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DAIRY CO-DIGESTION USING AN ANAEROBIC DIGESTER

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PREFACE

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ABSTRACT

This project identified, describes, and determined the most cost- and environmentally effective co-digestate (material remaining after anaerobic digestion of a biodegradable feedstock) available to increase biogas production and improve biogas quality (reduced hydrogen sulfide) in a dairy-based anaerobic digestion system. Testing and understanding the effect that liquid, solid, and biogas digester effluents, as well as off-site organic dairy substrates (mainly grease trap and egg wastes) have on air and water quality is critical for developing sound public policy on regulatory standards to control the release of these substances. Identifying the nutrient makeup, biological oxygen demand, and total dissolved solids (salt) loading of the various substrates has narrowed the list of substrates available for use in a digester to produce sufficient biogas to operate a 710 kilowatt hour Guascor combined heat and power generation unit for electrical output. One-liter samples of various were collected and sent to a local laboratory familiar with the regulatory constraints. These substrates were tested for biological oxygen demand, total suspended solids, total dissolved solids, nitrogen, phosphorus, and potassium. The study concludes that offsite organic substrates provide the proper constituents to optimize biogas production without having a negative impact on the quality of effluent and exhaust emissions related to use of biogas as a fuel.

Keywords: Anaerobic digestion, substrates, hydrogen sulfide, grease trap waste, organic waste, biological oxygen demand, electrical output, Guascor

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EXECUTIVE SUMMARY

Introduction

This project analyzed the efficiency, effectiveness, and regulatory compliance of a renewable energy power generation system using alternative, offsite organic feedstock in a dairy anaerobic digestion power generation system at the Fiscalini Farms, L.P. dairy in California's San Joaquin Valley. This project addresses public interest energy research goals of agricultural end use energy efficiency, energy-related environmental research, energy systems integration, and renewable energy technologies.

Gathered data verified the combination of European technologies for anaerobic digestion and power generation will operate effectively, efficiently, and economically using multiple feedstocks and meet California's strict environmental regulations. This project measured quality and quantity of substrates in the form of captured gas produced by waste feedstocks that included cow manure, energy crops, whey, cheese waste, and other organic material such as grease trap wastes or eggs from offsite processes and completed a cost-benefit analysis of the entire anaerobic digester power generation system. The project also quantified all environmental attributes created by this system design and verified that the anaerobic power generation system will meet or exceed all environmental regulatory requirements for California. This project demonstrated that the anaerobic digestion system will produce higher amounts of biogas using multiple feedstocks, increased power generated for an acceptable economic return on the investment, and comply with environmental regulatory requirements. These results will improve the ability to commercialize these technologies in California and the United States; provide the necessary technical data to regulatory agencies to increase the predictability of public policy; and facilitate the permitting process of anaerobic digesters. Improving this process will encourage more dairy operations to consider installing this type of system.

Project Process

The anaerobic digestion power generation system used for this project consists of two above-ground concrete tanks for anaerobic digestion and an internal combustion engine and generator set designed to operate on biogas generated from dairy manure to generate electricity that feeds into the Modesto Irrigation District's electrical grid, and produce heat for use at the dairy. When evaluating the various technologies that were available for anaerobic digestion and power generation, the technologies selected for use in this project are a highly suitable configuration for a dairy operation. The various alternative power generation systems evaluated include diesel engines redesigned and rebuilt to operate on biogas, mictroturbines, biogas to pipeline, and fuel cells. For each of these technologies, it was determined there were too many unknowns as well as extraordinary costs to select them. Furthermore, in a commercial dairy setting, these technologies either had not operated as expected and/or failed, are the first projects of their type in a commercial dairy setting, have not gone online, or have historically experienced excessive engine break downs due to the reconfigured old diesel engines not initially designed for biogas. After extensive research of all of these technologies, it is clear that none of them had a proven track record to meet California's air and water regulations. Many research studies investigating these technologies have determined the following:

- Redesigned and rebuilt diesel engines will not meet the new air emission quality standards passed in May 2007 because of emissions of oxides of sulfur (hydrogen sulfide), oxides of nitrogen , particulate matter, and carbon monoxide.
- Older diesel engines are getting harder to find and retrofit with the appropriate technology to bring them into the new air quality standards.
- Microturbine engines continue to have problems with the higher hydrogen sulfide levels found in biogas, as well as low operating efficiencies and therefore do not operate long enough to reach a positive return on investment.
- Fuel cell technology has yet to be proven using exclusively dairy biogas, and the cost to install and operate is prohibitive for a dairy operation to manage.
- Biogas-to-pipeline design has not yet been proven to be a viable business model, operates inconsistently for a 12-month period under field conditions, and requires a main gas line from a utility within two miles of the biogas production and scrubbing facility to be economically feasible. Evolving the power generation component of this system to continuously meet the air emission regulations and have a positive economic return on investment within seven years is critical to the commercialization of this technology.

The anaerobic digester technology used in this project is also a new application in California; the above-ground tank design is the first of its kind in a California dairy farm. Throughout the past 35 years, the typical anaerobic digester design at California dairies has either been an in-ground lagoon style system or a "plug flow" design, where the slurry inside the vessel moves when a new batch of manure is introduced at the front end, displacing a similar volume that moves out the back end. The existing in-ground lagoon-style anaerobic digester has had trouble with key metrics: it has not consistently met California air and water environmental regulations, it may not maintain a uniform production of gas year round, and it requires a larger overall project footprint that takes valuable land out of production. Although there are more than a dozen of these systems operating at California dairies, developing a system that allows for improved management of the slurry, higher efficiency and effectiveness in biogas production, and improved digestion of the nutrients will enable the system to achieve a greater economic return in a shorter period. This project documented the environmental and economic viability of this state-of-the-art system.

Project Results

The project's measurable technical goals determined the quality of the power and heat, the quantity of power and heat generated, and the optimum operating parameters to enhance the system. The economic viability of this source of renewable energy has also been evaluated by a cost/benefit economic analysis.

This research project gathered and analyzed data to evaluate further development of dairy anaerobic digesters in California and improve energy efficiency for dairies using off-farm organic feedstocks. Although anaerobic digesters historically have been used in California to

break down practically anything digestible, state regulations have prevented using more than cattle manure as a feedstock in dairy digester systems. There is concern that if additional or alternative feedstocks are added to the dairy digesters, the water and/or air quality emissions will be negatively impacted. However, this project with the alternative anaerobic digestion technology design and a Guascor internal combustion engine specifically designed to operate on biogas from off-farm substrates, produced exhaust emissions and effluent water of sufficient high quality to meet or exceed California's strict air and water regulations. The cost/benefit analysis task performed determined that this system can operate successfully with an acceptable economic investment with the use of off-farm substrates. To achieve the identified goals, system performance data were gathered to quantify actual energy production and environmental quality. This project, using the anaerobic digestion technology, the lean–burn, biogas-driven designed engine, and outside organic substrates has demonstrated the financial and regulatory viability of the systems. Verification of the reliability and environmental benefits of this system through extensive monitoring will ease permitting numerous additional systems within California to benefit California residents in the form alternative energy production, improved energy efficiency of the dairy industry, and high environmental standards.

A potential project outcome is an increased number of dairy-based renewable power generation projects in California. The potential electrical power generation from dairies in California alone was estimated by the California Energy Commission in a June 8, 2007 report, *Estimation of Power Production from RB5 Dairies* to be about 1,530 gigawatt hours (GWh) per year.

The project findings show that using organic off-farm-generated wastes have a positive impact on the financial viability of these types of anaerobic digestion and power generation facilities. The off-site material allows the farm to generate revenues from fees that are charged providers of wastes ("tip fees") and from increased electrical sales revenues; without these additional revenue streams, these types of systems are not financial viable. Furthermore this study has demonstrated that using off-site substrates has very little impact on air and water emissions.

Benefits to California

This system has been successfully demonstrated in other states and in Europe, but has not been tested in California in a working agricultural environment. To be commercially viable in California this system must meet existing environmental regulations, primarily air and water. Of particular importance for the project is the codigestion of whey (cheese waste) from an onsite cheese production facility, manure waste, and off-site generated organic materials. This system is one of the first anaerobic digester systems permitted by the Region 5 Water Quality Control Board to codigest more than one feedstock. The ability to permit a dairy digestion system using more than one feedstock is critical to the economic viability and commercialization of this system.

It is critical to prove that using alternative feedstocks in a dairy anaerobic digester power generating system will benefit the environment through improved management of waste streams from food service companies, improved air and water quality, and improved nutrient and waste management. It is also important to demonstrate that the recovery and/or sale of electricity, heat, environmental attribute credits, and "tip fees" can be profitable to dairy

operations. All of these sources of revenue become very important when determining the economic viability of the project and, thus, in further developing the commercialization of the technology. The economic viability of this type of system is critical to deciding if an anaerobic digester power generating system would be installed at a dairy. The additional potential revenue stream is important in evening out the extremely volatile milk industry economics.

This project identified and determined the most cost- and environmentally effective co-digestate (material remaining after anaerobic digestion of a biodegradable feedstock) available to increase biogas production and improve biogas quality (reduced hydrogen sulfide) in a dairy-based anaerobic digestion system. Testing and understanding the effect that liquid, solid, and biogas digester effluents, as well as off-site organic dairy substrates (mainly grease trap and egg wastes) have on air and water quality is critical for developing sound public policy on regulatory standards to control the release of these substances. Identifying the nutrient makeup, biological oxygen demand, and total dissolved solids (salt) loading of the various substrates has narrowed the list of substrates available for use in a digester to produce sufficient biogas to operate a 710 kilowatt hour Guascor combined heat and power generation unit for electrical output. One-liter samples of various were collected and sent to a local laboratory familiar with the regulatory constraints. These substrates were tested for biological oxygen demand, total suspended solids, total dissolved solids, nitrogen, phosphorus, and potassium.

The offsite organic substrates provided the proper constituents to optimize biogas production without having a negative impact on the quality of effluent and exhaust emissions related to use of biogas as a fuel.

CHAPTER 1:
Purpose and Scope of this Study

1.1 Purpose

This project addressed the technical, economic and regulatory feasibility of using various organic feedstocks generated off-site to produce biogas in a dairy based anaerobic digestion power generation system located at Fiscalini Farms, L.P. in the San Joaquin Valley of California.

The study involved identifying and contracting sources of off-site organic substrates, which were then inputted into an agricultural based anaerobic digester system and co-digested with on-site dairy manure. A number of parameters were measured as the substrates were processed through the digester including:

- Volume of substrates received on a monthly basis
- Economic value of "tip fees" from outside substrates on a monthly basis
- Volume of biogas generated on a monthly basis
- Electrical production on a monthly basis
- Volume of manure processed on a monthly basis
- Electrical revenue on monthly basis
- Anaerobic digester facility costs on a monthly basis
- Analytical results from a number of sample locations

This data was used to generate a number of different analyses including:

- Air Emission Summaries
- Influent Characteristic Summaries
- Effluent Characteristic Summaries
- Substrate Characteristic Summaries
- Production Reports
- Financial Reports

CHAPTER 2:
Fiscalini Farms Anaerobic Digester Physical Facilities

2.1 Facility Overview

The anaerobic digester located at the Fiscalini Farms dairy was installed in 2008. Its European-based system was designed and built by Biogas Energy, Inc., a California company. The system is comprised of two circular concrete above ground tanks, approximately 80 feet in diameter and 23 feet deep. Allowing for approximately two feet of free board inside the tank, the working hydraulic capacity is approximately 850,000 gallons per tank. The tanks are insulated to minimize heat losses from the vessels and plastic piping, embedded in the concrete tank at the time of construction, is used to provide the heat exchange capacity for the digester Hot water generated from the combined heat and power (CHP) system is circulated through the piping to maintain the temperature within the digester of approximately 100 degrees Fahrenheit (°F). The 100°F operating temperature is the standard anaerobic digestion temperature for mesophilic operation.

The digesters are setup to act as complete mix vessels operating in parallel to each other; a common setup for the European digester designs. Each digester was initially configured with 4 Flygt submersible mixers. These mixers are suspended on a cable system allowing them to be raised and lowered in the water column in the digester. The mixers are also configured with a manual rack and pinion system allowing them to be rotated within the digester. This configuration allows changes to be made to the mix systems while the digester is in operation.

Each digester tank has an inflatable top of a canvas type material. It is inflated using continuously running ¼ horsepower air blowers. Each tank has a second membrane structure under the inflatable roof. This membrane is of 60 millimeter (mm) polyethylene construction and is designed to contain the methane gas generated from the digester operations as well as preventing an infiltration of outside air into the digesters. The digesters are equipped with several safety devices designed to prevent overpressurization of the tank. A small amount of air is pumped into the headspace of the digesters to promote the growth of facultative bacteria, which convert some of the hydrogen sulfide generated from the digestion process into insoluble sulfur compounds. These compounds slough off and are removed via the digester liquid effluent withdrawal.

Using the air injection system decreases the hydrogen sulfide (H_2S) from approximately 2,000-4,000 parts per million (PPM) to typically under 500 PPM. Due to the complex nature of the biological process the H_2S varies from a low of less than 20 PPM to a high of over 1,000 PPM with an average of approximately 200 PPM during the test period.

The digesters are equipped with high-density polyethylene piping systems, which collect the biogas generated from the digester tanks. The biogas is then pressurized via a centrifugal blower and sent to a chiller system, which chills the gas to approximately 45 °F to remove the moisture (water vapor) in the gas prior to combustion.

The conditioned biogas is then combusted in a Guascor 500 series engine, which is coupled to an electricity producing generator. The Guascor engine is configured to burn biogas that is 60% methane and 40% carbon dioxide, and has a name plated electric generation capacity of 710 kilowatts per hour (kWh). The engine is equipped with a Selective Catalytic Reduction (SCR) unit, which removes the majority of the nitrogen oxide (NOx) and carbon monoxide (CO) from the exhaust gases. A portion of the heat generated from the combustion process is captured in a heat exchanger system, heating water as a means of moving the heat to the digester tanks and other parts of the dairy. This hot water is circulated through the piping system described above to maintain the digester at 100 °F. The Gausor generator set and the associated heat recovery systems were designed and installed by Martin Machine. All of the electricity generated by the CHP system is sold to the Modesto Irrigation District (the local electrical utility) under a 15-year power purchase agreement (PPA).

The influent to the anaerobic digester system originates during the flushing of the lanes where the diary cattle are maintained. The flush lanes are approximately 900 feet long and are flushed 6 times per day for 2-3 minutes at a flow rate of approximately 1,000 gallons per minute. There are 4 barns with 2 lanes per barn and each barn houses approximately 450 dairy cows. Based on many previous studies conducted by the dairy industry, the amount of manure generated per lactating dairy cow is between 90-120 pounds (lb) per day. Each flush lane is collected into a common concrete conduit and flows into an inlet structure at the digester.

The inlet structure for the flushed manure is divided into 4 separate concrete basins. Basin number one is used to settle the heavy primarily non-organic particulates from the flow. This includes sand, dirt, rocks, and other materials unsuitable for the anaerobic digester system. From the initial inlet structure the manure slurry flows into the “East” pumping chamber where the slurry is pumped across a “slope screen” seperator (a device which separates the large solids from the slurry mixture) where the discharge gravity flows into the “settlement pit”. The ”settlement pit” basin was originally designed and built to feed the digester from the conical bottom.

The use of the original flow scheme allowed a very high percentage of inorganic solids to pass through the slope screen into the conical bottom basin. These inorganic solids, primarily sand, were then pumped directly into the digester tanks. Due to the density of the inorganic materials, 7 feet of sand settled out in the digestion vessels, causing serious erosion issues to the mixers and pumps and ultimately led to the multiple failures of the mix system in digester tank number 2. This tank was emptied and cleaned three times, the last time being in June 2013, when the tank was pumped out and the inorganic buildup removed as shown in the photo in Figure 1 below. The mixers were repaired and re-installed and tank 2 was returned to service the end of July 2013, after being out of commission for 7 weeks. This build up of inorganic materials was similar to the other two times the tank had to be emptied and cleaned. Note the mixer blades and static mixing system added after the original design failure; the top funnel is 8 feet off the bottom of the tank

Figure 1: Sand Buildup in Digester Tank 2

In July 2013, the inlet structure for the digesters was modified to allow the sand to settle out in the conical bottom basin. The organic materials now overflow into a pumping pit as shown in Figures 2 and 3 below.

Figure 2: Revised Organic Vs. Inorganic Separation Pit

Figure 3: Manure Separation Wall Completed and Operational

To date this system has eliminated the vast majority of sand and inorganic material infiltration into the digestion systems. An earlier study funded by the United States Department of Energy, Fiscalini Farms Biomass Energy Project (Stringfellow, Camarillo, Hanlon, Jue, & Spier, 2011) and conducted by the University of the Pacific, showed the influent feed to the digesters was as much as 70% inorganic. As is seen from the data later in this report, the influent isnow in the 60% organic range, which is typical for dairy digesters.

The primary influent pump failed in July 2013 as a result of sand and debris ingested from the original inlet structure configuration. The entire pump required a major rebuild and it was sent to the European company, Volgalsang, repair facility in Ohio. The secondary influent pump was also disassembled and inspected. The pump's internal assembly was also found to be seriously eroded and required replacement. After replacing the internals of the secondary influent pump, the digester system was operated in manual mode. The secondary pump system was reinstalled only to serve as a backup and therefore not coupled into the system's Supervisory Control and Data Acquisition (SCADA) control system. The daily operational sequence was as follows:

- The effluent valves were opened and each digester was allowed to drain to a level of approximately 19.5 feet
- The effluent valves were then closed to stop flow
- The influent valves were again opened and the digester was refilled to a level of approximately 20 feet.
- The influent valves were then closed to complete the daily test cycle

This process occurred each day, 7 days per week until the main influent pump was returned to service on September 27, 2013. Based on tank size and fill level, the total volume of influent processed on a daily basis was approximately 30,000 gallons per digester per day. This gives a hydraulic retention time (HRT) of about 28 days for the eastern most digester 2 (D2) and less than 28 days for western most digester tank 1 (D1), as D1 was expected to have a loss of capacity of 10-15% due to sludge buildup as was initially found in D2. The HRT is calculated by dividing the total volume of the digester by the daily influent volume. Normal HRTs are in the 20-30 days range. Anaerobic digester performance improves when the influent and effluent rates are consistent, and typically anaerobic digesters are fed frequently on a 24-hour period. The manual system used at the Fiscalini site processed less influent on a daily basis and resulted in some loss of digestion efficiency.

Organic substrate reception facilities located offsite consist of two 14,000 gallon fiberglass receiving tanks that are shown in Figure 4 below. These tanks are interconnected giving a total receiving capacity of 28,000 gallons. The tanks are connected to the digestion system via two Vaughan "chopper"pumps that circulate the contents of the reception tanks. The pumps reduce the particle size of the organic materials thereby improving the digestion process. The outside organic substrates are fed either manually or automatically into the digestion system. The tanks are diked to prevent loss of material in the event of a tank failure. These tanks are pumped empty every day.

Figure 4: 14,000 Gallon Digestate Mixing Tanks Located Offsite

2.1.1 Facility Operations

The digestion facility was started up in December 2008. This was the first agricultural based complete mix system in the state of California. There were numerous startup issues that are rooted mainly in these four areas: lack of on-farm knowledge, lack of technology provider support, and engineering miss-calculations.

Anerobic digestion was, and still is a rather new technology addition to the dairy/farming community. Although dairy/farming today is a relatively high technology industry, anaerobic digesters are a significant departure from typical dairy/farming activities. The skill sets required by operators of anaerobic digestion facilities are considerably different compared to normal dairy/farming activities. Anaerobic digestion is a fairly complicated bio-chemical process, which requires specialized mechanical systems that are unique to anaerobic digestion facilities. Fiscalini Farms personnel initially struggled with the learning curve for both the bio-chemical and mechanical components. There was a very steep learning curve with little outside support from dairy/farming co-ops or other user groups with past experience. Therefore, the digester suffered operationally related issues such as mechanical breakdown, improper feed rates, and improper and/or ineffective responses to technical issues.

The agricultural industry digester (AID) business in the United States has been, and continues to be a very small niche market. Unlike Europe, the agricultural market in the United States has few anaerobic digester systems in place. It is a market that has few technology providers located in the United States. The only two current manufacturers in the United States are DVO and RCM. The other providers of anaerobic digester are all of European origin, and these manufactures are represented in the United States only by small distribution companies.

Fiscalini Farms selected a digester of European design and origin because the lack of local support would mean increased time and cost to resolve technical and mechanical issues. This issue continues today as components fail, the vast majority of replacement parts typically are only available in the European market place. Over time, some of the support equipment such as chilling systems, pumps, valves, and electronics will be able to be replaced with components manufactured in the United States.

On October 1, 2013, as part of this study, substrates were no longer introduced to tank D1. D1 was only operated on raw manure. Tank D 2 was operated on both manure and substrate. Both digesters share a common gas collection system but the effluent in each digester tankwas still sampled and analyzed for comparison purposes. These protocols remained through the end of October when the last sets of effluent samples were taken and tested. This protocol allowed for the direct comparison of the effluent and operational differences between the two digester tanks fed different feedstocks through a complete HRT cycle. For the purpose of this study and as is normally the case for most AID systems based in the United States, the HRT is considered to be the same as the sludge retention time (SRT). This is due to the lack of any type of “return activated sludge” (RAS) used as part of the process. There are some digester designs that use some RAS, however this particularAID system does not.

2.1.2 Substrate Identification and Contracting

Animal manure is the most widely recognized feedstock for AID systems, however it is not the most desireable feedstock because it provides a relatively small amount of biogas per pound of material when compared with other potential feedstock. The reason is that the cows' digestive systems have removed much of the nutrient and energy value of the feed they consumed before their manure waste reaches an anaerobic digester. Therefore, combining animal manure with other organic substrates greatly increases biogas production and helps to make the use of digesters significantly more economically feasible than using animal waste alone; this is called co-digestion.

Co-digestion is a process in which additional organic waste materials such as carbohydrates and energy rich fats, oils, and grease (FOG) and/or food wastes are added to the digester with the dairy manure. An added bonus is the diversion of food scraps, FOG and other organic wastes from landfills and sewer lines. These high-energy materials typically have at least three times the methane production potential of manure. The biogas production potential correlates to the amount of energy that the material produces when digested anaerobically. Table 1 shows the biogas potential of numerous organic feedstocks.

Table 1: Biogas Potential of Organic Feedstocks (Basisdaten Biogas Deuthchland, Marz, 2005)

Substrate	Biogas Yield (m^3 per metric ton)
Fats and Grease	961
Bakery Waste	714
Food Scraps	265
Corn Silage	190
Grass Silage	185
Green Clippings	175
Brewery Waste	120
Chicken Manure	80
Potato Waste	39
Pig Manure	30
Cow Manure	25

Food wastes are typically rich in organic matter and as a result are troubling in landfills, as it decomposes it releases methane; a potent greenhouse gas. More than 36 million tons of food waste was generated in 2011 and as much as 95% was thrown into a landfill (Challenge, 2013). Energy generation, including AID, is an industrial use of food wastes. Several municipalities across the United States offer either household or commercial collection of food wastes. In

addition, there are many private organic recycling companies across the United States collecting and receiving organic waste streams.

Food wastes have high moisture content and are often the wettest component of household garbage. This high-quality organic energy source can be mixed easily with other organic materials. The energy content in the resource is a function of the type of food waste but usually ranges between 1,500 and 3,000 British thermal units (Btu) per pound of waste. The energy content determines how much energy can be produced from a feedstock. According to the United States Environmental Protection Agency (EPA), food wastes comprise most of the material sent to landfills, and only 2.5% is diverted annually. A University of Texas study estimates U.S. food wastes could be diverted from landfills to produce 4,900 trillion Btu of energy (Cullar & Weber, July, 2010).

Table 2 below lists some food waste characteristics.

Table 2: Food Waste Characteristics; Solid Waste Profile (Cullar & Weber, July, 2010)

Food Waste Characteristics	
Moisture content	70%
Energy content	1,500 - 3,000 Btu/lb
Density	2,000 lb/cubic yard

Table 3: Top 10 Most Prevalent Items in California Waste Disposal Systems

Rank	Material	Percent Total Waste	Estimated Tons
1	**Food**	**15.5%**	**6,158,120**
2	**Lumber**	**14.5%**	**5,765,482**
3	Remainder/Composite Inerts and Other	5.5%	2,175,322
4	**Remainder/ Composite Paper**	**5.2%**	**2,056,546**
5	**Uncoated Corrugated Cardboard**	**4.8%**	**1,905,897**
6	**Remainder/ Composite Organic**	**4.3%**	**1,719,743**
7	**Leaves and Grass**	**3.8%**	**1,512,832**
8	Bulky Items	3.5%	1,393,091
9	**Carpet**	**3.2%**	**1,285,473**
10	Rock, Soil and Fines	3.2%	1,259,308

Table 3 displays the top ten most prevalent material types in California's waste dispoal system, the top seven most desireable being highlighted. Many different facilities produce significant food waste volumes attractive to use in an AID system. These facilities include food manufacturers, restaurants, hospitals, universities, and supermarkets. Hospitals and universities produce similar wastes streams comprised of typically 50% fruit/vegetables and 50% protein (meat, fish, and poultry) and baked goods. Restaurant food waste exhibits more variability in composition. Restaurants preparing food as it is ordered are likely to generate largely fruit and vegetable wastes with minimal amounts of bakery, sugar, starch, and dairy products. Supermarket waste is mostly produce (90%) with small amounts of bakery, seafood, and deli wastes. Supermarket meat wastes are generally collected by rendering facilities. (Group, 2009)

CHAPTER 3: Method

3.1 Substrate Characterization

The substrate study evaluated food waste generators within a 60-mile radius of the study area (approximately centered on Modesto, California). This included the counties of Stanislaus, Merced, San Joaquin, Alameda, Santa Clara, Contra Costa, Mariposa, Tuolumne and a small portion of Sacramento County.

3.1.1 Background

A previous study conducted in Massachusetts evaluated the amount of organic sources available in the State of Massachusetts (Darper/Lennon, 2002). That study derived formulas to theoretically quantify food waste generated by various industries. These formulas were utilized in this study to quantify potential organic feedstock amounts from food manufacturers, supermarkets and grocery stores, restaurants, universities and hospitals. This study uses the same calculation for food manufacturers, grocery stores, and restaurants assuming 3,000 pounds of waste each year per employee. Food manufacturers included producers of animal food, bakeries, dairy products, grain processing, oil processing, chocolate manufacturing, vegetable and fruit processing, frozen foods, animal slaughtering, seafood processing and snack food manufacturing.

Numerous studies were analyzed to determine an approximation of the amount of food waste generated by grocery stores. The CASCADIA study (Group, 2009) is based on California stores; the Massachusetts Department of Environmental Protection ("MDEP") study (Darper/Lennon, 2002) is based on Massachusetts stores; and both the Jones (Timothy W. Jones, 2002) and Buzby (Buzby, Wells, Axtman, & Mickey, 2009) studies are conducted by the United States Department of Agriculture (USDA) over the United States as a whole, followed by a study based on North Carolina stores.

The CASCADIA study found each supermarket produces approximately 64 tons of food waste per year. Applying this number to each store, the Chicago Metropolitan Area's tonnage would be approximately 89,600 tons per year (tpy). According to the MDEP study, each supermarket produces approximately 222 tpy and convenience stores produce approximately 43 tpy (note: this study does not include stores with numbers of employees less than 10). On average, that would mean each store produces 132.5 tpy. Applying these values to the Chicago Metropolitan Area correlates into approximately 185,500 tpy from grocery stores. Based on the Jones study produced by the USDA in 2002, supermarkets produced 22 tpy and convenience stores produces 10 tpy of food waste, giving us an average of 16 tons per store per year. If applied to the Chicago Metropolitan Area, that would result in approximately 22,400 tpy (Timothy W. Jones, 2002). This study is believed to be consistent with supermarket tonnage in the Modesto area.

The USDA-sponsored 2009 Buzby study cites 105 tpy of food waste per supermarket and does not distinguish between supermarkets and convenience stores (Buzby, Wells, Axtman, & Mickey, 2009). Based on this study, the Chicago Metropolitan Area would produce 147,000 tpy of food waste.

In North Carolina, small grocery stores produce 83 tons of food waste per year, and large stores produce 117 tons of food waste per year. With a total of 2,558 stores and a total tonnage of 273,902 tons, the average tonnage per store was 107.1 per year (Leven, 2012). Therefore, based on the North Carolina model, the Chicago Metropolitan Area's 1,400 grocery stores would produce approximately 149,940 tons of food waste per year. The chart below shows an average of studies.

Table 4:UseableWaste Generation by Individual Store (Darper/Lennon, 2002)

	CASCADIA (2006)	MDEP (2003)*	Jones (2002)	Buzby (2009)	North Carolina (2012)	**Per Store Annual Tonnage (Average)**
Fast-Food (NAICS 7222)	21	51	76			**50**
Restaurants (NAICS 7221)	33	Included above	25			**29**
Supermarkets (NAICS 44511)	64	222	22	105	117	**106**
Convenience Stores (NAICS 44512)	Included above	43	10		83	**45**

*Massachusetts' estimates do not include stores with less than 10 employees.

North Carolina Study:

Table 5: Results of the North Carolina Study (Leven, 2012)

	Weekly Tons per Store	Annual Tons per Store	Number of Stores in N.C.	Annual State Total
Large Store (Supermarket)	2.25	117	1,807	211,419
Small Store (Convenience)	1.6	83	751	62,483
			Total	273,902

In a few additional studies, the Connecticut Department of Environmental Protection (CTDEP) indicates an average of approximately 170 tpy for supermarkets .This basis would give the Chicago Metropolitan Area 238,000 tpy of food waste per year. A study of Orange County stores by type established 101 tons food waste is generated per year, based on a four-year average from 2008-2012 (Leven, 2012), thereby generating 141,400 tons of food waste per year in the Chicago Metropolitan Area.

Table 6: Waste Generation per Type per Store (tons), Orange County. (Leven, 2012)

	Number of Establishments	Average Monthly Tonnage 08-09	Average Monthly Tonnage 09-10	Average Monthly Tonnage 10-11	Average Monthly Tonnage 11-12	Four-Year Average per Store per Year	Projected State Tonnage
Restaurants (NAICS 7221)	12	2	3	3	3	32	225,393
All college	5 (one missing in 08)	10	8	11	11	120	
Supermarkets (NAICS 44511)	3	9	8	8	8	101	181,942
Grocery (NAICS 44512)	5 (all Weaver St.)	4	4	4	4	48	35,932
Residences and hotels	3 (one missing in 08)	4	4	5	5	54	
Schools	3	*n/a*	*n/a*	*n/a*	0.15	*n/a*	
Conference Center	1	4	3	5	5	52	
Hospital	1	12	15	19	17	188	
Other	3 (inconsistent)	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	

According to the MDEP study, the average restaurant produces 51 tpy, yielding an estimated 257,000 tpy of food waste per restaurant. Different studies find different results as CASCADIA estimates food waste production to be 33 tpy, the Jones study estimates the amount at 25 tpy and the Orange County report estimates the amount at 32tpy.

For the "fast food" category, the CASCADIA, MDEP, and Jones studies report an average of 49.33 tpy per "fast food" restaurant.

For example, assuming half of all food Chicago restaurants are classified as "fast food" and the other half are "restaurants", food waste will total an estimated 172,667 tpy from "fast food" establishments, and 123,375 tpy from "restaurants," and a total food waste generation of 296,042 tpy.

Restaurants considered were full service restaurants. Universities considered were those with enrollments of 4,000 or more. Food wastes from universities with dining halls were based on the number of students and meals per year. Food wastes from hospitals were estimated using number of beds. Only hospitals with inpatient services and with 25 beds or greater were considered for the study. The formulas for the industries mentioned are as follows;

Food manufactures and grocery stores: Organic food wastes (lbs/year) = number of employees x 3,000(lbs/employee/year

Restaurants: Food waste (lbs/year) = Number of employees x 3,000 lbs/employee/yr

Hospitals: Food waste (lbs/year) = # of beds x 5.7 (meals/bed/day) x 0.6 lbs (food waste/meal) x 365 (days/year)

University: Food waste (lbs/year) = # of students x 0.35 lbs (food waste/meal) x 405 (meals/student/year)

The Census Bureau identifies types of businesses using numerical codes known as the North American Industry Classification System (NAICS). The Census Bureau contains a database which quantifies and classifies industries by county based on the NAICS code and provides information on the number of establishments by industries and range of number of employees. The database is known as County Business Patterns (County Business Patterns, Zip Code Business Patterns, 2013). This study evaluated business categories including food manufacturing, supermarkets and grocery stores, restaurants, hospitals and universities. Only facilities with 70 employees or more were included in the evaluation. Smaller facilities were eliminated due to the expectation of low volumes and insufficient staff to separate wastes.

NAICS reports the number of facilities for a particular type of establishment for several categories of employment size. Because exact number of employees per establishment is unknown, the average number of employees per employment class size was used.

Grease Trap Waste (FOG)

Given that the number of restaurants and population is tightly correlated an MSA's population and its number of restaurants can be used as proxies for the pounds/year of brown grease generated. For each Metro Area, the NREL (National Renewable Energy Laboratory) report (Wiltsee & Appel Consultants, 1998) compared the number of restaurants to the population. The number of restaurants per thousand people in each Metropolitan Area was relatively consistent, between 1 and 2 for all 30 areas with a weighted average of 1.41. Restaurant generates approximately 6,000 lbs. of brown grease per year.

Using this data Organic Solution Management (OSM) contracted with a number of haulers, grease trap service companies, and brown grease processors to provide the necessary substrates for the study at Fiscalini Farms. The specific volumes contracted are outlined in this report.

3.2 Results of Characterization

The results of the research to discover what off site organic resources were available in the Modesto Ca region, using the calculation basis discussed above; the follow two charts are the results of those efforts.

Table 7: Number of Facilities by Industry with 70 Employees or More

Substrate Generator Category	Number in Category	Number of Employees	Est. Annual Tons of Substrate	Substrate Potential
Bakery	4	691	1,037	Low
Diary	10	1,879	2,819	Very Good
Fruit and Veg	21	7,107	10,661	Good/Seasonal
Meat Packing	9	1,524	2,286	Low/Good
Snack Food	5	1,355	2,033	Good
Soft Drink	2	200	300	Good
Wine	9	4,973	7,460	Good/Seasonal
Breweries	1	100	150	Low
Candy Mft.	4	1,050	1,575	Low
Pharmaceutical	5	400	600	Good
Edible Oils	1	135	203	Low
Food Mft	4	905	1,358	Good
Spices	4	350	525	Low
Non Alcoholic Bev	3	575	863	Good
Poultry Production	1	400	600	Good
Breakfast Cereal	2	592	888	Low
Total	**85**	**22,236**	**33,354**	

Table 8: Grease Trap Waste Within 60 miles of Modesto, California City Center

Counties Within 60 Miles	Population	# Restaurant	Tons of Brown Grease/Yr.
Stanislaus County	511,263	583	1,748.5
Merced County	245,514	280	839.7
San Joaquin County	670,990	765	2,294.8
Alameda County	1,464,202	1,669	5,007.6
Santa Clara County	1,748,976	1,994	5,981.5
Contra Costa County	1,019,640	1,162	3,487.2
Mariposa County	18,036	21	61.7
Tuolumne County	55,806	64	190.9
Total	5,734,427	6,537	19,611.7

CHAPTER 4:
Data Collection and Monitoring

4.1 Data Collection and Monitoring Program

The study collected data from a number of different sources.

A. Substrate volumes were collected from daily weight tickets from the transportation companies that hauled the material to the site. This process involved the transporter weighing their trucks on the truck scales at Fiscalini Farms. The trucks were weighed in full and weighed out when empty giving a tare weight. This data was entered into an Excel spread sheet and summarized on a monthly basis by supplier and total.

Table 9: Substrate Volumes by Supplier by Month

Tons					
Customer Name	**July**	**August**	**Sept**	**Oct**	**Nov**
Mountain Valley	37.10	24.42	0	22.05	13.37
EPS	164.33	380.40	163.22	44.38	155.71
Porter	125.08	51.44	48.13	112.49	48.71
Clark	336.41	259.46	203.98	308.74	485.16
HP	442.9	396.26	373.08	474.88	569.72
Miguel Plumb	7.73	20.61	0	3.48	0
CAB				97.39	125.83
Total Tons	**1,113.55**	**1,132.59**	**788.41**	**1,063.41**	**1,398.50**

B. The economic value of management costs from "Tip fees" collected from the outside substrate suppliers were summarized monthly based on the tip fees and the monthly tons delivered to the site. This data was entered into the monthly proforma summary as "Tip Fee" Income.

C. The volume of biogas generated was recorded weekly and summarized on a monthly basis in the monthly production reports. The data was generated from the sites gas totalizer.

D. Electrical production was recorded on a monthly basis based on an electrical totalizer located at the site and installed by Modesto Irrigation District, the local utility provider.

E. The volume of manure slurry processed was collected on a monthly basis and was either recorded from the influent meter totalizer (mass flow meter) or from the changes in liquid level within the digesters during manual operations

F. Electrical revenue generated from biogas was based on the monthly kilowatt hours (kWh) produced multiplied by the sales rate of $ 0.109 per kWh

G. The costs to operate the anaerobic digester facility were recorded on a monthly basis and are outlined later in this report.

H. Samples from a number of locations were collected and submitted to Denelee Laboratories in Turlock, California for analysis. Sample locations included:

- Manure influent to the digester inlet structure
- Effluent from the combined digester as well each individual digester
- Composites from the substrate storage tanks
- Manure solids from the slope screen
- Manure solids from the on-site drying operations

Monthly Averages from daily readings of H_2S and NOx levels from the onsite meters were conducted.

4.1.1 Fiscalini Farm Production Report Discussion

As part of this study, a monthly digester "production" report was prepared. This report was used to compare the month-to-month variations in the inputs and outputs of the digester system. As outlined above the following information was collected from the various data collection equipment on the site:

- Volume of substrates received on a monthly basis
- Volume of biogas Sent to the CHP
- Electrical production on a monthly basis
- Volume of influent processed on a monthly basis
- Hours of engine operation
- Number of engine starts

The collected raw data was utilized to develop the monthly production summary report for the digester system. An explanation of how the numbers were developed is as follows:

Engine Hours:

The total hours the engine system ran were collected on the first of each month from the totalizer on the engine control system. The CHP system has an hour meter that records total hours the engine had run since it was installed. The summary of the total hours the CHP system operated during the month was determined by subtracting the previous months totalizer hours from the current months total. It was attempted to take the totalizer readings at 8:00 AM on the

beginning and end of each month to keep the data consistent. This data gave the total hours of operations for the month.

Engine Up-Time:

The CHP system "Up-Time" was determined by taking the total hours available for that particular month (number of days in the month times 24 hours per day) and dividing that into the actual total hours the CHP operated. The CHP system at Fiscalini Farms operated nearly continuously with only a few down time hours that were due to routine scheduled maintenance (oil and plug changes, valve adjustments) and periods of time when there simply was a lack of sufficient biogas to operate the system. There was also a problem at a point in the project when the Modesto Irrigation District power distribution network required the system to be shut down for 35 hours during the month of September. Based on the performance of the engine during the study period and the scheduled down time for maintenance, the engine system could maintain a 90% plus uptime if the biogas is available. This is consistent with other AID/CHP systems OSM has reviewed including:

- Indiana Beef Cattle facility (Average 87% uptime)
- Indiana Poultry Facility (Average 91% uptime)
- Wisconsin Dairy Facilities (3) (Average 85% Uptime)
- Ohio Poultry Facility (Average 90+%) Uptime

Electrical Energy Produced:

The CHP system was monitored for the total electrical energy produced on a monthly basis. The CHP system has an electrical totalizer that records the kWh produced since the system was installed. The totalizer was read at the beginning and end of each month to determine the total kWh produced for the month. The difference between the previous month and the current month resulted in net kWh produced

Percent Capacity Produced:

The total kWh actually produced was compared with what could be produced if the engine ran 24/7 at maximum output. The CHP system is nameplate rated at 710 kilowatts (kW) according to Fiscalini Farms. Load testing conducted by OSM determined that due to the configuration of the cooling system, and biogas feed blower, the CHP system could only produce 600 kW at full load. Attempting higher operating outputs caused the CHP system to fault out for a variety of reasons including:

- High jacket water temperature (cooling system issue)
- High oil temperature (cooling system issue)
- Low fuel gas supply (biogas blower issue)

Therefore, for the purposes of the study the maximum continuous CHP output was assumed to be 600 kW. It is important to note that the overall financial viability of the digester system is

closely related to operating the CHP at or near its maximum electrical output capacity to maximize electrical revenue. Digester developers and technology providers often "sell" their systems based on the maximum electrical output capability of their installed CHP capacity. OSM's experience has found that many digester systems DO NOT operate at their full rated capacity but often at a lower capacity. As is seen from the Fiscalini Farms digester summary, the CHP system operated at less than 30% of capacity the vast majority of time. The capacity problem, assuming high CHP "up time", is solely a function of lack of biogas to operate the system at higher electrical loads. This was the case during the study period at Fiscalini Farms. There was not enough biogas to operate the CHP at high load continuously.

Biogas Production:

The volume of gas was recorded from the gas flow meter totalizer at the beginning of each month. The previous month was subtracted from the current month to determine the quantity of the gas produced for that month. However, biogas was not flared during the study period. Biogas is typically flared for two reasons:

1. Excess gas produced beyond that which can be consumed by the CHP system or
2. Excess gas caused by excessive down time of the CHP system

Flares are typically designed to operate when biogas pressure reaches a certain level forcing a pressure control valve open. The biogas is then ignited to prevent the biogas from escaping to the atmosphere.

Biogas production is primarily a function of the volume and type of organic materials inputted into an anaerobic digester. The actual bio-chemical reaction to convert organic materials into methane and carbon dioxide is well known. The basic process involves various facultative and anaerobic microorganisms converting the feed organic materials to organic fatty acids and then converting these fatty acids to methane and carbon dioxide. There are several variables associated which effect the quantity of biogas generated from this biochemical process. These can be broken down into:

- The quantity of volatile solids in a material added to the digester
- The conversion rate of these volatile solids to biogas
- The volume of biogas generated from the conversion of volatile solids

There have been numerous laboratory studies conducted on these various conversion rates and generation rates. This study has attempted to capture actual biogas generation rates and associated power outputs at an operating digestion facility. For the purposes of the study OSM used several data assumptions to calculate theoretical biogas generation rates to compare to actual generation rates. The following outlines those assumptions based on historic OSM operational knowledge:

- Manure Volatile Solids Destruction (VSD) Rate = 40%
- Manure Biogas generation rate per lb. of VSD = 15 cubic feet (CF)

- Substrate VSD Rate = 90%
- Substrate Biogas generation rate per lb. of VSD = 20 cubic feet

Theoretical Gas Generation Analysis based on just the manure input would be as follows:

The average volatile manure solids input is equal to approximately 2,500 milligrams per liter (mg/l) and the average HRT is 25 days. Using 25 days HRT gives an influent rate of 34,000 gallons per day per digester or 0.068 million gallons per day (MGD) total.

Using the following formula:

Lbs./Day = MGD * 8.34 (approximate liquid density)*mg/l gives the following results:

0.068 MGD * 8.34 * 2,500 (study average) = 1,418 lbs. per day of volatile solids

Using the assumptions above the formula would be:

1,418 lbs./day *0.40 (manure destruct rate) * 15 (cubic foot gas/lb. VSD) =

8,508 CFD (Cubic Feet of Gas per Day)

The utilization of biogas by a CHP varies with engine load, methane concentration, state of tune, and other factors. The CHP industry will state various nameplate biogas utilization rates per kilowatt of electrical power output. It has been OSM's experience that an average gas utilization rate per megawatt (MW) of electricity produced is approximately 300 standard cubic feet per minute (scfm). Using this actual field performance data, the manure feed alone to the digesters will generate approximately the following output:

8,508 CFD/1440 (minutes per day) = 5.9 scfm

Using 300 scfm per MW gives the following theoretical power output from the farms manure only input to the digester.

5.9 scfm biogas * (1,000 kW/300 scfm) = 20 kW per hour.

Performing the same calculation on the incoming substrates using an average of 1,000 tons per month gives the following numbers. For the purposes of this theoretical calculation 240 gallons per ton was used for the substrate density. Specific gravity of the substrates was not evaluated but based on historic analysis of grease trap type wastes by OSM suggests that it is close to that of water.

Using 1,000 tons per month, a 30-day month, and 240 gallons per ton gives the following

The average total volatile solids (TVS) in the substrate reception tank was 2.6% or 26,000 mg/l.

Using 1,000 tons per month and a 30-day month gives 33.3 tons per day (TPD).

Based on the above assumptions the biogas generation rate is:

33.3 TPD * 2.6 % VS * 90% VSD * 2000 Lb./Ton * 20 CF per VSD = 32,000 CFD

Using 300 sfcm per 1,000 kW gives the following:

32,000 CFD/1,440 minutes per day * 1,000 kW/300 scfm = 75 kW per hour

This would give a combined total average electrical output of

A. Power from Manure = 20 kW

B. Power from Substrates = 75 kW

Total Average Power Projected: 95 kW per hour

As can be seen in the chart below the actual versus projected the theoretical output was consistently less than the actual during the study as the digesters came to steady state. As the gas volume increased the engine ran more efficiently and therefore used less gas per kW produced. This can be seen in the monthly production report. The kW produced per cubic foot of gas increased. During the study, methane concentrations varied between 50% and 70%. Higher methane concentrations tracked higher gas production rates. The gas production rates were proportional to increased substrate input into the digester. It is therefore reasonable to assume that the increased substrates improved the methane concentration in the biogas. Improved efficiency was also a function of the engine operating at a higher loading rate.

Table 10: Calculated Power Versus Actual Production

Calculated Power vs. Actual				
Month	**Substrate kW**	**Manure kW**	**Projected Ave kWh**	**Actual Ave kWh**
May 2013	43	38	81	80
June 2013	66	16	82	101
July 2013	78	16	94	136
August 2013	79	16	95	181
September 2013	57	31	88	133
October 2013	74	31	106	162
November 2013	101	36	137	284

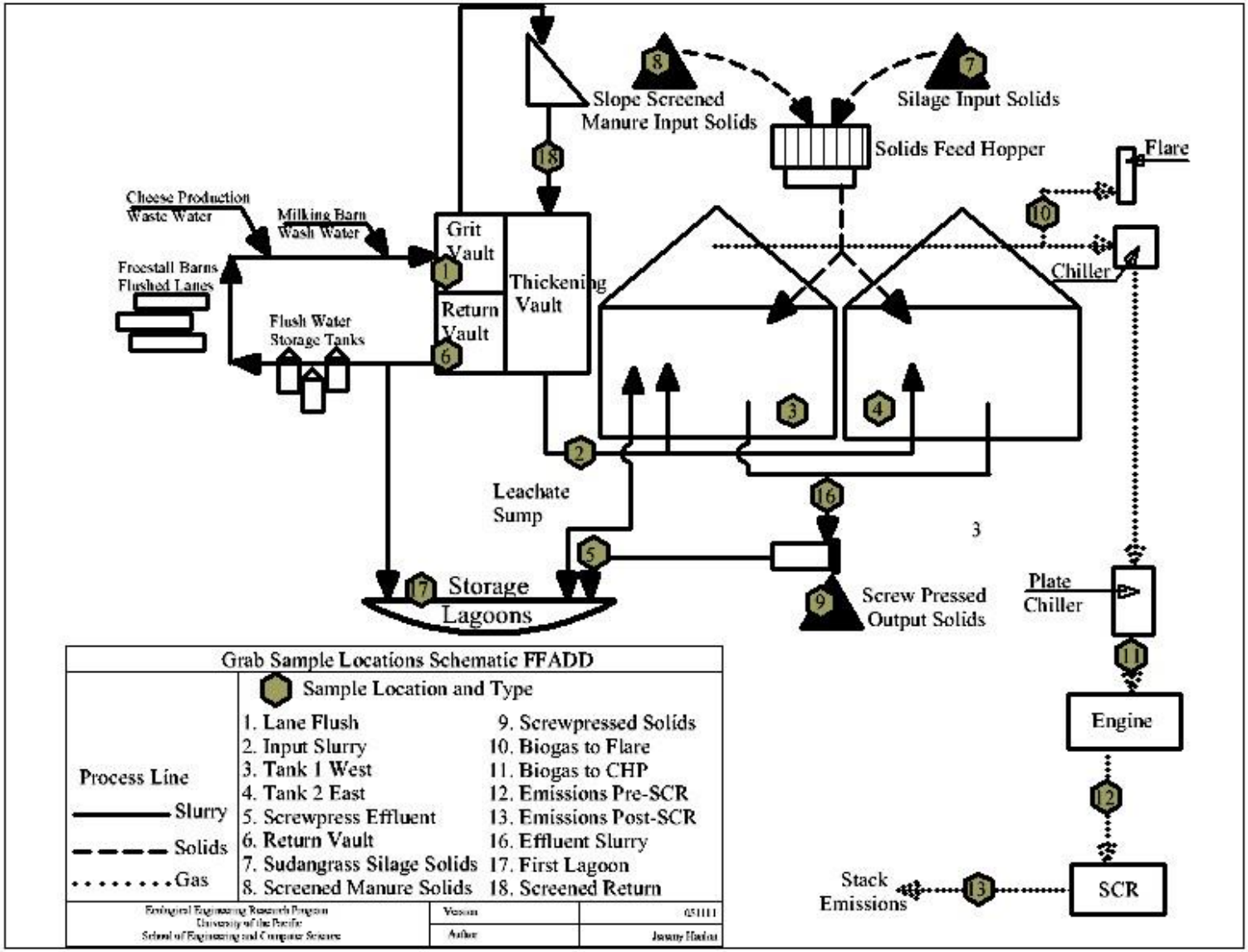
CHAPTER 5:
Sampling Method

5.1 Sampling

Samples were taken from several locations at the digester during this study. The purpose of the samples were to profile the inputs and outputs of the digester system to determine energy production potential as well as identification partitioning of the various components. Figure 5 below identifies the sample site locations relative to the system layout:

- Manure influent to the digester inlet structure
  - Grab samples were taken as the flush water flowed into the digester feed "pit" shown at location point 1.
- Effluent from the combined digester as well each individual digester
  - Grab samples were taken from each digester tank when the drain valve was open and discharging effluent. This is shown at location points 3 and 4.
- Composites from the Substrate Storage tanks
  - The mix pumps were started which circulated the substrate tanks and a grab sample was taken from a sample line installed on the influent feed pump.This location corresponds to point 18.
- Manure solids from the Slope Screen
  - Grab samples were taken from the separated solids from the slope screen. This location is at point 8.
- Manure solids from the on-site drying operations
  - Grab samples were taken from several different piles of dried manure solids. This location was in the field where the solids were dried.

Figure 5: Map of Facilty Layout and Sample Locations



A number of analyses of these samples were conducted using the approved testing protocols listed to include:

- Chemical Oxygen Demand SM5210B
- Biochemical Oxygen Demand SM5210B
- Total Solids (TS) SM2540D
- Total Volatile Solids (VS) SM2540D
- pH SM4500-H+B
- Total Kjehldahl Nitrogen SM 4500-NH3 C
- Nitrate as N (NO_3-N) SM 4500-NH3 C
- Ammonia as N (NO_3N) SM 4500-NH3 C
- Phosphorus SM 4500-P E
- Potassium EPA 200.7
- Chloride EPA 300
- Electroconductivity EPA 120.1
- Soluble Salts EPA 120.1
- Total Dissolved Solids SM 2540C
- Boron EPA 200.7
- Metals EPA 200

The raw data can be found in Appendix 1: Denalle Laboratory Test Results. The data is further broken down into data summaries:

- Influent Summaries
- Both D1 and D2
    - Concentration and Mass Based
- Effluent Summaries
- Both D1 and D2
    - Concentration and Mass Based
- Substrate Summaries
    - Concentration and Mass Based

The summaries reflect comparison of the data related to these sampling locations.

5.2 Influent/Effluent

The influent analysis is based on collection of grab samples pulled as the manure liquid flowed into the new inlet structure outlined above. The influent results clearly indicate low input volatile solids. The average volatile solid input was 2,577 mg/l and the average total solid level was 4,710 mg/l. This reflects a TS/VS ratio of approximately 55%. This is about 15% lower than typical manure from a scrap dairy and is due to the higher dilution associated with a flush dairy. Typical VS numbers for a scrap dairy in the mid-west would be 40,000 mg/l range. The low VS input rates are reflective of low gas production associated with manure only digestion.

Both chemical oxygen demand (COD) and the biological oxygen demand (BOD) are lower than would be expected compared to a scrap dairy, again associated with the flush type dairy system and the diluted input to the digester. The average COD was 6,665 mg/l and the BOD average was 2,603 mg/l. This gives a COD to BOD ratio of approximately 40%, which is 5% lower than a typical scrap dairy.

Electroconductivity averaged approximately 5 micromhos per centimeter (mmhos/cm) and soluble salts averaged 3,256 mg/l.

The nitrogen, phosphorus and potassium (NPK) were low compared to scrap dairies located in the Midwestern United States. The averages were as follows, N: 483 mg/l, P: 51 mg/l and K: 405 mg/l. Based on numbers generated from a number of mid-west dairies these numbers are as follows, N: 2,700 mg/l, P: 340 mg/l and K: 1,700 mg/l. This reflects the low concentration of manure in the digester feed solids.

Table 11 is a comparison of data between a mid-west scrap dairy and from this flush dairy:

Table 11: Comparison of Midwest Scrap Dairy Versus California Flush Dairy Influent Nutrient Waste Values

Influent	Fiscalini Farms	Midwest Scrap Dairy
Total Solids (mg/l)	4,710.0	40,000.0
Total Volatile Solids (mg/l)	2,577.0	21,000.0
Total Kjehldahl Nitrogen (mg/l)	483.0	2,500.0
Total Phosphorus (mg/l)	51.0	320.0
Total Potassium (mg/l)	405.0	1,400.0
pH Units	6.8	8.4
Ammonia Nitrogen (mg/l)	101.0	1,700.0
Carbonaceous Oxygen Demand (mg/l)	6,665.0	63,200.0
Bio-Chemical Oxygen Demand (mg/l)	2,603.0	23,100.0
Magnesium (mg/l)	116.0	800.0
Calcium (mg/l)	276.0	1,600.0

The differences in the scrap vs. the flush type manure handling systems are very evident. The flush system used by Fiscalini Farms removes many of the constituents from the manure prior to digestion.

Similar results are seen when the effluent from the Fiscalini Farms anaerobic digester system are compared to mid west dairy scrap anaerobic digester system:

Table 12: Comparison of Midwest Scrap Dairy Versus California Flush Dairy Effluent Nutrient Waste Values

Effluent	Fiscalini Farms	Mid-West Scrap Dairy
Total Solids (mg/l)	4,591.0	30,000.0
Total Volatile Solids (mg/l)	1,874.0	19,000.0
Total Kjehldahl Nitrogen (mg/l)	655.0	2,500.0
Total Phosphorus (mg/l)	49.0	300.0
Total Potassium (mg/l)	450.0	1,400.0
pH Units	7.3	8.5
Ammonia Nitrogen (mg/l)	329.0	1,800.0
Carbonaceous Oxygen Demand (mg/l)	10,648.0	63,200.0
Bio-Chemical Oxygen Demand (mg/l)	1,632.0	23,100.0
Magnesium (mg/l)	79.0	780.0
Calcium (mg/l)	383.0	1,400.0

Again the dilute input shows in the dilute effluent from the facility.

A comparison of the influent and effluent numbers for the FF digester system based on the mass of materials processed through the digester during the study period. This mass basis is based on averages from the samples taken.

Table 13: Comparison on a Mass Basis Removal of Nutrient Loading

Mass Loading	Influent lbs	Effluent lbs	Removal %
Influent Vs. Effluent	**Fiscalini Farms**	**Fiscalini Farms**	
Total Solids	762,918.6	468,318.6	**39%**
Total Volatile Solids	550,026.2	191,111.1	**65%**
Total Kjehldahl Nitrogen	47,683.0	66,779.5	**-40%**
Total Phosphorus	4,396.1	4,967.9	**-13%**
Total Potassium	33,846.0	450.0	**99%**
Ammonia Nitrogen	13,684.2	33,578.0	**-145%**
Carbonaceous Oxygen Demand	1,277,569.1	894,627.7	**30%**
Biochemical Oxygen Demand	399,550.1	134,035.9	**66%**

As can be seen from the results the conversion of VS and BOD were very high. Nitrogen was converted to ammonia in the digestion process that is preferred for land application as ammonia is much more easily converted compared to other organic nitrogen sources by the plants, therefore reducing the amount of organic nitrogen filtrated through the soil profile to generate nitrate. Overall these results show an anaerobic digestion process that is functioning well.

5.3 Summary of Total Dissolved Solids (TDS)

One of the concerns about adding off-site substrates to the digester system is the potential increases in TDS levels in the effluent water. The average concentrations for inorganic ions that were measured for the raw manure, substrate and anaerobic digester effluent are presented in Table 13 above. Note that the total volume of substrate added accounted for approximately 17% of the total flow sent to digestion of the period May through October. There was an increase in TDS in D2 vs. D1 during the October test period. The overall loading to D2 was higher which attributed to some of the TDS increase

The largest increases were observed for NH4-N. Note the NPK of the substrate was higher than the raw manure. Having said that there would have been some increase in NH4-N from just the manure as organic nitrogen is mineralized to ammonia/ammonium. The remainder of the increase is likely due to some additional sodium and increased bicarbonate (HCO_3) formed as the ammonia gas (NH_3) produced combines with carbon dioxide (CO_2)in the biogas.

The exact increase in ammonium (NH_4) that would have occurred during anaerobic digestion of the manure itself is not known, approximately 40% of the organic nitrogen is generally converted to ammonium in anaerobic digester systems. Additional increase in TDS is also due to some additional bicarbonate produced in the anaerobic digestion process.

5.4 Heavy Metals

Some limited testing for heavy metals was conducted at the start of the project; once for the raw manure, twice for the digestate and 4 times for the substrate streams. Accordingly, too much cannot be read into the results but some useful information was obtained nonetheless.

A summary of heavy metal testing for the substrate, raw manure and anaerobic digester digestate is presented in Table 13. Most metals were less than 0.005 mg/l in all samples. The additional substrate had about 22.5 mg/l of iron based on several data points. The concentrations of the other metals were quite low and not generally a concern for disposal. Copper (copper sulfate is used as a bio-stat in the milking parlor) was observed in the manure feed but not the substrate; the digestate had 0.53 mg/l. Cadmium was present in all three with 0.003 mg/l in the digestate. The only other metal observed was zinc, which was present at 1.57 mg/l in the digestate and 2.07 mg/l in the substrate feed. Overall it does not appear that heavy metals were an issue.

Boron was measured on each stream on 5 to 6 dates. The concentrations averaged close to the same for all three streams at between 0.5 and 0.6 mg/l

5.5 Air Emissions

During the study period the H_2S level in the biogas was monitored daily using the onsite meter. Additionally the exhaust NOx level was monitored daily. A summary of the results are demonstrated in Table 14 below.

Table 14: Comparison of Average NO_X ppm in CHP Exhaust Verses Average H_2S ppm in the Biogas

Month	Average Nox PPM	Average H2S PPM
May	6	165
June	5	213
July	7	285
August	6	212
September	8	192
October	7	264
November	8	228

There does not appear to be any correlation with the levels of substrates inputed into the digester and the concentration of H_2S in the biogas or NOx in the engine exhaust.

CHAPTER 6:
Cost/Benefit Analysis

6.1 Financial Analysis

For the purpose of the study, OSM tracked the costs associated with the normal operation of the Fiscalini Farm digester. There were a number of costs associated with repair and replacement of components that were due to poor design. These costs although noted in the table, are not considered "normal" operating costs.

Table 15: Costs Associated With Continued Operation of the System

Digester Nonstandard Costs	
Component	**Repair/Replacement Cost**
Influent Pump	$5,382.00
D2 Mixer Repair	$42,000.00
Digester Cleanout	$60,000.00
Influent Structure Construction	$12,000.00
Total	$119,382.00

The financial analysis tracked the following cost categories:

6.1.1 Labor

The digester has a full time operator and a full time supervisor/operator. The fully burdened cost for the labor was on average $6,100 per month during the study period. Based on discussion with Fisacalini Farms ownership, this is consistent with previous expenses for the site. Additionally, there is the cost of administrative activities associated with securing permits, submitting various filings, securing financing, legal matters, etc. Based on discussions with the ownership, these costs were fixed at $1,200 per month, bringing the total monthly labor cost to $7,300.

6.1.2 Other Labor

Certain maintenance activities such as servicing the chillers, routine electrical trouble shooting and repair required skills beyond the digester operators. Outside contractors were utilized for this work. Based on the work conducted during the study period and based on discussions with Fiscalini Farms ownership this cost was fixed at $1,000 per month.

6.1.3 Engine Capital Replacement Reserve

The engine generator system requires certain significant maintenance at defined intervals. The *pro forma* outlines these costs based on typical costs of $ 15.75 per hour of engine operation. This is a standard number in the industry for a biogas engine.

6.1.4 Engine Routine Service

This includes oil and filter changes as well as plug changes. The engine oil was changed at 500 hours and included oil filters. The volume of oil was 55 gallons per change. Plugs were changed every 1,500 hours. Other were parts such as hoses, air filters, act were estimated to be $250 per month. The monthly operational cost of the engine was $ 1,025 per month during the study period. Discussion with Fiscalini Farms ownership confirmed that this was a reasonable historic monthly cost.

6.1.5 Digester and Engine Room Parasitic Load

The digester and engine have a number of pumps, mixers, and electronic components that consume electricity. The electrical consumption was metered via two separate Modesto Irrigation District meters, located at the digester and the engine room. Modesto Irrigation District billed Fiscalini Farms for the electrical consumption for these two locations and those costs are captured under the parasitic load line item and averaged $9,600 per month.

6.1.6 Engine Room Phone Bill/Internet Connection

Modesto Irrigation District requires Fiscalini Farms to have a designated phone line to allow them to monitor and control the electrical interconnect switch, and has the ability to remove the load from the generator set to their distribution system in the event of an emergency. This is a fixed cost of $200 per month. Additionally the digester has an Internet connection at a cost of $58 per month.

6.1.7 Miscellaneous Costs

There are a number of normal wear items that require replacement. This includes:

- Belts
- Hoses
- Dust Filters
- Pump Seals
- Gaskets
- Lubricants
- Housekeeping supplies
- Miscellaneous

Based on actual costs during the study period and in discussions with ownership this cost was fixed at $300 per month.

Historically, in an attempt to increase gas production, silage normally used as animal feed was put into the digester system. Although this did have a positive effect on gas production it was not sustainable due to the high cost of the silage and the volitity of the feed commodity pricing.

6.2 Debt Service

The capital expenditure for this site was determined to be $4.0 million and the debt service plus principle payment are based on a 20-year loan at 5.8% interest. This produces a monthly debt service payment of $ 28,198.

6.3 Revenue

As was outlined above there are 2 revenue streams associated with the Fiscalini Farms anaerobic digester system. These are:

6.3.1 Electrical Revenue

Electrical Revenues are associated with the sale of electricity from the anaerobic digester system to the Modesto Irrigation District who monitors the amount of electricity generated from the system and sends a monthly check to Fiscalini Farms for electrical power generated. The current rate is $0.109 per kWh. The monthly revenues are entered into the *pro forma*.

6.3.2 Tip Frees Revenue

Tip Fees are associated with the processing of outside substrates brought into Fiscalini Farm's anaerobic digestersystem. The tip fees associated with off-site substrates is entered into the *pro forma.*

Presented in Appendix B- Profit and Loss Table is the combined profit and loss statement for the study period showing revenue and expense. It also shows the average for the selected study period of May through November 2013. Addiotionally, the table shows the average profitability of the digester during the selected study period.

It is interesting to note that the profitability of the site improved over the time of the study. This improvement was substantially related to the increase in use of off-site substrate. The processing of the off-site substrate generated more gas and therefore more electrical and "tip" fee revenue. As can be seen from the financials, the digester system operated at a loss during the study period. Discussions with ownership indicate that this has been the case for the majority of the time the digester system has been in operations.

Also note in the profit and loss statement under the column "Full Operation" is a projected financial return based on running the engine at full load for 90% of the year. To allow the engine to run full load would require approximately 2,000 tons per month of total substrate. The corresponding tip fees are entered into the financial model. This column indicates that a profitable scenario can be achieved with additional off-site substrate utilization.

The column labeled "Manure Only" shows the profitability if the digester is run on only manure waste from the dairy farming activities. As can be seen from the numbers it would not be financially viable to operate the digester on manure only.

CHAPTER 7: Conclusions

The Fiscalini Farms anaerobic digester system located in Modesto, California, functions as designed. Manure generated from the dairy operations is inputed to the digestion system where it is converted to biogas that is combusted in a reciprocating engine coupled to an electric generator. The coversion rates of the manure are consistent with most properly operating dairy digesters (approximatley 40% Volitile solids distructed). The site has a reasonable power purchase agreement with the Modesto Irrigation District, their local electric utility.

The vast majority of the dairy operations in California utilize "flush" manure handling systems. This system due to the climate in California is very effective in removing the manure solids on a frequent basis from concentrated animial feeding operations . Water recycling is very effective in minimizing the overall water use for the flush systems. Most of these flush systems also rely on utilization of the dried manure solids for animal bedding. Again the climate in California allows this practice to be very successful.

However, the utilization of flush systems has a significant impact on the potential profitability of an anaerobic digestersystem installed on flush dairy facilities. The recycling of the flush water does aerobically degrade some portion of the manure prior to digestion limiting the digestable volitile soilds input to the digester. As was seen with the Fiscalini Farms anaerobic digestersystem during this study, low input volitile solids from the manure operations results in low gas production and corrospondingly low electrical generation production rates.

The low electrical production from the anaerobic digester systems like the one installed at Fiscalini Farms significanly hinders the finanical viability of these types systems when operated on manure alone. However, they can and do capture methane and do reduce the overall loading of constituentes for land application. Anaerobic digestionD is also very effective in converting organic nitrogen into ammonia which increases the crop uptake of nitrogen. Organic nitrogen has a larger propensity to migrate further down into the soil media, which could increase the nitrates.

As identified through this study the use of off-site organic substrates significantly improves the finanical viability of anaerobic digester operations. Substrates processed through the Fiscalini Farms system accounted for large increases in both gas volumes and electrical generation production rates. The increased revenues both from electrical generation and "tip" fees will provide a postitive cash flow for Fiscalini Farms. Furthermore, overall additional constituente loading of the off-site substrates had little impact on the effluent mass loading from the digester.

The TDS and electroconductivity tracked consistently with the volume of substrates added to the digester. It did not appear that the mass loading on the land application would be impacted by the use of substrates. Levels of nitrogen and phosphorus were realativily low in the substrates. Additional substrate sourcing could further limit the TDS and electroconductivity in

the substrates. Substrate additions had no effect on the hydrogen sulfide levels or the nitrogen oxide levels in the exhaust from the engine.

The Fiscalini Farms digester will require additional off-site substrates to meet a break even point. Based on market studies of the surronding area, the volume required is availible. Therefore, it is recommended that an additional volume of approximatley 1,500-2,000 tons per month of off-site substrates be sourced into the digeseter system. This will produce the necessary revenues for continued operations of the digester system in a financially sound method. Proper selection of the substrate types will minimize any impact to the effluent constituent loading to a minimum.

Future steps to increase the likelihood of economic, environmental and regulatory success should include the following:

1. Develop a Procedure to select and manage off-site substrates as co-digestate in agricultural anaerobic digesters, to include:
    a. Analytical characteristics
    b. Sampling frequency
    c. Based around the operations nutrient management plans
2. Develop "Best Practices" for off-site co-digestate to include:
    a. Storage
    b. Record keeping
    c. Reporting
3. Develop a regulatory system to promote the use of off-site substrates as co-digestate, outlining requirement in:
    a. Specific permit standards for influent and effluent
    b. Reporting
4. Develop data base of regionally based off-site substrates, include the following data per each substraght:
    a. Energy value
    b. Analytical characteristics
    c. Regulatory compliance for effluent concerns
    d. Mass balance calculations

5. Develop a data sharing system for digester operations to identify a specific substraight characteristics to determine potential use at the site. Sharing could be thru:
    a. Web-Site
    b. Meetings
    c. Co-ops

GLOSSARY

Term	Definition
ADPG	Anaerobic digester power generation
AID	Agricultural industry digester
BOD	Biological oxygen demand
Btu	British thermal unit
CDEP	Connecticut Department of Environmental Protection
CF	Cubic feet
CFD	Cubic feet per day
CHP	Combined heat and power
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Carbonaceous oxygen demand
CSTR	
EPA	United States Environmental Protection Agency
°F	Degrees Fahrenheit
FOG	Fats, oils, and grease
GWh	Gigawatt-hour
H_2S	Hydrogen sulfide gas
HRT	Hydraulic retention time
kWh	Kilowatt-hour
lb	Pounds of mass
MDEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
mg/l	Milligrams per liter
mm	Millimeter
mmhos/cm	Millimhos per centimeter

MSA	Metropolitan Statistical Area
MW	Megawatt
NAICS	North American Industries Classification System
NH_3	Ammonia
NH_4	Ammonium
NOx	Oxides of nitrogen
NPK	Nitrogen, phosphorous, potassium
NREL	National Renewable Energy Laboratory
OSM	Organic Solutions Management company
PPA	
ppm	Parts per million (by volume)
RAS	Return-activated sludge
RD&D	Research, development, and demonstration
SCADA	Supervisory data acquistition and control
scfm	Standard cubic feet per minute
SCR	Selective catalytic reduction
SRT	Sludge retention time
TDS	Total dissolved solids
TPD	Tons per day
tpy	Tons per year
TS	Total solids
TVS	Total volatile solids
USDA	United States Department of Food and Agriculture
VS	Volatile solids
VSD	Volatile solids destruction

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APPENDIX A:
Profit and Loss Table

Profit and Loss Statement for Study Period
Fiscalini Farms, L.P.

	May 2013	June 2013	July 2013	Aug 2013	Septr 2013	Oct 2013	Nov 2013	Dec 2013
Income	$15,442	$23,497	$30,389	$33,495	$24,573	$31,107	$46,584	$55,228
Electrical Revenue	$11,115	$8,061	$11,174	$14,608	$10,635	$12,575	$23,107	$26,312
Tip Fees	$4,328	$15,437	$19,215	$18,887	$13,938	$18,532	$23,477	$28,916
Expenses	$24,702	$26,434	$27,269	$30,136	$28,466	$29,789	$30,325	$31,687
Labor	$7,300	$7,300	$7,300	$7,300	$7,300	$7,300	$7,300	$7,300
Other Labor	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Digester Parasitic Load	$9,600	$9,600	$9,600	$9,600	$9,600	$9,600	$9,600	$9,600
Digester Phone Bill/Internet	$258	$258	$258	$258	$258	$258	$258	$258
Engine Maintenance	$1,425	$1,425	$1,425	$1,425	$1,425	$1,425	$1,425	$1,425
Engine Capital Reserve	$5,119	$6,851	$7,686	$10,553	$8,883	$10,206	$10,742	$12,104
Gross Income	-$9,259	-$2,937	$3,120	$3,359	-$3,893	$1,318	$16,259	$23,541
Debt Service	$28,198	$28,198	$28,198	$28,198	$28,198	$28,198	$28,198	$28,198
Net Income	-$37,457	-$31,135	-$25,078	-$24,839	-$32,091	-$26,880	-$11,939	-$4,657

Jan 2014	Feb 2014	March 2014	Apri 2014	Study Average	Full Operation	Manure Only
$60,632.72	$61,120.61	$ 71,582.21	$64,413.08	$ 43,172.01	$ 98,000.00	$ 1,289.00
$23,073.34	$30,984.95	$ 36,174.31	$28,145.33	$ 19,663.70	$ 53,000.00	$ 1,289.00
$37,559.38	$30,135.66	$ 35,407.90	$36,267.75	$ 23,508.31	$ 45,000.00	$ -
$30,196.74	$33,836.08	$ 36,223.18	$32,529.85	$ 30,132.70	$ 30,523.00	$ 53,016.02
$ 7,300.00	$ 7,300.00	$ 7,300.00	$ 7,300.00	$ 7,300.00	$ 7,300.00	$ 12,514.29
$ 1,000.00	$ 1,000.00	$ 1,000.00	$ 1,000.00	$ 1,000.00	$ 1,000.00	$ 1,714.29
$ 9,600.00	$ 9,600.00	$ 9,600.00	$ 9,600.00	$ 9,600.00	$ 9,600.00	$ 16,457.14
$ 258.00	$ 258.00	$ 258.00	$ 258.00	$ 258.00	$ 258.00	$ 442.29
$ 1,425.00	$ 1,425.00	$ 1,425.00	$ 1,425.00	$ 1,425.00	$ 1,025.00	$ 2,385.71
$10,613.74	$14,253.08	$ 16,640.18	$12,946.85	$ 10,549.70	$ 11,340.00	$ 10,741.00
$30,435.98	$27,284.53	$ 35,359.03	$31,883.23	$ 13,039.30	$ 67,477.00	$ (51,727.02)
$28,198.00	$28,198.00	$ 28,198.00	$28,198.00	$ 28,198.00	$ 28,198.00	$ 28,198.00
$ 2,237.98	$ (913.47)	$ 7,161.03	$ 3,685.23	$ (15,158.70)	$ 39,279.00	$ (79,925.02)