++kWh = kilowatt hour
PTC = Production Tax Credit

Below is a table showing the estimated annual revenue from all three revenue streams.

Table 14: Revenue

Description	% of total	Cost
Electrical Sales	40%	$ 1,031,222.65
By-products	15%	$ 368,878.13
Carbon Credits	45%	$ 1,167,608.37
	Total Cost	**$ 2,567,709.15**

The model has an 18 percent internal rate of return (IRR) based on several income streams. The majority of the revenue is from electrical generation and carbon credits, which provide 85 percent of the revenue, and the by-product sales make up the remaining 15 percent. The revenue for the electrical generation is comprised of two different portions: a capacity payment, which is dependant upon an 82 percent load factor, and the energy produced payment. The capacity and energy payments were calculated with information from Tri-State buy-back program. In order to recover 100 percent of this revenue, the biogas facility will need to feed power directly to Tri-State. This is unlikely given that Tri-State is a wholesaler and supplies many smaller distributors. Most likely, the biogas facility will need to pay a small “Wheeling Charge” to utilize the distributor’s grid for feeding power back to Tri-State. The other wholesale electrical utility in the area is Xcel Energy.

11.2.1 Electrical Sales

For a facility of this size (4 MW) the process of marketing the power to the utility will be a bidding process. Amendment 37 requires that all utilities, such as Xcel energy and Tri-State, operating in Colorado must increase the amount of renewable energy to 10 percent by 2015. Xcel and Tri-State have a bid process for projects in the 50 to 100 MW size, so the payback for the energy produced will be negotiated. Base load or added capacity (in this case 4,000 kW) for the utility is rewarded at a very high rate. In order to qualify for this payback, the facility must run at a greater than 82 percent load factor. The actual payback for the energy produced (kWh) is rather minor in comparison to the additional reliable capacity provided to the utility. This is an important factor that must be considered in the early stages of planning for the facility. Ultimately, each facility will need to assemble a bid package and negotiate a energy purchasing agreement with a utility accessible to their site.

11.2.2 By-product Sales

Nutrients, such as phosphorus and nitrogen, generally passes through the anaerobic process and is discharged in the liquid stream. Both nitrogen and phosphorus can be recovered easily using RO and a high nutrient liquid fertilizer can be created for land application. While this is a small percentage of the overall payback, it is very important because farmers now have to account for these nutrients. Therefore, farms that are landlocked and need to remove nutrients from their property will greatly benefit from this process.

Bedding is a cost to most farmers and the processed bio-solids are excellent bedding, which will be processed easily in the anaerobic digester. Additionally, these solids will make an excellent soil amendment in the form of compost.

11.2.3 Carbon Credits

Current commercial animal operations produce huge amounts of GHGs including carbon dioxide and methane. Methane is 21 times more harmful to the atmosphere than carbon dioxide. Current manure handling allows the majority of this methane to be released to the atmosphere. Anaerobic digestion will not only capture the methane, but also produce electrical energy and heat using it. The largest single contribution to the payback of the system is carbon credits valued at $1.16 million per year. The advent of the CCX and the European carbon markets make these biogas projects feasible.

12.0 FINDINGS

- Benefits to the dairy farmers include:
    - Significantly reduced costs for manure management. Manure is removed from their site daily reducing odor and nutrient management problems.

- Significantly reduced bookkeeping. Nutrient management record keeping required by the EPA is maintained at the centralized site, freeing the dairyman of this responsibility.
- Nutrients available for land application. Liquid nutrients can be applied to farmer's land as needed.

- The smallest feasible concentration of dairy cows for a regional digester is 5,000 cows within a 2-mile or smaller radius due to transportation costs.
- There are six locations within both Weld and Morgan counties that have a high enough concentration of dairy cows (greater than 5,000) within a 2-mile radius to support regional anaerobic digesters based on the proposed model.
- Dairy farmers are interested in regional anaerobic digester projects; however, the main concern is how to make it financially feasible.
- Regional digestion facilities can help landlocked farmers by reducing the land necessary for irrigation and nutrient disposal.
- A preferential electrical pricing scheme for renewable energy or "Net Metering" would offer an additional financial incentive making a biogas facility more feasible.
- Historically, biogas facilities have required an intensive capital investment, which has been beyond the reach of the average dairy farmer. Carbon trading markets create an additional payback, which has created investors interested in "Green Power" projects.
- Other legislative action may be needed to create further economic incentives for developing dairy biogas facilities in the state of Colorado. Areas to investigate include sales tax exemptions, income tax credits, preferential wholesale pricing for renewable energy, and other investment incentives.

13.0 CONCLUSIONS/RECOMMENDATIONS

Regional biogas facilities have some hurdles to overcome; however, the potential is great for these facilities to provide a clean renewable energy source for the future. The model created for this report has an initial capital investment of $8.2 million, which includes a fleet of vehicles for transporting manure and by-products. The projected annual revenue is $2.5 million and the annual expenses are $1.1 million, which gives a simple payback of less than six years and an IRR of 12 percent. This model assumes O&M costs of 5 percent on all capital costs. The payback is five years and the IRR is almost 18 percent.

The model for this system shows that it is possible to develop a regional biogas facility and receive a reasonable return on investment. The next step should be to find a site with a group of dairy producers who are interested in participating in the project and perform a targeted feasibility study to include a pilot plant. With a specific site in mind and specific wastes to process, the accuracy of the report can be greatly increased and the feasibility of a regional biogas facility can be more accurately proven.

There are numerous biogas facilities all over Europe and Scandinavia producing MW of electrical and heat energy. In the United States, the trend is starting to catch on with many individual farms taking the lead and installing their own digesters. There is an economy of scale that will come from regional facilities, which will benefit the farmers and electrical producers.

Additionally, nutrient management will force many farmers to address their current manure management systems. Regional biogas facilities provide a simple environmentally safe and cost-effective solution to nutrient management.

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