THESIS

FOOD WASTE DIVERSION FOR ENHANCED METHANE GAS PRODUCTION AT THE DRAKE WATER RECLAMATION FACILITY

Submitted by

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ABSTRACT

FOOD WASTE DIVERSION FOR ENHANCED METHANE PRODUCTION AT THE DRAKE WATER RECLAMATION FACILITY

Food waste diversion to enhance methane gas production in municipal wastewater treatment plants is an emerging trend in the United States. The methane gas produced in anaerobic digesters of a municipal wastewater treatment plant can be used to produce renewable energy to meet electric and heating needs of the plant. The Drake Water Reclamation Facility in Fort Collins, Colorado is very interested in implementing energy generation from anaerobic digester biogas and a food waste diversion program. The objective of this study is to determine the efficacy and viability of implementing a food waste diversion program coupled with energy generation technology to provide electricity and heating generation to meet the plant's needs.

A food waste characterization study of the Colorado State University's Ram's Horn Dining Facility processed food waste was conducted to determine important characteristics of a readily available food waste. An analysis of the operating capacity of the Drake Wastewater Reclamation Facility anaerobic digesters was conducted to determine the maximum amount of food waste that could be added on a daily basis. The maximum amount of food waste that could be added to the Drake Water Reclamation Facility anaerobic digesters is 37.5 tons per day. 2010 data for the Drake anaerobic digesters was analyzed and used as a baseline for analysis of the addition of various amounts of food waste ranging from 800 pounds of food waste per day to the maximum amount of 37.5 tons per day. The effects of the food waste on anaerobic digester biogas production and solids reduction in the digester were reported.

Various technologies for generating energy from biogas were evaluated using reported cost data and characteristics. An economic analysis utilizing flared methane gas as fuel for the various technologies was completed which showed that microturbine and reciprocating engine technologies are economically viable options for the Drake Water Reclamation Facility to use for both electricity and heating generation. A triple bottom line analysis, with a rigorous economic analysis, of implementing a food waste diversion program at the Drake Water Reclamation Facility was conducted. Costs associated with a food waste processing facility and associated equipment was outlined and evaluated against the energy savings that enhanced methane gas production from various amounts of food waste addition provided. It was determined that it is not economically viable for the Drake Water Reclamation Facility to implement a food waste diversion program at this time. If energy prices rise and cost of equipment for a food waste diversion program decrease in the future, then the economics of this project may improve making it more viable.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. BACKGROUND

Food waste diversion from landfills for beneficial uses is an emerging trend in the United States with great potential. As landfill capacity becomes scarce and greenhouse gas emissions from landfills increase, the need to divert a significant portion of the municipal solid waste (MSW) stream from landfills is becoming more prevalent. European countries have been diverting food waste since the mid 1990s. As of 2008, there are 218 operating anaerobic digestion plants of commercial scale in Europe with a majority of those plants utilizing the organic fraction of the MSW stream as feedstock (IEA Plant List, 2008.)

In the United States, the East Bay Municipal Utility District (EBMUD) wastewater treatment plant (WWTP) in Oakland, CA is the largest plant with a food waste diversion program. There are a small number of WWTPs throughout the US that have investigated or implemented portions of a food waste diversion program using their anaerobic digesters. There are at least 3 WWTPs in California that are in the planning or final stages for implementation of a food waste diversion program using their anaerobic digesters.

The Environmental Protection Agency (EPA) provided a grant in 2006 to EBMUD to investigate anaerobic digestion of food waste. The purpose of the study was to identify design and operating criteria for anaerobic digestion of food waste, and to compare food waste digestion to that of municipal wastewater solids digestion. In California alone, there are approximately 137 wastewater treatment plants with anaerobic digesters for biosolids handling with an estimated excess capacity of 15-30%. The EPA and EBMUD both saw an opportunity to use excess anaerobic digestion capacity to provide a recycling opportunity for pre- and post-consumer food waste. Adding a food waste stream to anaerobic digesters can greatly enhance the methane production which in turn can be converted to energy. This can provide a significant financial benefit for plants that implement food waste diversion along with decreasing the carbon footprint of their plant.

The City of Fort Collins is very interested in pursuing food waste diversion at the Drake Water Reclamation Facility (DWRF) within the next couple of years. Environmental benefits such as reducing the amount of food waste that is sent to the Larimer County landfill and reducing greenhouse gas emissions are very appealing for DWRF. Additionally, the financial benefits of utilizing the enhanced methane gas production to help heat and power the plant and subsequent reduction in energy costs and potential to sell excess methane gas for revenue is very appealing. DWRF is in a unique situation for a wastewater treatment plant in that the plant would like to increase their Biological Oxygen Demand (BOD) to enhance their activated sludge process. The plant has been operating with low amounts of carbon in its waste stream since the Anheuser-Busch brewery began treating their own wastewater and stopped sending it to DWRF in 2009. DWRF would like to find an additional carbon source to add to its wastewater stream prior its secondary treatment process to enhance its activated sludge process. A food waste stream may have the added benefit of providing this carbon source.

1.1.1. Objectives

The objective of this study is to evaluate the feasibility of implementing a food waste diversion program to the existing DWRF anaerobic digesters. The tasks associated with this objective are listed below.

- Food waste characterization study
- Analysis of DWRF anaerobic digesters' capacity
- Determine increase in anaerobic digester biogas production from food waste addition
- Determine increase in solids residual from the anaerobic digesters
- Evaluation of various energy generation technologies
- Economic and triple bottom line analysis of energy generation and food waste diversion program at DWRF

The food waste characterization study included locating and characterizing food waste from sources in Fort Collins. Specifically, the characterization study focused on food waste from the Colorado State University Ram's Horn Dining Facility and determining the total solids concentration and volatile solids to total solids ratio of this food waste. The anaerobic digesters' capacity at DWRF was evaluated to determine the amount of food waste that can be added. The increase in methane gas production from the anaerobic digesters will be estimated along with an estimation of the increase in solids residual coming out of the anaerobic digesters. An evaluation of various energy generation technologies ability to utilize anaerobic digester biogas as a fuel source was completed in addition to determining the financial viability of each technology. Finally, an economic and triple bottom line analysis will be completed to determine the costs associated with implementing food waste diversion at DWRF along with the economic, environmental, and social benefits. This study will provide DWRF with a recommendation on whether it is economically feasible at this time to implement food waste diversion to DWRF or if it should not be implemented and a reassessment conducted at a later time.

1.2. ANAEROBIC DIGESTION PROCESS

The anaerobic digestion treatment process is a common method at wastewater treatment plants to treat primary and secondary biological sludge (biosolids) streams. Anaerobic digestion involves three distinct stages (Figure 1.8). In the first stage, complex waste components, including fats, proteins, and polysaccharides, are hydrolyzed to their component subunits. Various facultative and anaerobic bacteria accomplish this task and then make available the products of hydrolysis (triglycerides, fatty acids, amino acids, and sugars) to fermentation and other metabolic processes leading to the formation of simple organic compounds and hydrogen in a process called acetogenesis (Davis, 2008). The second stage is referred to as acid fermentation and organic material is converted to organic acids, alcohol, and new bacterial cells, so that little stabilization of biochemical oxygen demand (BOD) or chemical oxygen demand (COD) is realized (Davis, 2008). In the third stage, the end products of the second stage are converted to gases (mainly methane and carbon dioxide) by several different species of strictly anaerobic bacteria. This stage is referred to as methane fermentation and is where the true stabilization of the organic material occurs. All stages take place simultaneously and synergistically. Waste stabilization in anaerobic digestion is accomplished when methane and carbon dioxide are produced (Metcalf & Eddy, 1991).

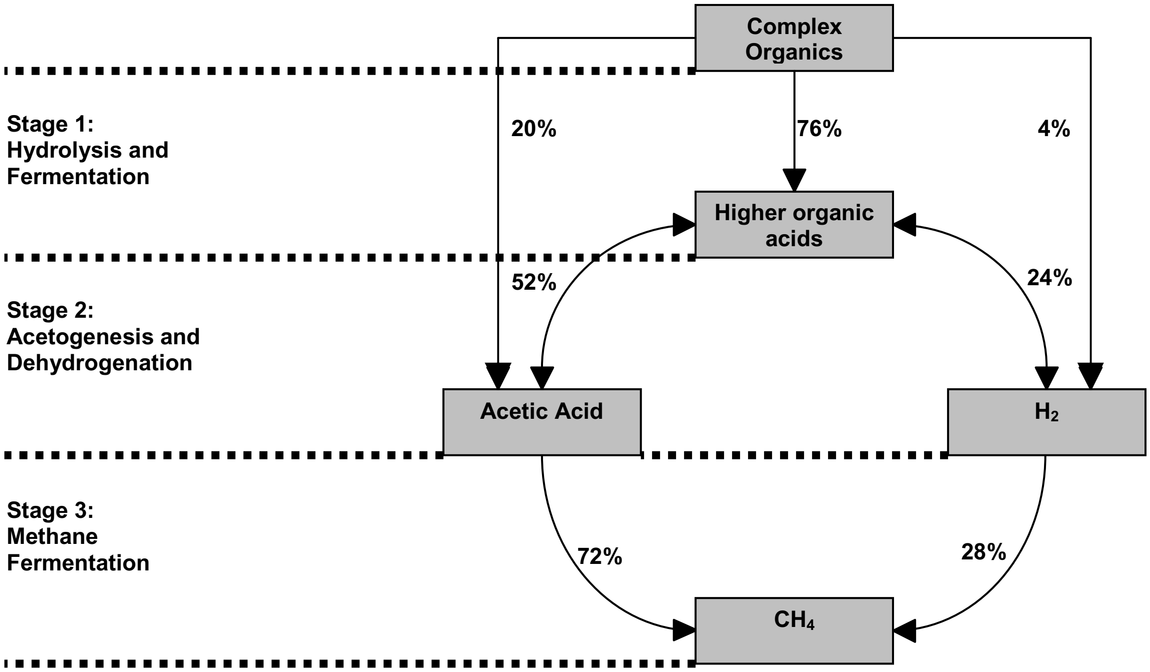

Figure 1.1. Three Stages in Anaerobic Digestion Process with Energy Flow (derived from Davis, 2008)

Methane bacteria can only use a limited number of substrates for the formation of methane. Methanogens use the following substrates: $CO_2 + H_2$, formate, acetate, methanol, methylamines, and carbon monoxide. Typical energy-yielding conversion reactions involving these compounds are shown below:

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \qquad (1\text{-}1)$$

$$4HCOOH \rightarrow CH_4 + 3CO_2 + 2H_2O \qquad (1\text{-}2)$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad (1\text{-}3)$$

$$4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O \qquad (1\text{-}4)$$

$$4(CH_3)_3N + H_2O \rightarrow 9CH_4 + 3CO_2 + 6H_2O + 4NH_3 \qquad (1\text{-}5)$$

In an anaerobic digester, the two principal pathways involved in methane formation are the conversion of hydrogen and carbon dioxide to methane and water (Reaction 1-1), and the conversion of acetate to methane and carbon dioxide (Reaction 1-3). To maintain an anaerobic treatment system that will stabilize organic waste efficiently, the nonmethanogenic and methanogenic bacteria must be in a state of equilibrium (Metcalf & Eddy, 1991). The anaerobic digestion reactor contents should be absent of dissolved oxygen and free from inhibitory concentrations of constituents such as heavy metals and sulfides to maintain the state of equilibrium to stabilize organic waste efficiently. Temperature is another important environmental parameter with the optimum temperature ranges being mesophilic (85 to 100°F) and thermophilic (120 to 135°F).

The disadvantages and advantages of anaerobic digestion of organic waste, as compared to aerobic treatment, result from the slow growth rate of the methanogenic bacteria. Slow growth rates require a relatively long detention time in the digester for adequate waste stabilization to occur (Metcalf & Eddy, 1991). With the methanogenic bacteria, most of the organic waste is converted to methane gas which is a useful end product and is an advantage of anaerobic digestion. If sufficient quantities are produced, the methane gas can be used to operate microturbines, dual-fuel reciprocating engines, fuel cells, and boilers to produce electricity and to provide heat for the plant (Metcalf & Eddy, 1991). Another advantage of anaerobic digestion is the low cellular growth rate and the conversion of organic solid matter to methane gas and carbon dioxide that results in solid matter that is reasonably well-stabilized. After drying or dewatering, the digested sludge should be suitable for disposal in sanitary landfills, composting, and land application (Metcalf & Eddy, 1991).

There are four main processes for anaerobic digestion at a wastewater treatment plant. They are standard rate digestion, single-stage high rate digestion, two-stage digestion, and separate sludge digestion (Metcalf & Eddy, 1991). The standard rate digestion process is typically used for small installations due to untreated sludge stratifying by forming a supernatant layer above the digesting sludge and the lack of intimate mixing which results in not more than 50 percent of the volume of a standard rate single-stage digester being used.

The single-stage high rate digestion process differs from the standard rate single-stage process in that the solids loading rate is much higher (Metcalf & Eddy, 1991). Single-stage high rate digesters also have improved mixing over standard rate digesters due to the sludge being mixed intimately by gas recirculation, mechanical mixers, pumping or draft tube mixers. Sludge should be pumped to the digester continuously or on a 30 minute to 2 hour time cycle to maintain constant conditions in the reactor. The digesters may have fixed or floating covers which can provide excess gas storage capacity (Metcalf & Eddy, 1991).

In two-stage digestion, a high rate digester is coupled in series with a second digester. The first digester is used for digestion and the second tank is used for the storage and concentration of digested sludge and for the formation of a relatively clear supernatant. Similar to single-stage digesters, the digestion tanks may have fixed or floating covers (Metcalf & Eddy, 1991).

Though uncommon, WWTPs can separate the digestion of primary and biological sludge in a process known as separate stage digestion. The reasons given for this design include the excellent dewatering characteristics of the digested primary sludge are maintained, the digestion process is specifically tailored to the sludge being treated, and optimum process control conditions can be maintained (Metcalf & Eddy, 1991).

WWTPs primarily use a wet anaerobic digestion process because sludge produced in wastewater treatment is approximately 10-15% total solids (TS). When using a feedstock, such as food waste, that tends to have a higher TS concentration then wastewater sludge, the feedstock needs to pulped and slurried to a 10-15% TS concentration with dilution water before being added into the anaerobic digester. At a WWTP, raw wastewater can be used for dilution. Wastes that have not gone through a treatment process must be processed to condition the wastes into a slurry devoid of coarse and heavy contaminants. To achieve the objective of removing inhibitory contaminants, a complex process of screens, pulpers, drums, presses, breakers, and flotation units will be needed (Vandevivere et al., 2002). The food waste treatment process for the EBMUD plant described in Chapter 1.4.1 is an example of a complex process to remove contaminants. In addition to being complex, the waste treatment process typically incurs a 15-25% loss of volatile solids with a proportional drop in biogas yield (Farneti et al., 1999). There may simpler approaches that are stand alone systems such as the DODA urban organics processing units that will be discussed in Chapter 1.5.

Dry anaerobic digestion systems gained popularity in the 1990s due to research conducted during the 1980s that demonstrated that biogas yield and production rate were at least as high in systems where the wastes were kept in their original solid state and not diluted with water (Vandevivere et al., 2002). The challenge lies in the handling, pumping, and mixing of solid streams. During the 1990s, new plants that were built were evenly split between wet and dry anaerobic digestion systems (De Baere, 1999). As the use of mechanically-sorted organic fraction of MSW as a feedstock becomes more popular, more will be known about the success of wet systems in dealing with this waste stream. Dry anaerobic digestion systems have already proven reliable in Europe (Kompogas, Valorga, DRANCO systems for example) for the biomethanization of mechanically sorted organic fraction of MSW and may surpass wet anaerobic digestion systems in popularity due to their reliability.

Table 1.1. Advantages and Disadvantages of One-Stage Wet and Dry Systems (information from Vandevivere et al., 2002)

Criteria	**One-Stage Wet Systems**	
	Advantages	**Disadvantages**
Technical	- Created from known process	- Short-circuiting - Complicated pre-treatment
Biological	- Dilution of inhibitors with fresh water	- Particularly sensitive to shock loads as inhibitors spread quickly in reactor - VS lost with inerts and plastics
Economical & Environmental	- Equipment to handle slurries is cheaper	- High water consumption - Higher energy consumption for heating large volume
Criteria	**One-Stage Dry Systems**	
	Advantages	**Disadvantages**
Technical	- No moving parts inside reactor - Robust (inerts and plastics need not be removed) - No short-circuiting	- Wet wastes (<20% TS) cannot be treated alone
Biological	- Less VS loss in pre-treatment - Larger organic loading rate (high biomass) - Limited dispersion of transient peak concentrations of inhibitors	- Little possibility to dilute inhibitors with fresh water
Economical & Environmental	- Cheaper pre-treatment and smaller reactors - Complete hygienization - Very small water usage - Smaller heat requirement	- More robust and expensive waste handling equipment

Table 1.1 lists the advantages and disadvantages of one-stage wet and dry anaerobic digestion systems. As discussed previously, wet anaerobic digestion systems need a

complex pre-treatment system to remove inerts, plastics, and other contaminants while a dry anaerobic digestion system does not. However, dry anaerobic digestion systems have a higher capital cost and cannot treat wet wastes with a 20 percent total solids concentration or less. Also, for a wastewater treatment plant, the sludge produced from primary and secondary treatment processes will contain high moisture content and thus a wet anaerobic digestion process is more suitable.

1.3. BENEFITS OF ANAEROBIC DIGESTION OF FOOD WASTE

Food waste is the second largest category of municipal solid waste (MSW), proceeded by paper, sent to landfills in the United States accounting for approximately 14% of the waste stream (USEPA). The US generates more than 34 million tons of food waste each year. Less than three percent of the 34 million tons of food waste generated in 2009 was recovered and recycled. Food waste represents the single largest component of MSW reaching landfills and incinerators. USEPA identified a multitude of benefits for the anaerobic digestion of food waste to include climate change mitigation, economic benefits, and diversion opportunities. The benefits are listed below with further explanation of the benefits later in this section.

- Reduction of greenhouse gas emissions at landfills
- Cost savings associated from food waste addition to anaerobic digesters
- Utilization of existing infrastructure for food waste diversion
- Meeting local and state waste diversion goals
- Food waste is highly biodegradable making it a desirable anaerobic digestion feedstock

Food waste in landfills generates methane which is considered a potent greenhouse gas. Typically at a landfill, the methane is not captured and is released directly into the atmosphere. Methane is 21 times more powerful at trapping heat and warming the atmosphere than carbon dioxide which makes methane a substantial contributor to the possibility of climate change (USEPA Methane webpage). Diverting food waste from landfills to WWTPs allows for the methane to be captured and used beneficially while reducing the methane released from landfills. Additionally, there exists the potential for further greenhouse gas emissions reductions due to the energy offsets provided by using an on-site, renewable source of energy.

By adding food waste to a plant's anaerobic digestion process, it can be expected that the plant will see a cost savings. These costs savings include reduced energy costs due to production of on-site power and a tipping fee for accepting the food waste. Also, the tipping fee can be set so that the food waste supplier sees a cost savings and the treatment plant may see revenue that can offset transportation costs.

By utilizing existing infrastructure located in most urban areas (anaerobic digesters at a WWTP), anaerobic digestion of food waste provides the most sensible diversion opportunity for most municipalities. As landfill capacity becomes scarcer, municipalities will need to find other ways to dispose of their solid waste streams. Since food waste comprises such a substantial portion of the MSW stream, sending it to be beneficially used provides an opportunity to relieve stress on landfill capacities.

Another reason to divert food waste from landfills and utilize it beneficially in an anaerobic digestion process is meeting local and state waste diversion goals (USEPA). As discussed previously, landfill capacity is being pushed to its maximum limits in many cities across the United States. Many state and local governments have mandated waste diversion goals or are investigating it to try to curtail reaching its landfill maximum capacities. Recycling has been implemented in many cities; however, food waste still makes up the largest percentage of what is still being landfilled. Along with composting of food waste, diverting food waste to WWTPs will greatly reduce the largest percentage of waste that is being sent to landfills in the United States.

Finally, food waste is highly biodegradable and has a much higher volatile solids destruction rate (86-90%) than biosolids produced at a WWTP (Gray, 2008). With the addition of a food waste stream to anaerobic digesters there will only be a small increase in solids residual. This is very important to a WWTP as handling of an increased amount of solids residual can increase operating costs.

1.4. REVIEW OF FOOD WASTE DIVERSION APPLICATIONS

1.4.1. Food Waste Diversion Applications in the United States

The EBMUD WWTP in Oakland, CA currently diverts food waste from the local area and adds it to their anaerobic digesters for enhanced methane production. EBMUD at its peak can process 80 million gallons a day of wastewater (EBMUD webpage). As the first WWTP in the United States to add processed food waste to anaerobic digesters, EBMUD is often used as a model for similar projects around the US.

In 2004, EBMUD constructed a food waste and high strength liquid receiving facility at the main WWTP (Gray, 2008). This began the process of adding food waste as an anaerobic digestion feedstock at EBMUD. The facility cost approximately $3 million and numerous upgrades and improvements were made over the past few years to improve reliability and performance. By 2007, methane gas completely fueled their 6 MW on-site power plant (EBMUD, 2010). By completely powering their on-site power plant with methane gas captured from the anaerobic digesters, EBMUD was able to produce nearly 100% of the electricity needed to power the plant (Toffey, 2010). By 2010, EBMUD had doubled its biogas production from 2004 and built two new 4.5 MW turbines to be fueled by methane gas (Toffey, 2010). In the future, EBMUD is looking to produce biogas fuels to power their vehicles and be provided with additional revenue from renewable energy credits (RECs).

In addition to the on-site food processing facility, EBMUD utilizes the NorCal Jepson Prairie Facility which began receiving commercial food wastes from San Francisco restaurants, markets, and hotels in 1997 (City of San Rafael and CMSA, 2009). The NorCal Jepson Prairie Facility initially processed the commercial food waste for composting but in 2005 began setting aside a portion of the food waste for EBMUD. The commercial food waste is sorted, screened, and processed initially at the NorCal facility and then transported to EBMUD for final processing before being added to the anaerobic digesters.

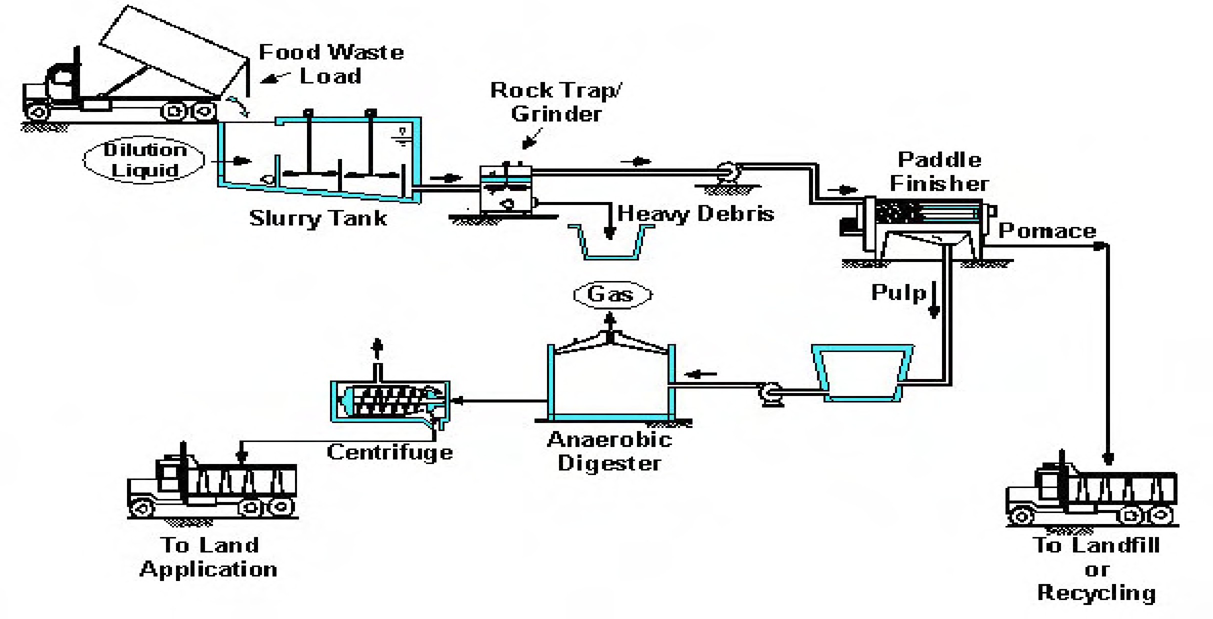

Figure 1.2. Depiction of the EBMUD Food Waste Treatment Process (Gray, 2008)

Figure 1.2 depicts the EBMUD food waste treatment process. 30- to 35-cubic yard covered dump trucks transport up to 20 tons of food waste per truck from the NorCal Jepson Prairie Facility to EBMUD (City of San Rafael and CMSA, 2009). The food waste ranges from 20% to 45% of total solids. The food waste is unloaded into 20,000 gallon slurry tanks and recycled water is added to reduce the total solids concentration to 10%. The food waste slurry goes through a rock trap/grinder to further reduce the size of material and remove rocks and metals. The food waste is pumped through a rotary conveyor screen, called a paddle finisher, with 0.06-inch openings to remove grit and other material that is not readily biodegradable (City of San Rafael and CMSA, 2009). Finally, the processed food waste slurry is pumped into the anaerobic digesters where it is converted to methane gas or becomes part of the solids residual that is sent through a centrifuge and land applied.

The Central Marin Sanitation Authority (CMSA) wastewater treatment facility (WWTF) in San Rafael, California has begun construction on a food waste processing facility to produce a feedstock for their anaerobic digesters. The main objective of this project is converting food waste to energy. The facility is expected to be operational by the summer of 2012 and will look similar to the EBMUD process.

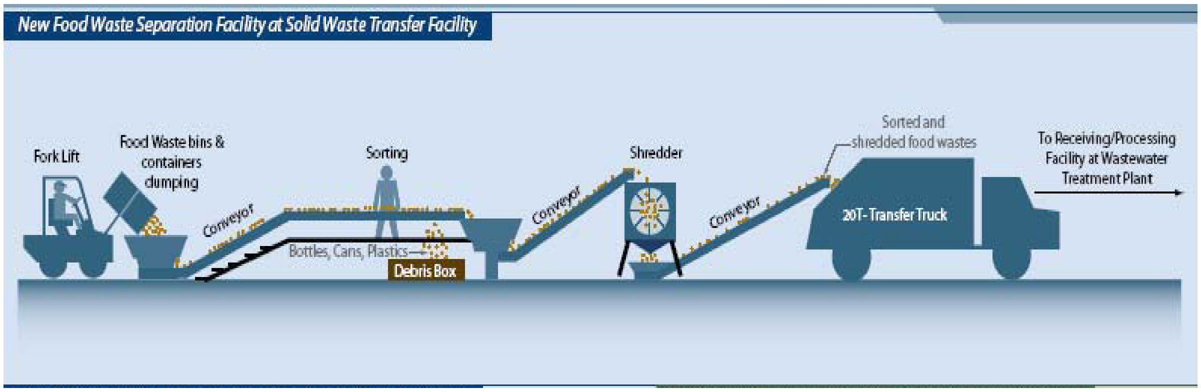

Figure 1.3. Proposed San Rafael Food Waste Preparation Process (City of San Rafael and CMSA, 2009)

The main difference is in the proposed San Rafael food waste preparation facility and the NorCal Jepson Prairie Facility. In the proposed San Rafael food waste preparation facility, food waste will be manually sorted as opposed to using a trommel screen to sort. Manual sorting will allow for the capture of much greater than 55% of food waste for digestion that the trommel screen sorting provides (City of San Rafael and CMSA, 2009). After sorting, a ¾-inch hammermill grinder/shredder will be used to grind and shred the food waste to a small size. After grinding, the food waste will be placed in 20-ton transfer trucks and sent to the CMSA WWTF to be further processed on site in a similar manner to the EBMUD process.

Also, the Yolo County Central Landfill in California conducted an anaerobic digestion pilot project using organic waste in 2010. An anaerobic digester cell was built and fed with organic waste from the landfill. The results were promising for methane production, energy generation using methane, and reduced greenhouse gas emissions at the landfill (Yazdani, 2010). This pilot project demonstrates the potential of utilizing organic waste as a feedstock for an anaerobic digestion process and the benefits that can be achieved.

1.4.2. Food Waste Diversion Application in Europe

A substantial amount of experience in using processed food waste as a feedstock for anaerobic digesters exists in Europe. Since the early 1990s, many WWTPs have been using food waste along with other waste streams such as manure and green yard waste to enhance methane production in their anaerobic digestion processes. Typically, the food waste is chopped to approximately a 3/8-inch diameter, slurried to a 5 to 10% solids concentration, and pasteurized or heat treated at 165 °F to 170 °F for an hour with municipal wastewater sludge. The treatment and pasteurization process results in a highly digestible material (City of San Rafael and CMSA, 2009). The treated and pasteurized food waste/wastewater sludge is then added to an anaerobic digestion process. These systems are stand alone and are typically added to the existing infrastructure of a WWTP.

In Europe, there are numerous anaerobic digestion plants that process organic waste. An example is in the municipal area of Barcelona, Spain. There are three anaerobic digestion plants that process source separated organic waste for energy generation. There are also WWTPs that conduct co-digestion of wastewater biosolids and organic waste. Examples of WWTPs that conduct co-digestion can be found in Voghera, Italy and Alicante, Spain (Korz, 2009).

As stated earlier, the International Energy Agency (IEA) listed 218 commercial scale operating anaerobic digestion plants in Europe in their 2008 plant list. The IEA defined commercial scale as plants that process 2500 tonnes per annum (tpa) of biowaste and/or organic industrial waste. One tonne (metric ton) is equal to approximately 1.1 tons, thus, commercial scale anaerobic digestion plants in Europe process at least approximately 2750 tons per year of biowaste and/or organic industrial waste. The majority of these plants use patented anaerobic digestion technologies from various manufacturers from around Europe. The most common of these anaerobic digestion technologies used in Europe are Kompogas, Valorga, DRANCO, and BTA. These processes are summarized below.

- Kompogas: Kompogas is a Swiss company founded in the late 1980s. The Kompogas system is a modular, stand alone single-stage dry anaerobic digester. The system utilizes a horizontal plug flow digester with internal rotors to assist in degassing and homogenizing the waste. The system is prefabricated into two sizes: 15,000 or 25,000 metric tonnes per year. Currently, at least 38 Kompogas systems are operating around the world with the majority of them in Europe (California Waste Management Board, 2008).
- Valorga: Based in France, Valorga was founded in 1981 to develop MSW treatment technologies (Nichols, 2004). The Valorga system is a one-stage dry digestion system. The digestion reactor is a vertical cylindrical tank that is a continuous single-stage modified plug flow reactor (California Integrated Waste Management Board, 2008). The digester receives the organic fraction

of MSW with a total solids content between 25 and 35 percent. Currently, at least 22 Valorga systems are operating in Europe.

- DRANCO: Organic Waste Systems developed the DRANCO process (dry anaerobic composting) for the anaerobic treatment of MSW and industrial organic waste. The first facility on an industrial scale began operating in 1992 (Nichols, 2004). The DRANCO process is a high-solids, single-stage anaerobic digestion system that operates at thermophilic temperatures and takes places in an enclosed vertical digester capable of treating a wide range of material with a solids content from 15 to 40 percent. The DRANCO digester operates without the addition of water and feedstock is added from the top of the reactor once a day. The DRANCO digestion process is considered a static fermentation process with no further mixing or agitating of the vessel needed aside from feeding and removal of the residue (Nichols, 2004). Currently, there are at least 18 commercial scale DRANCO systems operating in Europe (IEA plant list, 2008).
- BTA (Biotechnische AbfallverwertungGmBH & Co. KG): The BTA process was initially developed in a pilot plant in Garching, Germany to gain experience testing a range of feedstocks and to fine tune its technology (Nichols, 2004). The first plant on an industrial scale was built in Denmark in 1990. The majority of BTA digesters are large (>110,000 tons/year) multi-stage, wet-wet units (California Integrated Waste Management Board, 2009). The process consists of mechanical wet pretreatment and biological conversion. The mechanical wet pretreatment phase removes contaminants

like plastics by means of a rake and a heavy fraction trap. A thick, pumpable pulp is produced and is fed to the digester. The BTA process offers various concepts for the biological conversion step. These concepts include single-stage digestion (mainly for relatively small decentralized waste management units), multi-stage digestion (mainly for plants with capacity of more than 50,000 metric tons per year), and two-stage digestion (mainly for plants with medium capacities) (Nichols, 2004). Currently, at least 15 commercial scale plants in Europe utilize the BTA process (IEA Plant List, 2008).

Table 1.2. Comparison of European Anaerobic Digestion Technologies (data found in California Integrated Waste Management Board, 2009)

Process	Digestion Type	Operating Plants (#)	Average Biogas Yield (scf/lb wet weight)	Typical Solids Content of Feed (%)	Average Capacity (tons/yr)	Solids Retention Time (days)
Kompogas	Single-stage, dry	38	3.4 – 4.2	23 - 28	23,000	15 - 20
Valorga	Single-stage, dry	22	2.6 - 5.1	25 - 35	86,000	18 - 23
DRANCO	Single-stage, dry	18	1.7 – 2.4	15 - 40	36,000	15 - 30
BTA	Single-stage, Multi-stage, Two-stage, wet-wet	15	3.8 - 4.6	~25 - 40	~110,000	~15 - 25

Table 1.2 shows a comparison of key parameters of the most popular European anaerobic digestion technologies described in detail previously. The data for the BTA process is approximate due to the variations of the process for the biological conversion phase.

The main issue with these European technologies is the high cost to purchase and install the technology in the United States. The manufacturers of these various anaerobic digestion technologies have been able to sell their processes in a limited fashion to countries outside of Europe such as Japan but have not made any real progress in exporting their technologies to the United States. As the popularity of the anaerobic digestion of organic fraction of MSW increases in the US, the interest may rise in the US for these technologies. However, at this time, these technologies are too expensive for most municipalities to purchase and implement in the United States.

1.5 COLORADO FOOD WASTE PROCESSING PROJECT

In Colorado, a project partially funded by a grant from the Colorado Department of Public Health and Environment (CDPHE) is being conducted to test an urban organics recycling system to process food waste into a suitable feedstock for anaerobic digestion and aerobic composting. A1 Organics, a Colorado organics recycling company, purchased an urban organics recycling system from DODA International (shown in Figure 1.4), an Italian company now operating in the United States. The project began in 2009 with the goal of capturing data and defining processes by which food waste can be cleaned of contaminants and made into a “clean” and consistent feedstock (Yost, 2010). It is nearing the completion with a final report due to CDPHE from Al Organics in 2012.

Figure 1.4. DODA Urban Organics Recycling System (Yost, 2010)

Installed at the A1 Organics Stapleton, Colorado site in the summer of 2010, the DODA urban organics processing unit's purpose is to remove plastic and other contaminants associated with source separated food waste streams (Yost, 2010). An issue identified with using food waste as a feedstock for anaerobic digestion is the prevalence of plastics, metals, and other contaminants in unprocessed food waste. An example of the unprocessed food waste is shown in Figure 1.5. These contaminants are not readily biodegradable and can hinder the anaerobic digestion process if large contaminant quantities exist. To try to minimize the upset of the anaerobic digestion process, a food waste stream that is added needs to be relatively contaminant-free. This project wants to evaluate whether the DODA urban organics processing unit can be a stand alone food processing unit that can perform as well as the EBMUD two-stage food waste treatment process.

Figure 1.5. Unprocessed Food Waste used for DODA Processing Unit (Yost, 2010)

An example of the food waste slurry produced by the DODA processing unit to be used as a feedstock for composting or anaerobic digestion is shown in Figure 1.6. If the results of the project support the DODA urban organics processing unit in creating a contaminant free, high organic stream as a digestion feedstock, then this could prove an option to attain a food waste stream for municipal anaerobic digesters, such as at DWRF in Fort Collins.

Figure 1.6. DODA Food Waste Slurry after Processing

1.6. SUMMARY OF ENERGY GENERATION TECHNOLOGIES UTILIZING BIOGAS AS FUEL

With increased biogas production from food waste addition, the supplemental biogas can be beneficially used to fuel an energy generation technology. By utilizing a technology such as a microturbine, fuel cell, or biogas powered reciprocating engine, electricity can be produced on site to offset a plant's electricity costs. Additionally, these technologies also can provide additional heat that can be used to offset heating costs. A brief explanation of fuel cells, microturbines, and biogas fed reciprocating engines is provided below.

- Fuel Cells: A fuel cell operates like a battery but does not run down or require recharging and will produce energy in the form of electricity and heat as long as fuel is supplied. It consists of two electrodes sandwiched around an electrolyte with oxygen passing over one electrode and hydrogen over the other which generates electricity, water, and heat. A fuel cell system which includes a 'fuel reformer' can utilize the hydrogen from any hydrocarbon fuel from natural gas to methanol (www.fuelcells.org website). A visual illustration of a fuel cell is provided in Figure 1.7 below.

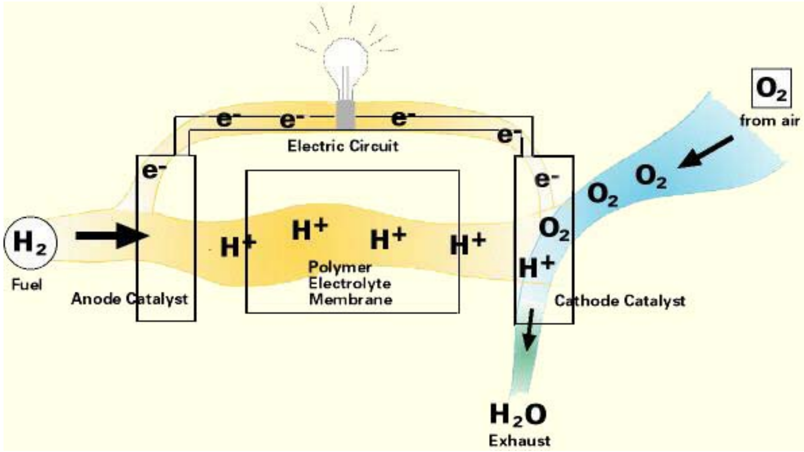

Figure 1.7. Depiction of a Fuel Cell (from www.fuelcells.org website)

- Microturbines: A microturbine can be fueled by natural gas, biogas, or other types of fuel. The fuel powers the turbine which turns a generator to produce electricity. The hot exhaust air created in this process can be recovered for heating needs (EPA Office of Air and Radiation, 2002). An illustration of the process schematic of a microturbine is provided in Figure 1.8 below.

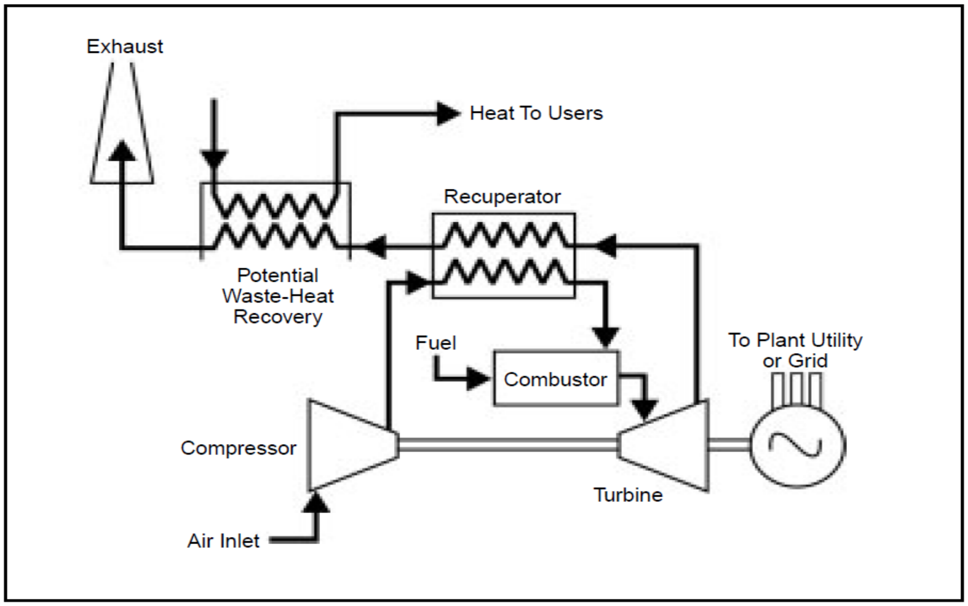

Figure 1.8. Microturbine Process Schematic (from EPA Office of Air and Radiation, 2002)

- Biogas fed reciprocating engines: These engines can use methane produced from anaerobic digesters to fuel internal-combustion reciprocating engines that run generators to produce electricity. Heat produced from the operation of the engines can be used for additional heating needs in the plant. The Point Loma WWTP in San Diego, California has a capacity of 240 MGD and is energy self-sufficient by using biogas fed reciprocating engines. Additionally, they can generate additional revenue by selling excess energy in the form of electricity into the power grid (Federal Energy Management Program, 2004).

The EPA Combined Heat and Power (CHP) Partnership produced a study providing data and information on various CHP technologies. A summary of the advantages and disadvantages from the study for the three types of technologies being analyzed for this project are provided (Table 1.3).

Table 1.3. Advantages and Disadvantages of CHP Technologies (derived from EPA CHP Partnership, 2008)

CHP Technology	Advantages	Disadvantages
Reciprocating Engines	- High power efficiency - Fast start-up - Relatively low investment cost - Can be overhauled on site with normal operators - Operate on low-pressure gas	- High maintenance costs - Limited to lower temperature cogeneration applications - Relatively high air emissions - Must be cooled even if recovered heat is not used - High levels of low frequency noise
Microturbines	- Small number of moving parts - Compact size and lightweight - Low emissions - No cooling required	- High costs - Relatively low mechanical efficiency - Limited to lower temperature cogeneration applications
Fuel Cells	- Low emissions and low noise - High efficiency over load range - Modular design	- High costs - Low durability and power density - Fuels requiring processing unless pure hydrogen is used

Reciprocating engines have a lower purchase cost than microturbines and fuel cells. Fuel cells require a ‘fuel reformer’ to use the biogas generated from an anaerobic digester which adds to the process complexity. Fuel cells and microturbines have higher purchase costs, but lower emissions and better efficiency than reciprocating engines. These advantages and disadvantages will be further evaluated in the economic analysis of the three types of energy generation technologies in Chapter 3.

An issue with using digester biogas or landfill gas to power energy generation technologies is siloxanes. Siloxanes are a family of man-made organic compounds that contain silicon, oxygen and methyl groups. Siloxanes are used in the manufacture of personal hygiene, health care, and industrial products and as a result of their widespread use are found in wastewater (Pierce, 2004). At WWTPs, low molecular weight siloxanes volatilize into digester gas. When this digester gas is combusted to generate power, siloxanes are converted to silicon dioxide (SiO_2), which can deposit in the combustion and/or exhaust stages of the equipment (Pierce, 2004).

The presence of siloxanes in biogas has been known for many years but rather than removing siloxanes, most operators chose to accept the increased maintenance costs associated with the use of biogas since the increase is being offset by the use of low cost or no cost fuel (Pierce, 2004). The most effective method of removing siloxane in commercial operation is carbon adsorption. Activated carbon is the media used to adsorb the siloxane and remove it from the biogas. Other siloxane removal technologies such as refrigeration, liquid adsorption, and silica gel are not widely used and will not be discussed.

The microturbine manufacturer Capstone in the early 2000s experienced siloxane induced turbine failures at multiple sites. As a result of this, Capstone established a fuel specification that requires less than 5 parts per billion by volume (ppbv) of siloxane. A 100 percent effective siloxane removal system is required by Capstone for all biogas applications (Pierce, 2004). In actual practice, Capstone microturbines are tolerant of limited amounts of siloxane and have operated continuously on biogas for many months prior to failure. Prolonged exposure to untreated biogas results in a progressive loss of performance due to silica buildup in the combustor and recuperator. The silica will ultimately build up to a larger mass that breaks off and causes the turbine wheel to seize resulting in the power unit needing to be replaced to restore full performance (Pierce, 2004).

For internal combustion reciprocating engines, there is extensive experience of operation on biogas. Reciprocating engine manufacturers imposed siloxane fuel restrictions that range from 150 to 900 times higher than the restrictions placed on fuel for microturbines (Pierce, 2004).

DWRF is applying for a grant for a microturbine from the Colorado Governor's Energy Office (GEO). In 2012, the state of Colorado expects to receive $42.6 million for projects that reduce energy use and fossil fuel emissions and improve energy efficiency (Colorado.gov website, 2012). This money must be spent by September 15, 2012 so there is urgency in distributing the grants to various cities and counties in Colorado. If approved for a grant, DWRF will be able to offset the purchase cost of a microturbine powered by biogas to generate electricity and heat for use in the plant. This could provide another avenue for DWRF to offset energy costs using methane produced from their anaerobic digesters.

2. FOOD WASTE CHARACTERIZATION AND EVALUATION OF DWRF ANAEROBIC DIGESTER CAPACITY FOR FOOD WASTE ADDITION

2.1 BACKGROUND

DWRF became interested in adding food waste to their anaerobic digestion process in the summer of 2011 and needed to determine the quantity and quality of food waste that was available in the Fort Collins area. Colorado State University (CSU) expressed interest in providing processed food waste from their Ram's Horn Dining Facility to DWRF for their use in the early fall of 2011. At the Ram's Horn Dining Facility and at the Braiden Hall Dining Facility, Somat close-coupled waste pulping systems (Figure 2.1) are used in the kitchens to process pre- and post-consumer food waste. Food service waste enters the pulping tanks both from a location in the kitchen (pre-consumer food waste) and a location where food service trays are cleared of trash (post-consumer food waste). The pulpers mix all of the food and paper waste with water and grinds up the material to create a slurry. The slurry is taken by pipe to a centrifuge called the Hydra-Extractor, which removes excess water and recycles it through the system. The resultant semi-dry pulp is discharged into 65-gallon bins located in loading docks in the back of the building (CSU Housing and Dining Services Webpage).

Figure 2.1. Somat Close-Coupled Waste Pulping System (Somat, 2009)

CSU currently uses the processed food waste as a feedstock for their aerobic composting program. The processed food waste generally is devoid of contaminants and is pulped and ground into small particles making it an excellent feedstock for the aerobic composting program. However, CSU is nearing capacity on their composting program and wanted to find another beneficial use for the food waste aside from sending it to the Larimer County landfill. CSU facilities stated they could provide 800 pounds per day of processed food waste to DWRF, and this amount could go up to 1400 pounds per day in a few years when another dining facility comes online with the pulpers and food waste processing system.

2.2. METHODS

Methods for developing a food waste sampling plan, characterization of the food waste, determining the DWRF anaerobic digesters' capacity for food waste addition, determining biogas and methane gas production from food waste addition, and options for the addition of food waste in the DWRF treatment process are described in detail in this section.

2.2.1. Ram's Horn Dining Facility Food Waste Sampling Plan

Since CSU was willing to provide a relatively inexpensive processed food waste that appeared devoid of contaminants, a characterization of the food waste was conducted. Food waste was collected from bins outside of the Ram's Horn Dining Facility from early November to mid-December and sent to the DWRF Pollution Control Laboratory (PCL) for testing. Two samples were collected on five separate occasions for a total of ten samples tested. The samples came from different bins for each sampling event to ensure representativeness of the food waste quality. The food waste samples were tested for three important parameters: chemical oxygen demand (COD), total solids (TS), and volatile solids (VS) to total solids ratio (VS/TS). The five separate sampling events provided enough variability in outside air temperature (the processed food waste is stored outside in 65 gallon bins), type of food waste processed, and length of time in storage bins to provide an accurate characterization of the variability of food waste quality.

A COD, Method 5220D "Closed Reflux Colorimetric Method" was conducted on the samples (ENCO Chembook, 2009). This provided a COD value for all samples in mg/L. This test uses potassium dichromate in a 50% sulfuric acid solution to oxidize both organic and inorganic substances in a sample. This results in a higher oxygen demand than biological oxygen demand (BOD) concentration for the same sample but is a more expedient method (Kiepper, 2010). The closed reflux method uses sealed and heated pre-prepared vials that change color from orange to green based on the amount of oxidation and that are read using a laboratory colorimeter to measure the relative color change. This provides a COD concentration for the samples (Kiepper, 2010).

To determine the TS of the food waste samples, the Total Solids SM 2540B method was conducted. This is a gravimetric test in which a well mixed aliquot of an unfiltered sample is transferred to a pre-weighed crucible and evaporated to dryness in an oven at 103 °C (ENCO Chembook, 2009). A total solids percentage can then be determined for the samples after being dried.

To determine the volatile solids percentage of total solids of a sample, the EPA Method 160.4 Residue, Volatile (Gravimetric, Ignition at 550 °C) test was conducted. This method determines the weight of solid material combustible at 550 °C and obtains a rough approximation of the amount of organic matter in the solid fraction of the sample (EPA, 1971).

For the sampling of food waste, a simple random sampling strategy was used. Simple random sampling is defined as the most basic sampling method where each of the N population units has an equal chance of being one of the n selected for measurement and the selection of one unit does not influence the selection of other units (Gilbert, 1987). The parameter N is defined as the total number of population items. The parameter n is the number of population units selected at random from the target population. The target population is defined as the set of N population units about which inferences will be made. All of the food waste that is collected in the bins on a daily basis represents the target population The food waste collected in the bins at the Ram’s Horn Dining Facility should not have any significant trend or cycle due to the random variability of the menu. As the menu varies throughout the semester, the type of food waste generated will also vary. Simple random sampling is considered appropriate for estimating means and totals if the population does not contain major trends, cycles, or patterns of contamination which is the assumption made in this case (Gilbert, 1987).

2.2.2. Ram's Horn Food Waste Statistical Analysis

Since the food waste is relatively homogeneous (concentrations are not expected to cycle with seasons and long term trends are not expected to exist), emphasis is placed on estimating the mean, variance, and standard error. The true mean, variance and standard deviation for the target population are unknown since it is impossible to measure all N units, but statistically unbiased estimates of the true mean, μ, true variance, σ^2, and the true standard deviation, σ, can be computed. The equations for the unbiased estimate of the sample mean, unbiased estimate of the variance of the sample mean, and the standard error of the sample mean is provided below:

$$\text{Sample Mean: } \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{(Equation 1)}$$

$x_1, x_2, \ldots, x_n$ are the sample data

$$\text{Variance of Sample Mean: } s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \quad \text{(Equation 2)}$$

$$\text{Standard Error of Sample Mean: } s(\bar{x}) = s\sqrt{\frac{1-f}{n}} \quad \text{(Equation 3)}$$

f is the sampling fraction; $f = \frac{n}{N}$

For this sampling scheme, n equals 10 which is the number of samples taken of the target population. N can be assumed to be infinite due to the large size of the target population, thus making f equal to 0.

Variance is a measure of how far a set of numbers are spread out and can provide a theoretical probability distribution of a not fully observed population. From the variance, an estimate for the standard error of the sample mean can be determined. The standard error is a statistically unbiased estimate of the standard deviation and is useful in determining the accuracy of the sample mean.

Sample size determination calculations can be made to determine if enough samples were taken. To accomplish this, the D.R. Cox's two-stage approach can be used. A relative error, represented by d, and a margin of error, represented by α, needs to be specified. A reasonable margin of error is 95% and a reasonable relative error for COD is 25,000 mg/L and for TS percentage and VS/TS ratio is 3%. The equation to determine the sample size required for the D.R. Cox's two stage approach is shown below:

$$n = \frac{s_1^2 Z_{1-\alpha/2}^2}{d^2}\left(1+\frac{2}{n_1}\right) \quad \text{(Equation 4)}$$

s_1^2 = estimated population variance

$Z_{1-\alpha/2}^2$ = standard normal deviate that cuts off ($100\alpha/2$) % of the upper tail of a standard normal distribution (Gilbert, 1987)

d = specified relative error

n_1 = number of samples taken

If $n > n_1$, then additional samples need to be taken to meet the requirements for margin of error and relative error specified. The additional samples needed would be equal to $n - n_1$. If $n \leq n_1$ no more samples will need to be collected.

2.2.3. Operating Capacity of the DWRF Anaerobic Digesters

DWRF operates 4 anaerobic digesters that receive primary sludge and scum from the primary clarifiers and thickened waste activated sludge (WAS) from the dissolved air flotation tank (DAFT). Digester influent solids concentrations typically range between three and four percent, while effluent solids average about two percent. Digester gas produced is used to fuel the boilers for digester heat and building heat. Excess digester gas is flared to the atmosphere (FCWU, 1998). The maximum volume of one anaerobic digester is 875,908 gallons or 117,100 ft^3. The DWRF anaerobic digesters are classified as high-rate digesters due to its mixing capability. Also, the DWRF anaerobic digesters utilize floating covers which provide some excess gas storage capacity.

In order to determine how much food waste can be added to the DWRF anaerobic digesters and the expected methane production associated with the added food waste, the operating capacity of the anaerobic digesters was determined. The anaerobic digesters' hydraulic loading rate, solids loading rate, and organic loading rate was compared to the maximum loading rates to determine the operating capacity as a percentage of the maximum capacity. Daily data from 2009, 2010, and part of 2011 was provided by DWRF for their anaerobic digesters. 2010 data was primarily used because it was the most recent and complete data. A sample of this data is shown in Appendix A.

The solids and hydraulic loading capacities for the DWRF anaerobic digesters are:

- Solids Loading Capacity
    - Per digester = 12,500 pounds per day of volatile suspended solids
    - For 3 digesters = 37,500 pounds per day of volatile suspended solids
    - For 4 digesters = 50,000 pounds per day of volatile suspended solids

- Hydraulic Loading Capacity
    - Per digester = 62,300 gallons per day
    - For 3 digesters = 186,900 gallons per day
    - For 4 digesters = 249,200 gallons per day

The loading capacities are from the 1998 Fort Collins Water Utility Solids Processing Study. Loading capacities based on 3 and 4 digesters are given with the intent of using the loading capacity for 3 digesters in calculations. Occasionally, one digester may go offline for maintenance or repair and by calculating based on 3 digesters a factor of safety is built in for the determination of how much food waste could be added.

The organic loading rate is the pounds of volatile solids added per day per cubic foot of digester capacity (Metcalf & Eddy, 1991). It is simply the solids loading rate divided by the volumetric capacity of the digester. The recommended organic loading rate for high-rate digesters are 0.10 to 0.30 lb VS/ft^3 · d of volatile solids (Metcalf & Eddy, 1991).

The solids loading capacity was evaluated first using DWRF anaerobic digester data from 2010. The daily solids loading was calculated by determining the pounds of VS per day added to the digesters. This was accomplished by taking the daily primary sludge flow in million gallons per day (MGD) and using a conversion factor of 8.34 (1 gallon of wastewater is equal to 8.34 pounds) to attain the pounds per day added to the anaerobic digesters. Then, that value was multiplied by the TS% and VS/TS percentage of the primary sludge to get the pounds of VS per day of primary sludge added to the anaerobic digesters. The same method was used to calculate the daily pounds of VS per day of thickened WAS added to the anaerobic digesters. These two values were added together to attain the daily solids loading in pounds of VS per day. Finally, the percentage of anaerobic digester capacity used was calculated based on solids loading.

The hydraulic loading for the anaerobic digesters was evaluated to compare to the solids loading capacity to determine which is limiting. The daily hydraulic loading was determined from the 2010 DWRF anaerobic digester data. The daily flow in MGD for the primary sludge and for the thickened WAS will be added together to attain the daily hydraulic loading.

Finally, the organic loading rate was compared to the solids loading to determine which s limiting. The organic loading rate was determined by dividing the daily solids loading (in lbs VS/day) by the volume of an anaerobic digester (117,100 ft^3) multiplied by 3 (number of anaerobic digesters operated).

2.2.4. Food Waste Addition and Associated Biogas and Methane Production

With the determination of the limiting loading rate and the operating capacity of the anaerobic digesters at DWRF, the next step was to calculate the theoretical maximum amount of food waste that can be added. Estimations can be also be made to determine how much methane can be expected to be produced from this amount of food waste added and various other amounts of food waste less than the maximum amount.

The average amount of volatile solids that can be added to the anaerobic digesters is the limiting loading capacity minus the average daily limiting loading. The maximum amount of food waste (in lbs VS/day) needs to be converted to the maximum amount in pounds of food waste per day for practicality. To do this, the average TS percentage and average VS/TS ratio for the food waste from the characterization study were used. The maximum amount of food waste (in lbs VS/day) divided by the average TS percentage and the average VS/TS ratio for the food waste would provide the maximum amount of food waste (in lbs/day).

$$\text{Max. Amt. of Food Waste (lbs/day)} = \text{Max. Amt. of Food Waste (lbs VS/ day)} \;/\; \text{TS\%} \;/\; \text{TVS/TS\%} \quad \text{(Equation 5)}$$

In order to verify that the maximum amount of food waste added to the anaerobic digesters does not exceed the solids loading capacity, the volume of the food waste added (in MGD) needed to be determined. The volume of a sludge, or for this case a food waste stream, can be calculated using Equation 6 (Metcalf & Eddy, 1991).

$$V = \frac{W_s}{\rho_w G_s P_s} \quad \text{(Equation 6)}$$

W_s = weight of dry solids, lbs

ρ_w = density of waster, lbs/ft^3

G_s = specific gravity of the food waste

P_s = percent solids expressed as a decimal

The weight of dry solids is calculated by multiplying the maximum amount of food waste to be added by the average TS% concentration (as a ratio). The density of water is a constant of 62.4 lbs/ft^3. The specific gravity of food waste was assumed to be equal to 1.02, which is a typical value for primary sludge (Metcalf & Eddy, 1991). The percent solids of the food waste equals the value determined in the characterization of food waste data. Inserting these values into equation 6, along with multiplying by a conversion factor of 7.48 and dividing by 1 million, results in the volume in MGD. This value is multiplied by a conversion factor of 8.34, then is multiplied by the average TS% and VS/TS% of the food waste. The resultant value is the maximum amount of food waste that could be added in lbs VS/day. This value was added to the average daily solids loading to get the maximum amount of food waste to be added in lbs VS/day.

In order to determine the expected gas production from the food waste, the amount of digested sludge (in lbs VS/day) that exited the anaerobic digesters was calculated. In the 2010 DWRF anaerobic digester data, the daily TS% and VS/TS% values are given for digested sludge. The amount of volatile solids that exited the anaerobic digesters daily can be calculated by adding together the primary sludge flow, thickened WAS flow, and food waste flow, multiplying this value by a conversion factor of 8.34, and finally multiplying this value by the TS% and VS/TS% concentrations of solids leaving the digesters.

The determination of the VS reduction was computed next using the data for the volatile solids going into and out of the anaerobic digesters daily. The volatile solids reduction (as a percentage) is calculated using the equation below:

$$\text{VS Reduction (\%)} = [(VS_{IN} - VS_{OUT}) / VS_{IN}] * 100\% \quad \text{(Equation 7)}$$

The pounds of VS destroyed also need to be calculated to determine the digester biogas production. The pounds of VS destroyed can be calculated by multiplying the volatile solids added to the anaerobic digesters with the volatile solids reduction (as a decimal).

Total gas production can be estimated from the percentage of volatile solids reduction. Typical values vary from 12 to 18 ft^3 of digester biogas produced per pound of volatile solids destroyed (Metcalf & Eddy, 1991). In order to provide a conservative estimate, the amount of volatile solids destroyed was multiplied by 12 ft^3/lb.

The amount of methane gas can be estimated from the total gas production. Typically, digester gas is about 65% methane (Metcalf & Eddy, 1991).

A goal of this study was to monetize the enhanced methane gas production from the food waste addition and determine if it is economically feasible to begin food waste addition to the DWRF anaerobic digesters in the near future. A thorough economic analysis was completed and a key component of that analysis was the estimated biogas and associated methane gas production from various amounts of food waste added. Beginning with the 800 pounds of food waste per day the Ram's Horn Dining Facility stated they could provide, multiple iterations were completed with varying amounts of food waste added. Of note, the Ram's Horn Dining Facility food waste's TS% and VS/TS% are used to represent all food waste. If a food waste processing facility is built to process raw food waste, water will be added to create a 10-15% TS slurry that would be easier to pump into the anaerobic digesters. This will also increase the daily hydraulic loading into the anaerobic digesters. These values may change depending on the source and type of food waste used, but using the values determined from the food waste characterization study conducted provided a good starting point.

Finally, depending on the type of food waste treatment process used, there may be losses of volatile solids associated with the processing of the waste. These losses are not accounted for during the iterative process to determine biogas production based on food waste addition amounts due to the complexity it would add. It is assumed that the amount of food waste per day specified would make it into anaerobic digesters. It may take more food waste to be collected then the specified amount to ensure that the amount of food waste makes it to the digesters due to losses.

2.2.5. Implementation of Food Waste Addition in the DWRF Treatment Process

At EBMUD WWTP and other WWTPs looking at adding processed food waste to their anaerobic digesters, a food waste pre-processing facility operates on site and creates a food waste pulp. The processed food waste pulp is pumped directly into the anaerobic digesters. This process provides a feedstock relatively devoid of contaminants for anaerobic digestion and ensures maximum benefit of enhanced methane production. However, this requires a large investment in additional infrastructure and thus a high capital cost for creating a process similar to EBMUD. Various options of adding food waste to the DWRF treatment process was discussed with the positives and negatives also noted.

During discussions with DWRF personnel, multiple options were presented that varied in costs and complexity of implementation. The first option was to use the existing septage receiving facility to add the 800 lbs per day of food waste from the Ram's Horn Dining Facility to the DWRF treatment process. The septage receiving facility is located in the head works building at DWRF. Septic trucks dump their waste into a large bay that has a large 2' x 4' bar screen with openings of approximately 2 inches between the bars. Large waste objects will be caught on the bar screen with most of the waste passing through the bar screen relatively easily. Water is sprayed on the bar screen to help move the waste through the bar screen. A picture of the septage receiving facility bar screen is provided in Figure 2.2.

Figure 2.2. Picture of DWRF Septage Receiving Facility Bar Screen

Once the food waste passes through the septage receiving facility, it will go through the grit removal and screening process in the head works building. These processes typically remove large waste objects. The food waste coming from the Ram's Horn dining facility is grinded into a pulp that contains relatively small particles. The food waste should move through the preliminary treatment processes with minimal loss.

After going through the preliminary treatment processes, the food waste along with the wastewater it has been added to will move into the primary clarifiers. The average detention time in the DWRF primary clarifiers is approximately 2 hours. A majority of the food waste should settle over this 2 hour timeframe and become a part of the primary sludge. DWRF would also like to attain a secondary benefit of adding BOD to their primary effluent for use in their secondary treatment processes. If some of the food waste BOD exits the primary clarifier in the primary effluent, then that is not looked at as a negative.

The primary sludge leaves the primary clarifier and is pumped through a strain press sludge cleaner. The sludge cleaner uses an auger and high pressure to move and push the sludge through an approximately 3 foot long screen with approximately 1 inch holes. The strain press sludge cleaner is used mostly to catch hair and other large and stringy material before reaching the anaerobic digesters. Based on visual observation of the process, the food waste, after being mixed with the wastewater in the preliminary treatment process and in the primary clarifier, should not be removed via the strain press sludge cleaner. A minimal amount of food waste loss could be assumed during this process.

After the primary sludge passes through the strain press sludge cleaner, it is pumped into the anaerobic digesters for processing. Based on the multiple processes that the food waste would go through from the septage receiving facility to the anaerobic digesters, it would be difficult to quantify losses of food waste and how much food waste would move with the primary effluent into the secondary treatment processes. To try to simulate this option in a bench-scale experiment would be relatively complex.

The option of utilizing the septage receiving facility is a low cost option because other than transporting the food waste from the Ram’s Horn Dining Facility to DWRF, there would be no added capital costs related to infrastructure improvements and additions. This option is also the most time-expedient option, because DWRF could start receiving processed food waste as soon as possible. Thus, food waste could begin to be transported to DWRF and the effects of the food waste addition as it relates to methane production in the DWRF anaerobic digesters and in increasing BOD in the primary effluent could be evaluated.

A drawback of this option is the unknown amount of loss of food waste that would occur from the septage receiving facility to the anaerobic digesters. The full benefit of the food waste for enhanced methane production in the anaerobic digesters would most likely not be reached due to losses during preliminary treatment and primary clarification. An option that allows for the food waste to bypass the preliminary treatment and primary clarifiers and being added directly to the anaerobic digesters would provide the maximum benefit for enhanced methane production (similar to the EBMUD process).

Another drawback of utilizing the DWRF septage receiving facility as the food waste addition point is that only processed food waste could be accepted. DWRF does not want to accept unprocessed food waste from other sources into the septage receiving facility because of the likelihood of this waste containing contaminants that could disrupt their processes. This would limit the amount of food waste that could be accepted. As of now, only the CSU dining facilities could provide a processed food waste that would be acceptable to add to the DWRF treatment process. The maximum amount of food waste that they could provide currently would be 800 lbs per day with an increase to 1400 lbs per day over the next few years. This would severely limit the possible benefits in enhanced methane production unless another processed food waste source could be found.

Another option would be to build a food waste skid mounted receiving station. There is self-contained septage receiving stations from manufacturers such as Parkson/Hycor that could be used to accept food waste. A skid mounted receiving station could possibly accept unprocessed food waste due to their ability to remove contaminants such as plastics, rocks, and rags during the pretreatment process. This food waste receiving station would most likely be located on the west side of the primary clarifiers or next to the head works building. If located on the west side of the primary clarifiers, the food waste could be added to the primary clarifier scum wet well which would bypass preliminary treatment and the primary clarifiers. The food waste would be mixed with the primary sludge and processed through the strain press sludge cleaner before being pumped to the anaerobic digesters. If the food waste receiving station is located adjacent to the head works building, the food waste would be added to the pipe right before going through the strain press sludge cleaner. Additional infrastructure, aside from the food waste receiving station, would be needed to connect the station to the pipe feeding the strain press sludge cleaner.

For both variations of this option, the food waste receiving station should be able to receive unprocessed food waste. However, there exists a higher probability that the food waste after being sent through the receiving station would have contaminants that could disrupt plant processes as compared to a food waste treatment process such as at EBMUD WWTP.

The capital cost for adding the receiving station would be high which is a drawback. This option may be a cheaper alternative to implementing the EBMUD process of both off-site and on-site food waste processing. However, this option may not provide a consistent, high quality feedstock for anaerobic digestion.

The third option would be to emulate the EBMUD food waste treatment process or use another technology, such as the DODA urban organics processing unit being tested in Colorado, to produce a contaminant-free feedstock from unprocessed food waste. In the long term, this would be the best option for getting the maximum benefit for enhanced methane production from food waste. However, the capital and O & M costs would be substantial to implement a process similar to EBMUD. A company that can handle and conduct pre-processing on the food waste would be needed to handle large amounts of food waste on an almost daily basis. Additionally, this contracted company would need to purchase equipment, similar to equipment used at the NorCal Jepson Prairie Facility in California, to complete the initial processing of the food waste. DWRF would need to purchase equipment to further process the food waste on site before adding it as a feedstock for the anaerobic digesters. A possible cheaper variation of this option would be to select a technology that could process the food waste on site and produce a feedstock similar in quality to the EBMUD food waste feedstock. However, many of these technologies are untested and costs could be large to purchase one, but the possibility exists of grants and subsidies to offset some of the cost.

2.3. FOOD WASTE CHARACTERIZATION AND STATISTICAL ANALYSIS RESULTS

The statistical analysis to determine sample mean, variance, and standard error associated with sampling along with the sample size determination results are provided. Furthermore, these results of the food waste characterization study are compared to results reported for food waste characterization studies reported in literature.

2.3.1. Food Waste Sampling Data for Characterization

The 10 samples collected in November and December 2010 were tested in accordance with the methods described in Chapter 2.2.1. The main parameters that needed to be determined to characterize the food waste were COD concentrations, TS percentage of the food waste, and the VS/TS ratio of the food waste. The results for COD concentrations, TS percentage, and VS/TS ratio are provided for the 10 samples (Table 2.1).

Table 2.1. CSU Ram’s Horn Dining Facility Food Waste Characterization Data

SAMPLE	SAMPLE DATE	COD (mg/L)	TS (%)	VS/TS (%)
FW001	8-Nov-11	158,697	17.72	87.0
FW002	8-Nov-11	225,333	23.11	85.91
FW001	15-Nov-11	331,506	29.61	96.74
FW002	15-Nov-11	368,352	28.02	95.44
FW001	29-Nov-11	181,362	11.26	93.83
FW002	29-Nov-11	312,264	25.27	89.54
FW001	6-Dec-11	269,967	20.22	91.08
FW002	6-Dec-11	311,631	26.56	86.13
FW001	13-Dec-11	240,831	23.42	94.32
FW002	13-Dec-11	224,013	23.89	94.44

Using the data reported in Table 2.1, a statistical analysis was completed to determine significant statistical values to characterize the food waste and to be able to complete an analysis of the impact of the addition of various amounts of food waste to the DWRF anaerobic digesters.

2.3.2. Statistical Analysis of Food Waste Characterization Data

Three important statistical values for the Ram's Horn food waste were determined. The sample mean, variance, and standard error were calculated according to the equations defined in Chapter 2.2.2. The sample mean for the TS percentage and the VS/TS ratio will be used for the analysis of the impact of the addition of various amounts of food waste to the DWRF anaerobic digesters. The standard error provides an assessment of the accuracy of the sample mean to represent the sample population tested. The values calculated for the sample mean, sample variance, and sample standard error of the three parameters used to characterize the food waste are provided (Table 2.2).

Table 2.2. Sample Mean, Variance, and Standard Error of Food Waste Sample Parameters

Parameter	$\bar{x}$	s^2	$s(\bar{x})$
COD (mg/L)	262,396	4,622,561,152	21,500
TS (%)	22.91	29.01	1.70
VS/TS (%)	91.44	16.59	1.29

The variance is extremely large for COD due to the variability between the individual sample concentrations and the overall sample mean for COD. Also, the sample variance for TS and VS/TS ratio are relatively large but not to the extent as for the sample variance of COD. The standard errors determined for COD, TS, and VS/TS ratio are relatively small (Table 2.2). Thus, it can be assumed that the estimate for the sample mean is relatively accurate. The TS percentage and VS/TS ratio of the food waste will be used for further analysis of food waste addition to the DWRF anaerobic digesters and thus are more important.

A determination of the sample size needed was completed using a specified relative error and margin of error defined in Chapter 2.2.2. The results of the sample size determination for the three parameters tested are shown in Table 2.3:

Table 2.3. Sample Size Determination Results

Parameter	n	$n - n_1$
COD	$17.4 \approx 18$	8
TS	$7.6 \approx 8$	N/A
VS/TS	$4.3 \approx 5$	N/A

For TS and VS/TS ratio, no more samples are needed to meet the specified relative error and margin of error. For COD, 8 more samples would need to be collected to meet the margin of error and specified relative error. No more food waste samples will be collected and tested due to lack of funding and COD concentrations being less important than the TS and VS/TS percentages for the samples. If the margin of error was changed to 90% and the relative error specified at 31,000 mg/L, n would equal approximately 10 and no more samples would be needed. Due to the reasons stated, the number of food waste samples collected is sufficient.

2.3.3. Comparison of Ram's Horn Food Waste to Other Food Waste Sources

A comparison of the TS and VS/TS ratio of the Ram's Horn food waste can be made with both food waste characteristics reported in literature and also to food waste used at the EBMUD plant. Table 2.4 provides the characteristics of food waste for various sources including dining facilities and mixed municipal sources.

Table 2.4. Characteristics of Food Wastes Reported in Literature (derived from Zhang et al., 2006)

Source	TS (%)	VS/TS (%)	Country	Reference
A dining hall	20	95	Korea	Han and Shin (2004)
University's cafeteria	20	94	Korea	Kwon and Lee (2004)
A dining hall	7	94	Korea	Shin et al. (2004)
A dining hall	16	96	Korea	Kim et al. (2004)
Mixed municipal sources	10	80	Germany	Nordberg and Edstrom (1997)
Mixed municipal sources	26	90-97	Australia	Steffen et al. (1998)
Emanating from fruit and vegetable markets, household and juice centers	15	89	India	Rao and Singh (2004)
CSU Ram's Horn Dining Facility	23	91	US	Robbins (2012)

When comparing the sample mean for TS of approximately 23% for the Ram's Horn food waste to values shown in Table 2.4 for various sources, the Ram's Horn food waste has slightly higher total solids content than most other sources. This most likely is a product of the pulping process used at the Ram's Horn dining facility and the moisture content of the food waste being processed. The TS content of the Ram's Horn food waste does not vary significantly from data reported in literature which support the results of the food waste characterization study conducted.

The Ram's Horn VS/TS ratio of 91.4% compares favorably to the data reported in literature for various food waste sources shown in Table 2.4. Typically, as shown in literature, food waste has a VS/TS ratio in the lower 90% range. This is consistent with the sample mean for the VS/TS ratio of the Ram's Horn food waste.

EBMUD conducted food waste characterization study of various food waste sources in the Oakland and San Francisco, CA area. EBMUD found that the TS concentration of food waste varies from less than 25% to more than 40% solids, with an average of about 28% (Gray et al, 2008). The Central Marin Sanitation Authority collected samples of food wastes from three restaurants and a market in August 2008 in and around San Rafael, CA. The average TS concentration of the food waste samples was 25% with a VS/TS ratio of 92% (City of San Rafael and CMSA, 2009). These values reported demonstrate that the Ram's Horn food waste average TS concentration and average VS/TS ratio compare favorably to other commercial food waste sources in the United States.

2.4. OPERATING CAPACITY OF DWRF ANAEROBIC DIGESTERS

The operating capacity of the DWRF anaerobic digesters were calculated for hydraulic loading, solids loading, and organic loading rates as described in Chapter 2.2.3. The loading rate that resulted in the largest operating capacity for the anaerobic digesters would be the limiting rate and would be used for the analysis of food waste addition in the digesters. The various loadings and data used in the determination of the capacities based on the three loading rates along with the operating capacity of the DWRF anaerobic digesters based on the three loading rates are provided in Table 2.5.

Table 2.5. Loading Rates and Associated Operating Capacities

Loading Rates	Max Daily Loading Rates	2010 DWRF Daily Loading Rates	DWRF AD Operating Capacity
Solids	37,500 lbs VS/day	21,746 lbs VS/day	57.99%
Hydraulic	186,900 gallons/day	68,411 gallons/day	36.60%
Organic	0.15 lbs VS/ft^3 · d	0.062 lbs VS/ft^3 · d	41.30%

2.4.1. Operating Capacity of Anaerobic Digesters Based on Solids Loading

To provide a conservative estimate for all loadings, only the capacity of three anaerobic digesters were used in the calculations. As there are occurrences of one digester not being operated due to maintenance or other reasons, it would provide a factor of safety for the amount of food waste which could be added to the digesters.

A conservative estimate was calculated by taking the daily solids loading and dividing that by the solids capacity of 3 digesters which is 37,500 lbs VS per day. For 2010, the average daily solids loading to the anaerobic digester was 21,746 lbs VS per day. The anaerobic digesters for 2010 operated at an average of 57.99% of their capacity for solids loading.

2.4.2. Operating Capacity of Anaerobic Digesters Based on Hydraulic Loading

The average daily hydraulic loading was 68,411 gallons per day in 2010. The hydraulic loading capacity for 3 digesters stated earlier is 186,900 gallons per day. The average daily hydraulic loading was divided by the hydraulic loading capacity for three digesters to determine a conservative estimate of the hydraulic loading operating capacity. For 2010, the anaerobic digesters operated at an average of 36.60% of their capacity for hydraulic loading. Thus, the solids loading rate is limiting when compared to the hydraulic loading.

2.4.3. Operating Capacity of Anaerobic Digesters Based on Organic Loading

Using the 2010 data, the average daily organic loading rate was 0.062 pounds VS per day per cubic foot of anaerobic digester volume. As stated previously, the recommended organic loading rate for high-rate digesters ranges between 0.10 to 0.30 lbs $VS/ft^3 \cdot d$. For a generally conservative estimate of capacity based on organic loading rate, 0.15 lbs

VS/ft^3 · d was chosen as the organic loading capacity. The organic loading operating capacity was determined by dividing the average daily organic loading rate by the organic loading capacity. The anaerobic digesters operated at an average of 41.30% of their capacity with respect to organic loading in 2010. When compared to the solids loading rate, the solids loading rate is limiting. Thus, the solids loading rate will be used in determining the maximum amount of food waste that can be added to the DWRF anaerobic digesters in further analysis.

2.5. FOOD WASTE ADDITION AND ASSOCIATED BIOGAS AND METHANE PRODUCTION

Using the solids loading rate and operating capacity of the DWRF anaerobic digesters along with the Ram's Horn food waste characterization data, the maximum amount of food waste that could be added can be determined. Determining the maximum amount of food waste will then place a cap on how much food waste can be added to the anaerobic digesters. Various amounts of food waste can be added up to the maximum amount to achieve the objective of determining an estimation of how much biogas and methane gas can be generated from the various amounts of food waste. These calculations will be made using the equations and methods described in Chapter 2.2.4.

2.5.1. Maximum Amount of Food Waste Addition to DWRF Anaerobic Digesters

The DWRF anaerobic digesters operated at 57.99% of its capacity for solids loading which was the limiting rate. The calculation for the maximum amount of VS (in lbs VS/day) that could be added to the anaerobic digesters is shown below:

Max. Amt. of Food Waste = 37,500 lbs VS/day – 21,746 lbs VS/day

Max Amt. of Food Waste = 15,754 lbs VS/day

The average TS concentration of the Ram's Horn food waste was 22.91% and the average TVS/TS ratio was 91.44%. These values will be used as representative of food waste in the Fort Collins area for these calculations. The calculation for the maximum amount of food waste (in lbs/day) is shown below:

Max. Amt. of Food Waste (lbs/day) = 15,754 lbs VS/day / 0.2291 / 0.9144

Max. Amt. of Food Waste (lbs/day) = 75,201 lbs / day ≈ 37.5 tons

A check on the maximum amount of food waste calculation was also completed using Equation 6. Inputting the variables defined in Chapter 2.2.4 for Equation 6 resulted in the average daily flow (in MGD) of food waste that at most could be added equaling 0.0088 MGD (or 8,838 gallons per day). This value was multiplied by the conversion factor of 8.34, the TS percentage, and VS/TS percentage of the Ram's Horn food waste and then added to the 2010 DWRF daily solids loading (in lbs VS/day). Based on these calculations, the maximum amount of food waste that could be added to the anaerobic digesters was 37,187 lbs VS/day. This is just slightly less than the 37,500 lbs VS/day for the anaerobic digesters' maximum solids loading capacity and verified that the maximum solids loading capacity was not exceeded and that 37.5 tons of food waste per day is the maximum amount that could be added to the DWRF anaerobic digesters.

Without the food waste added, the average daily digested sludge out of the digesters equaled 7,603 lbs VS/day. With the maximum amount of food waste added, the average daily digested sludge out of the digesters equaled 8,587 lbs VS/day. These values were divided by the daily VS/TS percentage (averaged 69.54% for 2010) reported in the 2010 DWRF anaerobic digesters data. The addition of the maximum amount of food waste resulted in an increase in residual solids of 1,415 lbs/day.

The average daily VS reduction for only the primary sludge and thickened WAS equaled 64.81% based on the 2010 data. The estimated average daily VS reduction when adding the maximum amount of food waste equaled 79.56%. This represents a significant increase in the VS reduction which can be correlated to the high VS/TS percentage of the food waste. This supports food waste being a very desirable feedstock for anaerobic digestion.

The daily average pounds of VS destroyed without food waste addition equaled 14,143 lbs. The daily average pounds of VS destroyed with the maximum amount of food waste added equaled 29,584 lbs. Again, due to the high VS/TS percentage of food waste, most of the food waste was consumed in the anaerobic digesters resulting in increased biogas production.

Without food waste addition, the estimated average daily biogas production for the anaerobic digesters equaled 169,717 ft^3 of biogas. With the maximum amount of food waste added, the estimated average daily biogas production for the anaerobic digesters equaled 355,005 ft^3 of biogas. The result is an average increase in gas production of 117.65% with the maximum amount of food waste added.

Using this estimation and assuming that methane gas comprises 65% of digester biogas, the average daily methane gas production without food waste addition was 110,316 ft^3. The average daily methane gas production with the maximum amount of food waste added was 230,753 ft^3.

The pertinent results of the maximum food waste addition analysis are summarized in Table 2.6:

Table 2.6. No Food Waste Addition and Maximum Food Waste Addition Results

2010 Data	No Food Waste (FW) Added	Max FW Added (~37.5 tons/day)
Solids Reduction (%)	**64.81**	**79.56**
Gas Production (ft^3/day)	167,717	355,005
Increase in Gas Production (ft^3 gas/day)	N/A	185,288
% Increase Gas Production	N/A	**117.65**
Residual Solids (lbs/day)	10,934	12,349
Increase in Residual Solids (lbs/day)	N/A	1,415
% Increase Residual Solids	N/A	**12.94**

Table 2.6 displays the results for both no food waste added and the maximum amount of food waste added (~37.5 tons/day). The results for no food waste addition represent the baseline and are used for a comparison with the various amounts of food waste added. The key parameters that are shown are the effects of adding food waste on solids reduction, gas production, and residual solids.

2.5.2. Addition of Various Amounts of Food Waste to the DWRF Anaerobic Digesters

Using the baseline values for important parameters determined from the 2010 anaerobic digester data reported in Table 2.6 and the maximum amount of food waste that could be added on a daily basis, an analysis utilizing various amounts of food waste for addition to the anaerobic digesters was completed. The first amounts used were the 800 lbs/day of Ram's Horn food waste that could be provided immediately and the projected 1400 lbs/day of CSU dining facility food waste that could be provided in the next couple of years. 2.5 tons of food waste per day being added to the DWRF anaerobic digesters was analyzed next followed by 5 tons of food waste per day up to 25 tons per day of food waste at 5 ton per day intervals. The results of the Ram's Horn Dining

Facility food waste characterization study were used as being representative of food waste in the local Fort Collins area.

The following tables show the various iterations of food waste addition compared to the baseline shown in Table 2.6.

Table 2.7. 800 lbs/day FW Added and 1400 lbs/day FW Added Results

2010	800 lbs/day FW Added	1400 lbs/day FW Added
Solids Reduction (%)	**65.08**	**65.28**
Gas Production (ft^3/day)	171,688	173,166
Increase in Gas Production (ft^3 gas/day)	1,971	3,450
% Increase Gas Production	**1.20**	**2.11**
Residual Solids (lbs/day)	10,949	10,961
Increase in Residual Solids (lbs/day)	11	20
% Increase Residual Solids	**0.14**	**0.24**

Table 2.8. 2.5 tons/day FW Added and 5 tons/day FW Added Results

2010	2.5 tons/day FW Added	5 tons/day FW Added
Solids Reduction (%)	**66.44**	**67.93**
Gas Production (ft^3/day)	182,036	194,356
Increase in Gas Production (ft^3 gas/day)	12,320	24,639
% Increase Gas Production	**7.52**	**15.04**
Residual Solids (lbs/day)	11,028	11,122
Increase in Residual Solids (lbs/day)	72	143
% Increase Residual Solids	**0.86**	**1.72**

Table 2.9. 10 tons/day FW Added and 15 tons/day FW Added Results

2010	10 tons/day FW Added	15 tons/day FW Added
Solids Reduction (%)	**70.53**	**72.74**
Gas Production (ft^3/day)	218,995	243,634
Increase in Gas Production (ft^3 gas/day)	49,278	73,917
% Increase Gas Production	**30.08**	**45.13**
Residual Solids (lbs/day)	11,310	11,498
Increase in Residual Solids (lbs/day)	286	429
% Increase Residual Solids	**3.44**	**5.16**

Table 2.10. 20 tons/day FW Added and 25 tons/day FW Added Results

2010	20 tons/day FW Added	25 tons/day FW Added
Solids Reduction (%)	**74.63**	**76.28**
Gas Production (ft^3/day)	268,273	292,912
Increase in Gas Production (ft^3 gas/day)	98,557	123,196
% Increase Gas Production	**60.17**	**75.21**
Residual Solids (lbs/day)	11,687	11,875
Increase in Residual Solids (lbs/day)	572	715
% Increase Residual Solids	**6.88**	**8.60**

The previous tables provide the estimated results of adding processed food waste directly to the anaerobic digesters. Graphical depictions of the results for the key parameters for the various amounts of food waste added are shown next to illustrate the effect of food waste addition.

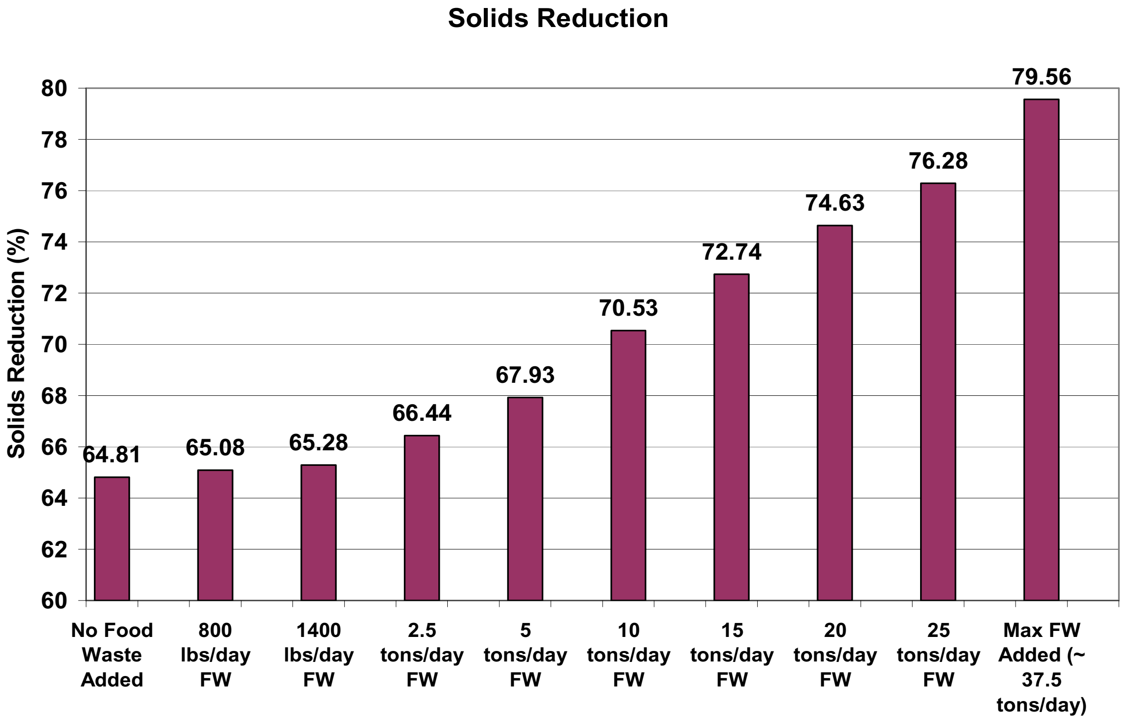

Figure 2.3. Solids Reduction Results

Figure 2.3 depicts the effect of the various amounts of food waste on the solids reduction. As the solids reduction rate increases, the pounds of VS destroyed will increase and thus the gas production rate will increase. Additionally, with a higher solids reduction rate, the amount of residual solids leaving the digester will not increase significantly which will minimize the costs associated with treating and disposing of residual solids caused by the food waste addition.

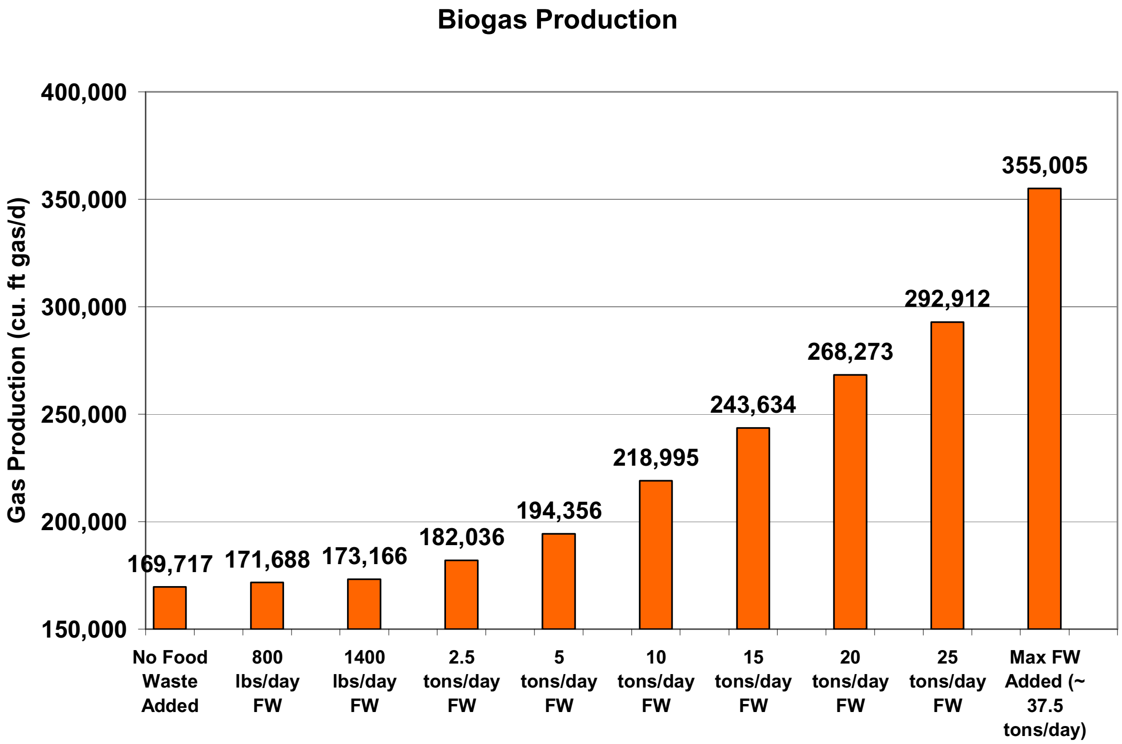

Figure 2.4. Gas Production Results

Figure 2.4 depicts the effect of adding food waste on digester gas production. Significant increases in gas production begin to be shown when 5 tons/day of food waste is added. At this point, gas production is estimated to increase by over 15%, which equates to approximately 25,000 ft^3/day of extra digester gas for use in the plant.

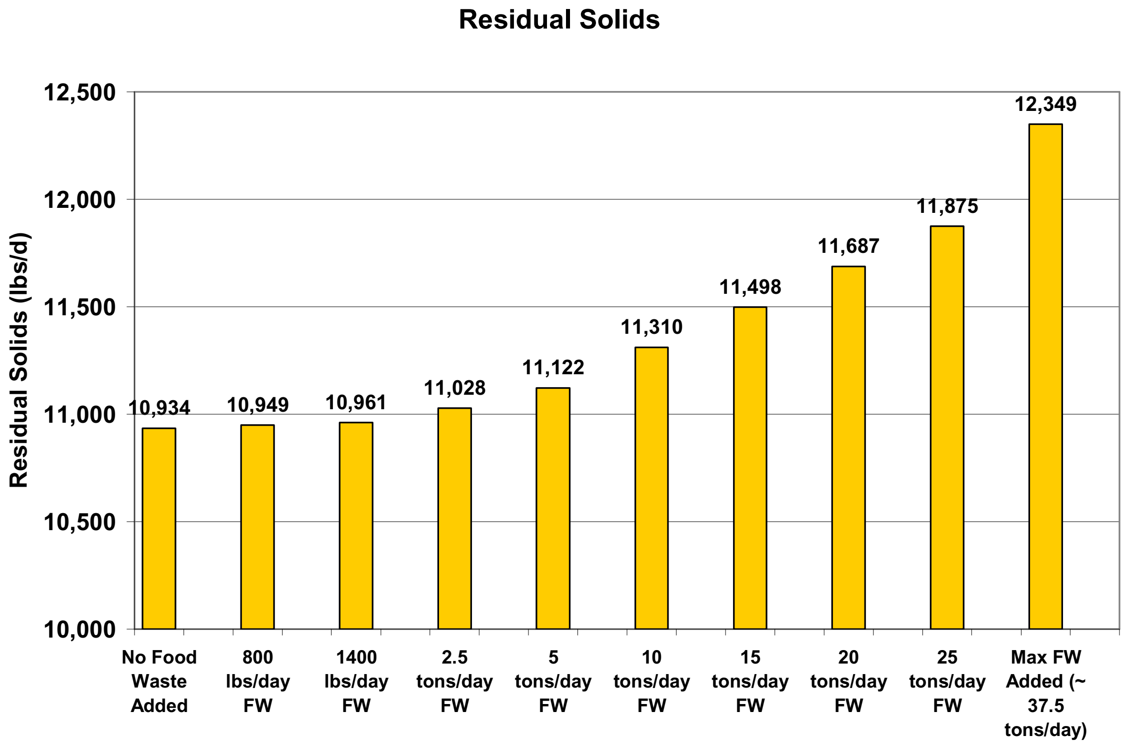

Figure 2.5. Residual Solids Results

The effect of adding food waste on the residual solids output from the anaerobic digesters is minimal as demonstrated in Figure 2.5. At the 5 tons/day of food waste addition point, the residual solids only increase by 1.72% (143 lbs/day). When adding 25 tons/day of food waste, the residual solids increase by 8.60% (715 lbs/day). This is a relatively small increase compared to the amount of food waste being added. Due to food waste having a high VS/TS ratio resulting in a higher VS destruction rate, the residual solids increase is relatively small and manageable and should result in a minimal increase in costs related to residual solids handling and disposal.

2.6. IMPLEMENTATION OF FOOD WASTE ADDITION IN THE DWRF TREATMENT PROCESS

Three 5 gallon buckets of Ram's Horn food waste was added directly to the primary clarifier to visually observe what would happen to the food waste. The food waste was inputted in the front portion of the primary clarifier and allowed to move with the wastewater for five minutes before any visual observations were made. A picture of some food waste floating in the primary clarifier is shown in Figure 2.6.

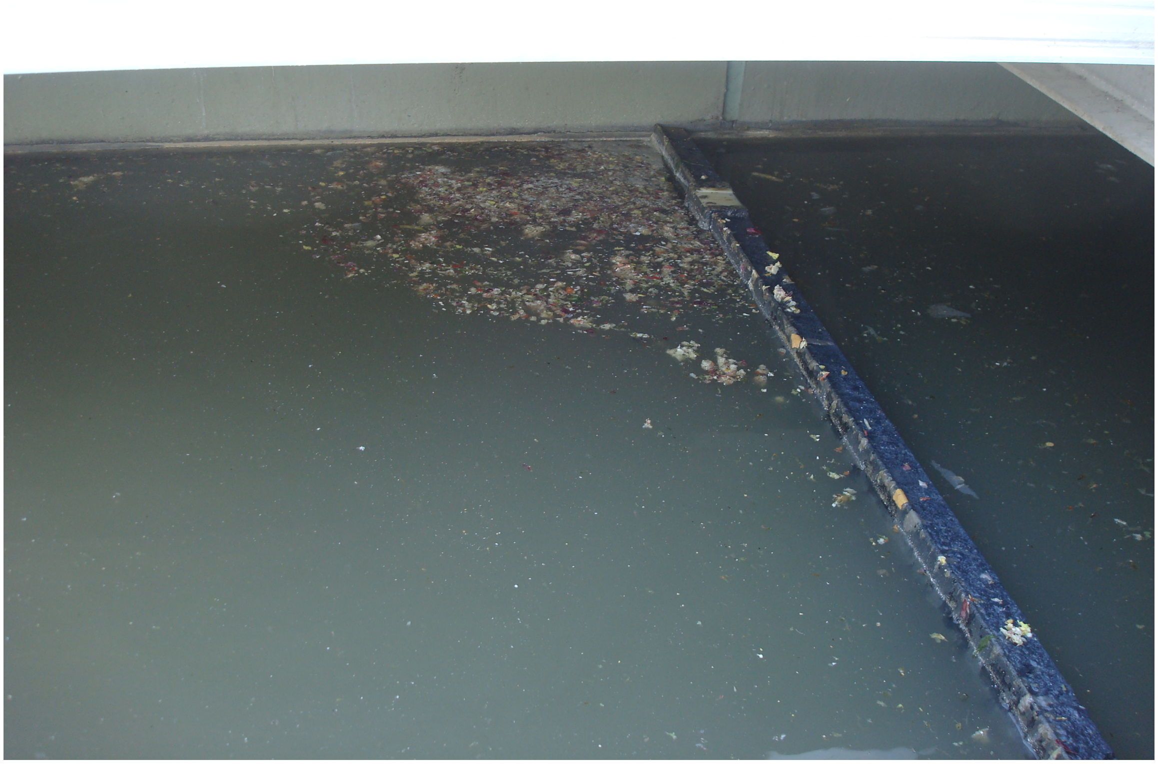

Figure 2.6 Food Waste Floating in the DWRF Primary Clarifier

Most of the contents of the three buckets of food waste added were not visually observable after 5 minutes of time in the primary clarifiers. There was a small accumulation of food waste floating where the clarifier wall and the clarifier skimmer meets (as shown in Figure 2.6), but for the most part the food waste had settled out of view. This bodes well that food waste would settle in the typical two hour detention time of the DWRF primary clarifiers.

Food waste from the Ram's Horn Dining Facility was collected to test the feasibility of the waste passing through the septage receiving facility bar screen. A 5 gallon bucket of the food waste was placed on the bar screen and water was used to pass the food waste through the screen (Figure 2.4).

Figure 2.7. Ram's Horn Food Waste Being Sent Through the DWRF Septage Receiving Facility Bar Screen

The food waste did not pass easily through the bar screen and required approximately 2-3 minutes to pass the food waste through the bar screen with water. For 800 lbs/day of food waste, this would be too time and labor intensive and thus would not be a viable option.

3. ECONOMIC AND TRIPLE BOTTOM LINE ANALYSIS OF ENERGY GENERATION FROM DWRF BIOGAS

3.1. Background

In order to determine whether DWRF wants to proceed with diverting food waste for enhanced biogas and methane gas production, an economic analysis needs to be completed. The value of the enhanced biogas and methane gas production needs to be monetized to provide an estimate of the cost savings and possible revenue generated from the diverted food waste. The possible costs need to be outlined in detail to provide an accurate estimation of the cost to DWRF in moving forward with food waste diversion to DWRF. Finally, other variables that may not be as easy to quantify and monetize such as reduced greenhouse gas emissions at the Larimer County Landfill and other possible environmental and social benefits of this project need to be discussed.

As discussed previously, DWRF uses methane gas from their anaerobic digesters in their boilers to provide heat for their plant. Any excess methane gets flared into the atmosphere as they currently do not have a way to store excess methane. The flaring of methane emits carbon dioxide but eliminates potent methane emissions into the environment. DWRF personnel stated that they can cover approximately 60% of their plant heating using methane gas and that there is a seasonal variation to the need for methane. Typically, in the winter, DWRF does not have enough methane to support their heating needs. In the summer, DWRF has an excess of methane and the flaring of methane increases. DWRF are currently looking at possibly using methane gas to produce electricity at their plant in the future. They have investigated the use of fuel cells and have applied for a grant from the state of Colorado for a microturbine that can be powered by biogas. If they do implement a technology in the future that can use biogas to produce electricity, then the need for methane gas will greatly increase.

3.2. METHODS

In this section, the procedures and methods to monetize the savings of the use of methane gas produced in the DWRF anaerobic digesters for heating needs were quantified along with the cost of using natural gas for heating. The value of the methane gas flared into the atmosphere at DWRF was also monetized. The procedures and methods to quantify electric costs at DWRF were laid out along with an overview of various combined heat and power (CHP), also known as energy generation, technologies that could be used at DWRF to generate energy and thus savings in electricity and heating costs. The procedures to complete an economic analysis for purchasing various energy generation technologies were outlined with only using DWRF flared biogas as the fuel source. The methods and procedures for an economic analysis of implementing a food waste diversion program at DWRF and in the city of Fort Collins were discussed in detail. Finally, a triple bottom line analysis was completed to discuss the economic, environmental, and social impacts of a food waste diversion project.

3.2.1. Methane Gas and Natural Gas for Heating at DWRF in 2010

Data was provided by DWRF personnel on methane use at their plant for 2009 and 2010. Biogas is used in three boilers, located in the east tunnel, to heat various processes and areas of the plant located mostly in the east side of the plant. Excess biogas was flared into the atmosphere as discussed earlier. Natural gas boilers, located in the west tunnel of then plant, meet the heating demands of the head works building and primary clarifiers. These boilers are not biogas compatible. Natural gas units provide heat for the operations and maintenance building. In order for the boilers in the east tunnel to heat processes in the central and west end of the plant, the infrastructure and piping of the glycol loop would need to be extended. This needs to be accounted for in any economic analysis incorporating savings by using biogas instead of natural gas for heating.

DWRF personnel only operate one boiler at a time due to not having large enough amount of methane gas production to operate more than one boiler. If needed with increased methane production at the plant, the operators could run two boilers or possibly all three to meet their heating needs. The data for DWRF methane use in standard cubic feet (SCF) in 2009 and 2010 is summarized in Table 3.1 and 3.2:

Table 3.1. 2009 DWRF Methane Use

Methane Use	Jan 2009	Feb 2009	Mar 2009	Apr 2009	May 2009	Jun 2009
Boiler (SCF)	3,216,000	2,602,200	2,385,700	1,971,800	1,241,000	1,036,800
Waste Flare (SCF)	534,700	833,000	1,109,500	1,794,400	2,507,700	2,129,200
Methane Use	**Jul 2009**	**Aug 2009**	**Sep 2009**	**Oct 2009**	**Nov 2009**	**Dec 2009**
Boiler (SCF)	4,817,500	1,370,000	680,200	1,458,300	2,714,400	5,049,700
Waste Flare (SCF)	2,168,200	2,581,900	2,458,500	1,824,500	1,447,800	190,400

Table 3.2. 2010 DWRF Methane Use

Methane Use	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010
Boiler (SCF)	3,174,200	3,465,900	2,461,000	3,066,606	2,409,211	2,148,754
Waste Flare (SCF)	42,400	183,900	1,251,100	1,891,400	2,225,100	2,410,600
Methane Use	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
Boiler (SCF)	1,604,962	783,301	187,600	2,447,500	2,573,100	2,962,200
Waste Flare (SCF)	2,376,200	2,840,000	3,024,300	2,891,300	1,706,000	851,500

Table 3.3. Summary of 2009 and 2010 DWRF Methane Use

Methane Use	2009	2010
Boiler (SCF)	28,543,600	27,284,334
Waste Flare (SCF)	19,579,800	21,693,800
Total (SCF)	48,123,400	48,978,134

The DWRF methane use tables illustrate that during the warmer months (May thru September), the amount of methane that is flared increases and during the colder months (December thru March) a much smaller amount of methane is flared. Figure 3.1 below provides a visual depiction of the monthly variation in methane use for plant boilers and excess methane that is flared into the atmosphere.

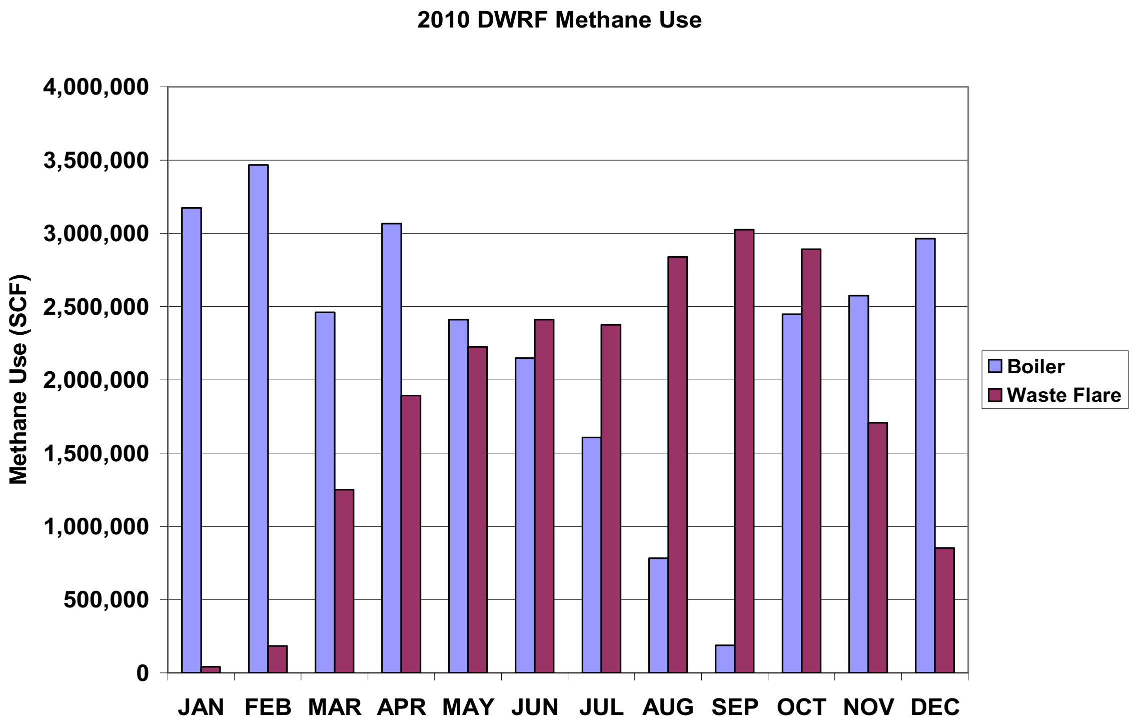

Figure 3.1. 2010 DWRF Monthly Methane Use

The actual methane produced and used for 2010 at DWRF reported in Table 3.3 can be compared to the estimation of the amount of methane produced for the same year discussed when calculating estimated biogas production from food waste addition. This provides a check of assumed parameters to estimate biogas production. The value reported in Table 2.6 in Chapter 2.5.1 for the average 2010 DWRF biogas production can be multiplied by 365 days to get the total production for the year. This value was multiplied by 65% which represents the typical methane concentration in digester gas discussed earlier. The equation for this calculation is provided below.

2010 DWRF CH_4 gas production/year = 2010 DWRF estimated biogas produced/year * 365 days/year * 65% CH_4 gas/2010 DWRF biogas produced (Equation 7)

A comparison was made between the calculated value from Equation 7 to the reported value for methane gas production at DWRF in 2010 reported in Table 3.3. These values may differ based on assumptions made such as 12 ft^3 of biogas produced per pound of VS destroyed, which is the low end of the range for estimating digester gas production and the methane content of DWRF digester gas being equal to 65%.

3.2.2. Heating Provided from Methane and Natural Gas Use at DWRF

Methane gas at standard temperature and pressure has a net heating value of 960 Btu/ft^3. However, since methane gas typically only comprises 65% of digester gas the low heating value of digester gas is 600 Btu/ft^3 (Metcalf & Eddy, 1991). This equates to 0.006 $therms/ft^3$. Using this conversion, the methane gas produced at DWRF in 2010 on a monthly basis was converted into therms that could be produced. This in turn was converted into a monetary value.

For comparison, data for natural gas use (in therms) for DWRF in 2010 was provided. The data provided was broken into the various uses within the plant. The majority of the natural gas went towards boiler use to heat various processes.

To provide a visual comparison of methane use versus natural gas use, a chart was created comparing on a monthly basis natural gas use, methane gas use for boilers, and methane gas that is flared.

3.2.3 Estimating Monetary Value of Natural and Methane Gas Use at DWRF

The cost of natural gas needed to be quantified along with the savings from use of methane gas in order to provide perspective on costs and savings associated with natural gas and methane gas use. Natural gas rates for 2011 were found via the Xcel Energy website. Xcel Energy provides natural gas for residential, commercial, and industrial use throughout the state of Colorado. Xcel Energy owns the Denver-based Public Service Company of Colorado which provides electricity and gas for many residents and businesses in Colorado. The Public Service Company of Colorado published new natural gas rates with an effective date of 5 April 2011. The rates varied based on whether the user was classified as a residential gas user, commercial – small gas service, commercial – large gas service, and interruptible industrial gas service (Colorado PUC No. 6 Gas, 2011). The commercial small gas and large gas service is divided by a 50,000 therm annual usage. In order for a commercial entity to qualify as a commercial - small gas service user, they must use less than 50,000 therms annually. Since DWRF uses over 50,000 therms annually, they would be classified as a commercial - large gas service user. The natural gas rates for a commercial – large gas service schedule is provided below.

Type of Charge	**Billing Units**	**Rate/Charge**
Service & Facility Charge	--	$62.65
Usage Charge	Dekatherm	$0.12529
Capacity Charge	Dekatherm	$7.01

The charges for a commercial – large gas service schedule are per dekatherm used. A dekatherm is equal to 10 therms and is the unit commonly used for high end users of gas.

Based on this rate structure, DWRF pays $0.71 per therm of natural gas. According to Department of Energy data from January 2012, the national average for the first 10 months in 2011 was $0.87 per therm (US Energy Information Administration, 2012). Further information was provided by state for natural gas costs by the US Energy Information Administration. For the state of Colorado in November 2011, the cost of natural gas was $0.74 per therm consistent with the rate structure provided. Thus, heating utilizing natural gas costs less in Northern Colorado than in most other areas in the United States.

Included in each charge type is an additional charge called a Demand Side Management Cost Adjustment (DSMCA). The purpose of the Demand Side Management (DSM) rules and cost adjustment charge is to reduce end-use natural gas consumption in a cost effective manner, in order to save money for consumers and utilities, and protect the environment by encouraging the reduction of emissions and air pollutants (Colorado Department of Regulatory Agencies, 2008). The DSMCA charge for each charge type only encompassed a small portion of the overall charge, typically less than 5%.

Based on the rate schedule above and the natural gas use in therms provided by DWRF, the cost of natural gas used in 2010 at DWRF was calculated. Additionally, the savings associated with methane used to fuel the boilers was also calculated. Finally, the monetary value for the methane gas flared into the atmosphere was estimated.

3.2.4. Electricity Rate Structure and DWRF Electricity Costs

Before evaluating various technologies to generate electricity at DWRF using biogas, the electric rate structure along with costs associated with DWRF operations needs to be defined. DWRF falls under the General Service (GS) 750 schedule. This schedule applies to customers served at the primary voltage of the Fort Collins' electric system and to individual services with an average metered demand of 750 kilowatts (kW) or greater (Fort Collins City Code Sec. 26-469, 2011). The other city of Fort Collins WWTP, Mulberry Water Reclamation Facility (MWRF), operates under the GS50 schedule which applies to individual services with an average metered demand not less than fifty kW and not greater than 750 kW. Both rate schedules for the two WWTPs are shown below for comparison along with the cost components for 2011 and projected for 2012 under the new rate structure.

Table 3.4. 2011 and 2012 Electric Rate Structure for MWRF and DWRF (derived from 2012 Rate Discussion – Mulberry and Drake Water Reclamation Facilities, 2011)

	2011 (E300)	2012 (E300)	2011 (E400)	2012 (E400)
Fixed	$18.36	$21.02	$54.11	$61.96
Extra meter	N/A	N/A	$47.81	$54.74
Coincident peak / kW summer	$12.80	$10.36	$12.61	$10.20
Coincident peak / kW winter	$12.80	$7.76	$12.61	$7.64
Dist Facility Demand / kW	$4.82	$5.52	N/A	N/A
< 750	N/A	N/A	$4.75	$5.44
> 750	N/A	N/A	$2.84	$3.25
Energy summer	$0.0248	$0.0372	$0.0245	$0.0367
Energy winter	$0.0248	$0.0355	$0.0245	$0.0349

In Table 3.4, a coincident peak demand charge for both summer and winter is listed. Coincident peak demand is defined in the *2012 Electric Rates City of Fort Collins*

Ordinance 142 and Ordinance 166 as 'the customer's sixty-minute integrated kW demand recorded at the hour coincident with the monthly system peak demand for Platte River Power Authority. The monthly system peak demand for Platte River Power Authority shall be the maximum coincident sum of the measured demand for the participating municipalities recorded during the billing month.' In simpler terms, the coincident peak demand charge corresponds to the one hour DWRF demand (in kW) when the Platte River Power Authority is at their peak demand for the month. Another charge listed in Table 3.4 is the distribution facilities demand. The distribution facilities demand charge is used by the utility to recover the costs of operating and maintaining the electric distribution system and it is based on a per unit rate tied to the peak demand (kW) of a customer's monthly electric use (2012 Electric Rates, City of Fort Collins Ord. 142 and Ord. 166, 2011). Finally, in Table 3.4, there is an energy charge listed for both summer and winter. This charge is per kW-hour (kWh) and is based on energy consumption on a monthly basis. The new 2012 electric rate structure for both schedules places an emphasis on consumption while lessening the emphasis on facility demand and coincident peak demand.

The city of Fort Collins provided a monthly breakdown of the 2011 DWRF electric bill along with the projected 2012 costs based on the electricity usage in 2011 (Table 3.5).

Table 3.5. DWRF 2011 and Projected 2012 Electric Costs

Date	Energy	Facilities Demand	Coincident Peak	Cost @ 2011 Rate	Cost @ 2012 Rate	Change	Season
1-Dec-11	910,000	1,680	980	$43,365	$49,195	13.4%	non-summer
1-Nov-11	971,600	1,680	980	$44,965	$51,474	14.5%	non-summer
1-Oct-11	938,000	1,680	952	$43,718	$50,004	14.4%	non-summer
1-Sep-11	985,600	1,736	1,288	$49,611	$60,055	21.1%	summer
1-Aug-11	904,400	1,652	1,260	$46,875	$56,304	20.1%	summer
1-Jul-11	929,600	1,792	1,036	$44,957	$55,345	23.1%	summer
1-Jun-11	985,600	1,764	1,120	$47,450	$53,415	12.6%	non-summer
1-May-11	946,400	1,848	1,036	$45,562	$51,574	13.2%	non-summer
1-Apr-11	980,000	1,792	1,064	$46,640	$52,851	13.3%	non-summer
1-Mar-11	938,000	1,792	1,120	$46,298	$51,751	11.8%	non-summer
1-Feb-11	1,016,400	1,764	1,064	$47,501	$54,101	13.9%	non-summer
1-Jan-11	1,022,000	1,764	1,092	$48,021	$54,535	13.6%	non-summer

From Table 3.5, the average monthly increase in electric costs with the new 2012 rate structure at DWRF is 15.4%. For the months of July, August, and September, which are considered the summer season, the change in costs from 2011 to 2012 is expected to be over 20%. This is a significant projected increase and wastewater revenues are increasing less than the electric rates. This could lead to DWRF operating at a deficit and needing to generate revenue to cover rising costs. Reducing the energy costs at DWRF by utilizing an energy generation technology utilizing biogas produced from the anaerobic digesters may be the solution.

3.2.5. Cost and Performance Characteristics of Energy Generation Technologies

In addition to the advantages and disadvantages of energy generation technologies discussed in Chapter 1.5, the EPA CHP Partnership provided information on typical cost and performance characteristics. The cost information along with National Renewable Energy Laboratory (NREL) analysis data on energy generation technologies, which will be provided later in the chapter, was used in the economic analysis of the various technologies. The cost and performance characteristics are provided in Table 3.6 for various energy generation technologies from the EPA.

Table 3.6. Cost and Performance Characteristics of Energy Generation Technologies (derived from EPA CHP Partnership, 2008)

Technology	Recip. Engine	Microturbine	Fuel Cell
Effective electrical efficiency	70-80%	50-70%	55-80%
Typical capacity	0.01 – 5 MW	0.03 – 0.5 MW	0.005 – 2 MW
Typical power to heat ratio	0.5 – 1	0.4 – 0.7	1 - 2
CHP Installed costs ($/kW)	1,100 – 2,200	2,400 – 3,000	5,000 – 6,500
O & M costs ($/kWh)	0.008 – 0.022	0.012 – 0.025	0.032 – 0.038
Electric heat rate (Btu/kWh)	8,758 – 12,000	13,080 – 15,075	8,022 – 11,370
Hours to overhaul	25,000 – 50,000	20,000 – 40,000	32,000 – 64,000
Start-up time	10 sec	60 sec	3 hrs – 2 days
Fuels	Natural gas, biogas, propane, landfill gas	Natural gas, biogas, propane, oil	Hydrogen, natural gas, propane, methanol

The effective electrical efficiency is a measure that expresses CHP efficiency as the ratio of net electrical output to net fuel consumption, where net fuel consumption excludes the portion of fuel that goes to producing useful heat output. The effective electrical efficiency measure for CHP captures the value of both the electrical and thermal outputs of CHP technologies (EPA CHP Partnership, 2008). The electric heat rate provides the amount of heat that can be expected to be produced (in Btu) per kWh of electric production. This is important because the additional heat generated from these technologies can help offset natural gas costs. The CHP installed costs were compared to those provided in the NREL analysis and were used along with the O & M costs for each technology in the economic analysis of the technologies.

For the NREL analysis, two types of fuel cells were used. The first fuel cell used was the UTC Power PureCell© Model 400. It provides up to a 400-kW electric output and can utilize natural gas or biogas as fuel. It is classified as a phosphoric acid fuel cell

(PAFC). The other fuel cell used was the FuelCell Energy (FCE) DFC 1500. It can provide up to a 1.4-MW electric output and can utilize natural gas or biogas as fuel. It is classified as a molten carbonate fuel cell (MCFC). For the NREL analysis, a 30 MGD WWTP serving 300,000 was used as an example. A plant operating at this capacity can produce an estimated 110 million SCF/year of biogas from their anaerobic digesters (Remick, 2009). The data provided in the table below for the NREL analysis of energy generation technologies will be scaled to meet the DWRF biogas production. This will provide an estimate on capacity and electricity production for an energy generation technology along with capital costs. The data is provided in Table 3.7.

Table 3.7. NREL Energy Generation Technology Analysis (derived from Remick, 2009)

110M SCF biogas per year				
Technology	**UTC PAFC**	**FCE MCFC**	**Microturbine**	**Recip. engine**
Capacity supported by biogas*	880 kW	1,100 kW	570 kW	470 kW
Electricity produced MW-hr/yr	7,700	9,150	5,000	4,110
Capital costs $/kW	$4,500	$4,300	$3,840	$2,870
Total Capital Cost	$3.96M	$4.73M	$2.19M	$1.35M
* Assumes full use of biogas without regard to generator unit size				

In Table 3.7, the capital costs (in $/kW) represent the cost of purchase of the technology, cost of installation of the technology at the plant, project management costs, and engineering costs. Most likely, the total capital cost in Table 3.7 will require a financial loan that would be paid over a duration of time thus increasing the actual cost of purchase due to interest.

A cost associated with the use of biogas for energy generation was the cost of an activated carbon adsorption system to remove siloxane. DWRF could choose not to remove siloxane from their biogas if it is determined that there is a minimal amount, but this could result in increased maintenance and shorter life for the energy generation technology. To avoid this, a carbon adsorption technology was added.

An estimate for the capital cost of a carbon adsorption technology to remove siloxane from biogas is $85 per kW (Pierce, 2004). This equates to $99.53 in 2011 dollars using a Gross Domestic Product (GDP) deflator method discussed later in Chapter 3.2.7. This extra capital cost was added into the economic analysis.

Not included in the economic analysis for the energy generation technologies are assumptions on labor costs associated with each technology. Ideally, plant operators will be able to operate and perform routine maintenance on the selected energy generation technology. There exists a possibility that increased man hours will be needed to maintain the energy generation technology which will result in an increase in labor costs. DWRF will need to factor this possibility into further analysis if an energy generation technology is shown to be economically viable in this analysis.

3.2.6. Savings on Electricity Costs from Energy Generation Technologies

The electricity production and capacities for the four technologies in Table 3.7 were utilized to provide an estimate on how much savings DWRF could expect from each technology. Average monthly values for electricity production were determined and then used to compute average monthly savings and an annual savings. An in-depth analysis using monthly data provided in Table 3.5 in Chapter 3.2.4 was completed to determine whether the average monthly values calculated for savings accurately represent the true savings and can be used in the economic analysis of the four energy generation technologies which followed.

3.2.7. Economic Analysis of Purchasing an Energy Generation Technology

An economic analysis needed to be completed to determine the viability of purchasing an energy generation technology and fueling it with DWRF biogas. To conduct the analysis, it was assumed that DWRF would take out a 20 year loan with an interest rate of 3.5% (DWRF personnel confirmed this as a typical scenario for a situation like this) to purchase the technology. Additionally, an inflation rate of 2.0% was used. The inflation rate was applied to both the savings from the energy generation technology along with the operation and maintenance (O & M) costs associated with each technology. In order to convert the capital and O & M cost values from 2008 dollars to 2011 dollars (information on 2012 has not been provided by the US Bureau of Economic Analysis), the GDP deflator for both years was calculated. The GDP is the total value of all final goods and services produced within an economy for a specified time period. The GDP deflator is a measure of the level of prices of all new, domestically produced, final goods and services in an economy. The GDP deflator was calculated utilizing the formula below.

$$\text{GDP Deflator} = (\text{Nominal GDP} / \text{Real GDP}) \times 100$$

The GDP deflator for 2011 was divided by the GDP deflator for 2008 and the resultant value was multiplied by costs in 2008 dollars. This resulted in the costs being adjusted into 2011 dollars.

For the initial analysis, only the savings as a result of the electric production from each technology was used. The possible savings from heating that each technology can provide was calculated using the electric heat rate for each technology. These savings were provided for selected technologies that were deemed economically viable. Furthermore, three cases were analyzed for each technology. These cases were predicated on varying capital and O & M costs for each technology. Typically, a range was provided for capital and O & M costs. The best case scenario provided relatively low capital and O & M costs based on information gathered from the EPA and NREL. The base case scenario provided an estimate utilizing typical capital and O & M costs and the worst case scenario provided high capital and O & M costs. The values used for the three cases are provided in Table 3.8.

Table 3.8. Capital and O & M Cost Ranges for Energy Generation Technologies (in 2008 Dollars)

Technology	Best Case (Capital - O & M)	Base Case (Capital - O & M)	Worst Case (Capital - O & M)
UTC PAFC	$4,000/kW - $0.032/kWh	$4,500/kW - $0.035/kWh	$5,000/kW - $0.040/kWh
FCE MCFC	$3,800/kW - $0.032/kWh	$4,300/kW - $0.035/kWh	$4,800/kW - $0.040/kWh
Microturbine	$2,400/kW - $0.012/kWh	$3,000/kW - $0.020/kWh	$3,840/kW - $0.030/kWh
Recip. Engine	$1,300/kW - $0.009/kWh	$2,000/kW - $0.018/kWh	$2,870/kW - $0.028/kWh

Table 3.8 provides the capital and O & M costs in 2008 dollars. These costs were converted to 2011 dollars utilizing the GDP deflator method described earlier in this section. Using data provided by the US Bureau of Economic Analysis, the nominal GDP for 2008 was 14,291.5 (in billions of current dollars) and the real GDP was 13,161.9 (in billions of chained dollars). The GDP deflator for 2008 equaled 108.58. The nominal GDP for 2011 was 15,087.7 (in billions of current dollars) and the real GDP was 13,313.4 (in billions of chained dollars). The GDP deflator for 2011

equaled 113.33. The capital and O & M costs converted to 2011 dollars are provided in Table 3.9.

Table 3.9. Capital and O & M Cost Ranges for Energy Generation Technologies (in 2011 Dollars)

Technology	Best Case (Capital - O & M)	Base Case (Capital - O & M)	Worst Case (Capital - O & M)
UTC PAFC	$4,176/kW - $0.033/kWh	$4,698/kW - $0.037/kWh	$5,220/kW - $0.042/kWh
FCE MCFC	$3,967/kW - $0.033/kWh	$4,489/kW - $0.037/kWh	$5,011/kW - $0.042/kWh
Microturbine	$2,506/kW - $0.013/kWh	$3,132/kW - $0.021/kWh	$4,009/kW - $0.031/kWh
Recip. Engine	$1,357/kW - $0.009/kWh	$2,088/kW - $0.019/kWh	$2,996/kW - $0.029/kWh

Using the ranges for capital and O & M costs provided in Table 3.9, the three cases were developed. As stated previously, the capital costs were amortized for a 20 year period at a 3.5% interest rate. The O & M costs increased by 2% each year for the 20 year period to account for inflation. The values were added together to provide a cost estimate for the various technologies. The total yearly savings determined as detailed in Chapter 3.2.6 for each technology were used as the first year savings on the project. The yearly savings increased by 2% each year for 20 years to account for inflation. The economic analysis was completed for all three cases.

As stated earlier, the electric heat rate can be used for energy generation technologies to determine the estimated heating provided. For microturbines, thermal energy contained in the exhaust gas can be used for various heating needs. Exhaust heat can be recovered and used for water heating, space heating, and driving thermally activated equipment such as an absorption chiller or a desiccant dehumidifier (EPA CHP Partnership, 2008). For reciprocating engines, heat can be recovered from the engine exhaust gas and cooling systems. The most common use of this heat is to generate hot water or low pressure steam for process use or for space heating, process needs, domestic hot water or absorption cooling (EPA CHP Partnership, 2008).

Using the low values for the electric heat rates for the energy generation technologies, the amount of therms produced on a yearly basis was calculated. This can be calculated by multiplying the electric production (in kWh) of each technology by the electric heat rate. This provided a heating value in Btu's which can be converted to therms by dividing the calculated value by 100,000. The amount of therms that the energy generation technologies can produce on a yearly basis was compared to the 2010 DWRF natural gas use (in therms) to determine the savings associated with the heating provided by these technologies. However, additional costs for added infrastructure to accomplish heating throughout the plant with heat generated from the energy generation technology needed to be incorporated into the economic analysis to determine the estimated savings. A sensitivity analysis for various capital costs for infrastructure additions to allow for the recovered heat from energy generation technologies to replace natural gas used for heating was conducted. This provided the estimated savings with a wide array of heating infrastructure costs added.

A carbon adsorption siloxane removal technology was selected to remove siloxane from biogas prior to being used as fuel by an energy generation technology. An estimate for the O & M cost (replacing the activated carbon media) of the siloxane removal technology is \$0.003 per kWh (Pierce, 2004). Using the GDP deflator method discussed previously, the O & M cost for a carbon adsorption siloxane removal technology is $0.0035 per kWh. This added O & M cost was incorporated into the economic analysis.

3.2.8. Economic Analysis of Food Waste Addition at DWRF

To further the analysis, implementing food waste addition into the plant's treatment process resulted in enhanced biogas production and thus resulted in further savings in energy costs. Using the information presented earlier for biogas production based on the various amounts of food waste added, further data was calculated showing the possible savings utilizing additional biogas production for electricity generation.

3.2.8.1. Costs for Food Waste Processing and Ancillary Equipment

DWRF does not currently have the capability of processing food waste for addition to their anaerobic digesters. In order to do this, DWRF will need to invest in pre-processing equipment along with determining the costs for transportation of the food waste. The EPA published a Co-Digestion Economic Analysis Tool (CoEAT) in 2010 with the objective of providing an initial economic feasibility assessment of food waste co-digestion with wastewater plant biosolids for the purpose of biogas production (EPA CoEAT, 2010). This model provides publicly available data on the emerging practice of food waste co-digestion at WWTPs and identifies various logistical and equipment considerations. CoEAT was used as a guide to determine the various expenses that are associated with trying to implement a food waste diversion program. For many of the preprocessing and ancillary equipment associated with food waste co-digestion, estimations on costs are provided based on research done by the Humboldt Waste Management Authority in California (EPA CoEAT, 2010). These values were compared with data gathered during this project to provide the best estimates for DWRF.

A list of the estimated expenses associated with trying to implement a food waste diversion and processing operation at DWRF are provided in Table 3.10.

Table 3.10. Capital Costs Associated with Food Waste Processing Operation (derived from EPA CoEAT, 2010)

Major Costs	Cost per unit ($/unit)	Units Needed	Total Cost ($)
Building ($/ft^2) w/ slab	$100	1000	$100,000
Odor Control System	$85,000	1	$85,000
H$_2$S Scrubber Tank	$5,000	1	$5,000
H$_2$S Scrubber Media (Sulfa Treat)	$5,760	1	$5,760
Pre-Processing Equipment	$450,000	1	$450,000
Metering Pumps	$40,000	2	$80,000
Pumps	$90,000	4	$360,000
Trommel Screen	$110,000	1	$110,000
Grinder/Shredder	$100,000	1	$100,000
Mixers	$40,000	2	$80,000
Gas Collection Equipment	$75,000	1	$75,000
FOG Receiving Station	$159,850	1	$159,850
20 Ton Food Waste Collection Trucks	$100,000	2	$200,000
55 Gallon Bins for Food Waste Collection	$150	100	$15,000
Engineering Planning & Design	$250,000	1	$250,000
Geotechnical Analysis	$17,500	1	$17,500
Land Preparation	$30,000	1	$30,000
Program Design	$100,000	1	$100,000
Yard Piping & Site Work	$225,000	1	$225,000
TOTAL CAPITAL COST		**$2,448,110**	

DWRF needs a building to house the food waste processing equipment. The most likely location for this building will be in the northwest area of the plant near the head works building and primary clarifiers. An odor control system will need to be purchased along with a hydrogen sulfide scrubber to minimize odors from the food waste processing. Primarily, it will be used to scrub odors from the food waste slurry tank where mixing occurs with recycled water. DWRF has various odor control systems throughout the plant for the various treatment processes and may be able to tie into those systems for savings.

The pre-processing equipment on-site at DWRF would include a slurry tank with a pump and mixer, a rock trap/grinder, and a paddle finisher. This layout would be very similar to both the EBMUD process and the proposed CMSA process. In Table 3.10, the pumps and mixers are broken out from the pre-processing equipment cost. As discussed in Chapter 1.5, CDPHE and A1 Organics are concluding testing in Colorado on a DODA urban organics processing unit that could suffice as a stand alone processing unit. This would replace the need for the equipment for pre-processing described above.

Another possible cost for food waste processing is the initial collection and processing of food waste off-site at a solid waste transfer facility. Both EBMUD and CMSA in California utilize a solid waste handling company to pick up their food waste and do the initial sorting and grinding of the food waste. The equipment needed for the initial processing include a trommel screen (listed in Table 3.10) and a grinder/shredder. A solid waste handling company may incur the cost of the equipment needed to be contracted by the city of Fort Collins to pick-up and handle food waste, but to be conservative the charges for the trommel screen and grinder/shredder are listed. DWRF and the city of Fort Collins may elect to add the trommel screen for sorting and grinder/shredder on-site at DWRF and conduct the initial processing of the food waste there.

An estimate for adding gas collection equipment and Fats, Oils, and Grease (FOG) receiving station are included in Table 3.10. FOG is a high value feedstock that requires separate handling and pre-processing. DWRF is very interested in receiving and processing FOG and with numerous restaurants in the Fort Collins area there is a plentiful supply. The EPA CoEAT provided an estimated breakdown of equipment needed and costs for a FOG receiving station. A FOG receiving station includes a tank (~ \$25,000), pumps (chopper and gravity pumps ~ \$10,000), tank pad (~\$12,000), heat exchanger (~\$5,000), agitator (~\$10,000), piping (~\$50,000), and electrical work (~\$27,000). A 15% installation and miscellaneous cost was added to arrive at the cost reported in Table 3.10. DWRF may elect not to add a FOG receiving station which would decrease the overall cost.

DWRF would need to purchase collection bins to provide to local restaurants, schools, hospitals, food suppliers, and supermarkets to dispose of their food waste. Currently, Clements Environmental Group are conducting a solid waste survey for the city of Fort Collins to determine the composition and quantity of solid waste going to the Larimer County Landfill. One of the categories being analyzed is food waste. Once the survey is completed, this information will help determine the largest food waste suppliers to the landfill and would be most amenable to diverting food waste from the landfill to DWRF. If DWRF and the city of Fort Collins contracts out the collection of food waste to a local solid waste handling company, then some of the cost may be reduced as a part of receiving a contract from the city.

Food waste collection trucks may be needed if the city and DWRF elect to collect food waste using their own resources. The city of Fort Collins does not have trucks that could collect solid waste and thus would need to purchase there own. Two 20-ton trucks should suffice for the collection of food waste. Again, if a solid waste handling company is contracted to collect food waste then the purchase of the two trucks is not needed.

Finally, in Table 3.10, various costs for engineering plan and design, construction type work, and food waste diversion program design are included. These costs capture the engineering, construction, and consulting work needed for a project of this scope. These charges either are estimates provide by the EPA CoEAT or from the CMSA methane capture feasibility study and CMSA Food Waste to Energy pre-design report.

The total capital cost to implement food waste diversion at DWRF on a full scale was approximately $2.45 million. O & M costs associated with diverting food waste will be discussed next along with the savings generated in energy generation and an economic analysis will be completed with food waste addition to the anaerobic digesters.

3.2.8.2 O & M Costs and Revenue Associated with Food Waste Processing

Implementing food waste diversion and processing has O & M costs linked to the transportation of food waste, processing of food waste, labor costs associated with processing of food waste, dewatering and disposal of solids created from food waste, and extra energy costs for the food waste facility and equipment. Some general assumptions needed to be made before determining O & M costs. These assumptions were derived from information provided in the CMSA Food Waste Facility pre-design document and the EPA CoEAT.

- Food waste will be delivered 300 days a year. 15 tons per day of food waste will be used for the initial calculations. The annual O & M costs and tipping fee revenue will be scaled for the various food waste addition amounts.
- DWRF will charge a tipping fee of $10/ton to accept the food waste. The landfill disposal fee averages around $13 to $14 per ton in Colorado (Biocycle, 2009).
- It will take approximately 1 operator hour to accept a truck load (ranging from 5 tons to 25 tons of food waste). It will take approximately 4 hours of maintenance staff time per month to maintain the facilities. For a year, this results in 413 extra O & M hours per year. The average fully burdened O & M rate is approximately $60/hour (CMSA, 2010).
- To account for extra dewatering electricity cost in the centrifuge, an extra run time of 0.5 hours per day is assumed.
- The extra energy costs for the food waste facility would result in an extra 20 kW of capacity needed and 60,000 kWh per year.
- Transportation costs are $0.18/ton-mile with one 20 ton truck operating a day with an average of 30 miles/trip. Both transportation costs associated with the collection of food waste and land application disposal at the ranch property DWRF owns will be included. DWRF personnel only make 2-3 trips a week to land apply dewatered biosolids with an estimated 60 miles round trip. Most likely, only one additional trip would be needed.

- Added O & M costs for the anaerobic digesters will be assumed to be minimal and captured within the various other costs of the project.
- If the city of Fort Collins and DWRF contract a solids handling company to collect food waste and deliver it to DWRF, then an additional cost relating to the contract will need to be added. An estimate for this type of contract will not be analyzed.

Using the assumptions listed, the annual O & M costs related to food waste collection and processing along with the tipping fee revenue were calculated. The results are shown in Table 3.11.

Table 3.11. Annual O & M Costs for Food Waste Transportation and Processing (15 tons of food waste per day)

Variable	$/Unit	Annual Costs/Revenue
Tipping Fee Revenue	$10/ton	$54,750
Annual Transportation Costs	$0.18/ton-mile	$32,400
Annual Labor Costs	$60/hour	$24,780
Annual Electricity Costs	$/kWh	$5,476
ANNUAL O & M COSTS		**$7,626**

With the revenue generated from tipping fees, the annual O & M costs were significantly reduced thus making them relatively small. To complete the economic analysis for food waste addition at DWRF, the total capital cost in Table 3.10 and the annual O & M costs in Table 3.11 (scaled for amount of food waste added per day) were incorporated in with the additional electricity savings associated generated from the additional biogas generated from food waste in the DWRF anaerobic digesters.

3.2.9 Triple Bottom Line Analysis of Food Waste Addition at DWRF

The economic analysis is only one part of a triple bottom line (TBL) analysis. A TBL analysis incorporates both the environmental and social benefits and impacts along with the economic analysis. This approach provides a way of evaluating options that takes into account more than just financial cost or value by incorporating indicators of social and environmental benefits, to provide a more holistic understanding (Peace River Regional District, 2008). Some environmental factors that were included in the analysis are annual food waste diversion from the Larimer County Landfill, greenhouse gas reduction potential in metric tons of carbon dioxide equivalent utilizing the EPA Waste Reduction Model (WARM), and landfill space savings. Social factors that were included in the TBL analysis are the accessibility and convenience of the food waste diversion program, the ability to equitably implement the program throughout Fort Collins, and possible reduction in wastewater treatment rates for customers.

3.3. VALUE OF METHANE GAS AND NATURAL GAS FOR HEATING

Using information provided in Chapters 3.2.1, 3.2.2, and 3.2.3, the value of methane gas and natural gas for heating at DWRF can be quantified and monetized. This will provide important financial information into the value of methane gas derived from DWRF anaerobic digester gas for heating, along with the value of methane gas that is flared into the atmosphere. Additionally, using the natural gas use for DWRF in 2010, the savings associated with replacing natural gas use with methane gas for heating can be determined.

3.3.1. Methane Gas Use at DWRF in 2010

DWRF provided information on methane use which is shown in Table 3.3 in Chapter 3.2.1. This information reported can be compared to the biogas production based on 2010 DWRF anaerobic digester data to verify the calculations made for biogas and methane gas production in Chapter 2.5.2. The biogas production in the DWRF anaerobic digesters in 2010 was calculated to be 167,717 ft^3/day (reported in Table 2.6). This value can be multiplied by 365 days to get a yearly production and then multiplied by 65% which represents the typical methane concentration in digester gas. This calculation results in the estimation that the DWRF anaerobic digesters in 2010 produced 39,790,858 ft^3 of methane. This estimated value when compared to the 2010 methane use provided in Table 3.3 is approximately 9 million ft^3 less. 12 ft^3 of gas produced per pound of VS destroyed, which is the low end of the range for estimating digester gas production, was used to estimate the gas production for 2010 in the DWRF anaerobic digesters. If 14.5 ft^3 of gas produced per pound of VS destroyed is used to estimate the gas production for DWRF in 2010 instead of 12 ft^3 of gas produced per pound of VS destroyed, the estimated gas produced is equal to 48,653,926 ft^3. This estimate is approximately 300,000 ft^3 less than the methane production reported in Table 3.3 for DWRF in 2010. Also, the methane content of DWRF digester gas could be higher than 65% of biogas produced. If the methane content of DWRF digester gas contained 80% methane and the low end estimation of 12 ft^3 of gas produced per pound of VS are used, the estimated 2010 DWRF anaerobic digester methane gas production equaled 48,973,364 ft^3 of methane gas. This is less than a 5000 ft^3 difference between the values. Most likely, a combination of these two estimation parameters being higher would be the scenario that results in the most accurate estimation of biogas and methane gas production in the DWRF anaerobic digesters. However, in order to maintain a conservative estimate of gas production, the parameters for methane content and gas production based on pounds of VS destroyed will remain at 65% and 12 ft^3 of gas per pound of VS destroyed respectively.

3.3.2. Heating Provided from Methane and Natural Gas Use at DWRF

The methane use provided in Table 3.2 was converted into a unit of heating, therms, by the method described in Chapter 3.2.2. Table 3.12 shows the amount of equivalent therms for both methane gas used in the DWRF boilers and methane gas flared into the atmosphere.

Table 3.12. 2010 DWRF Therms Produced from Methane Gas

Methane Use	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010
Boiler (therms)	19,045	20,795	14,766	18,399	14,455	12,893
Waste Flare (therms)	254	1,103	7,507	11,348	13,351	14,464
Methane Use	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
Boiler (therms)	9,630	4,700	1,126	14,685	15,439	17,773
Waste Flare (therms)	14,257	17,040	18,146	17,348	10,236	5,109
2010 Total Therms Produced = 293,869 therms						
2010 Boiler Use = 163,706 therms / 2010 Waste Flare = 130,163 therms						

For comparison, data for natural gas use for DWRF in 2010 was provided. The data provided was broken into the various uses within the plant. The majority of the natural gas went towards boiler use to heat various processes. For simplicity, the 2010 monthly natural gas use for DWRF summed up from the various categories of use are shown in Table 3.13 below.

Table 3.13. 2010 DWRF Therms Produced from Natural Gas

Nat. Gas Use	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010
DWRF (therms)	20,439	16,761	14,328	3,346	1,577	1,171
Nat. Gas Use	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
DWRF (therms)	900	1,004	1,011	1,309	13,806	14,286
2010 Total Therms Produced = 89,938 therms						

To provide a visual comparison of methane use versus natural gas use, a chart was created comparing on a monthly basis natural gas use, methane gas use for boilers, and methane gas that is flared. The 2010 DWRF data was used for the comparison and therms were used as the unit of comparison. This comparison is shown below in Figure 3.2.

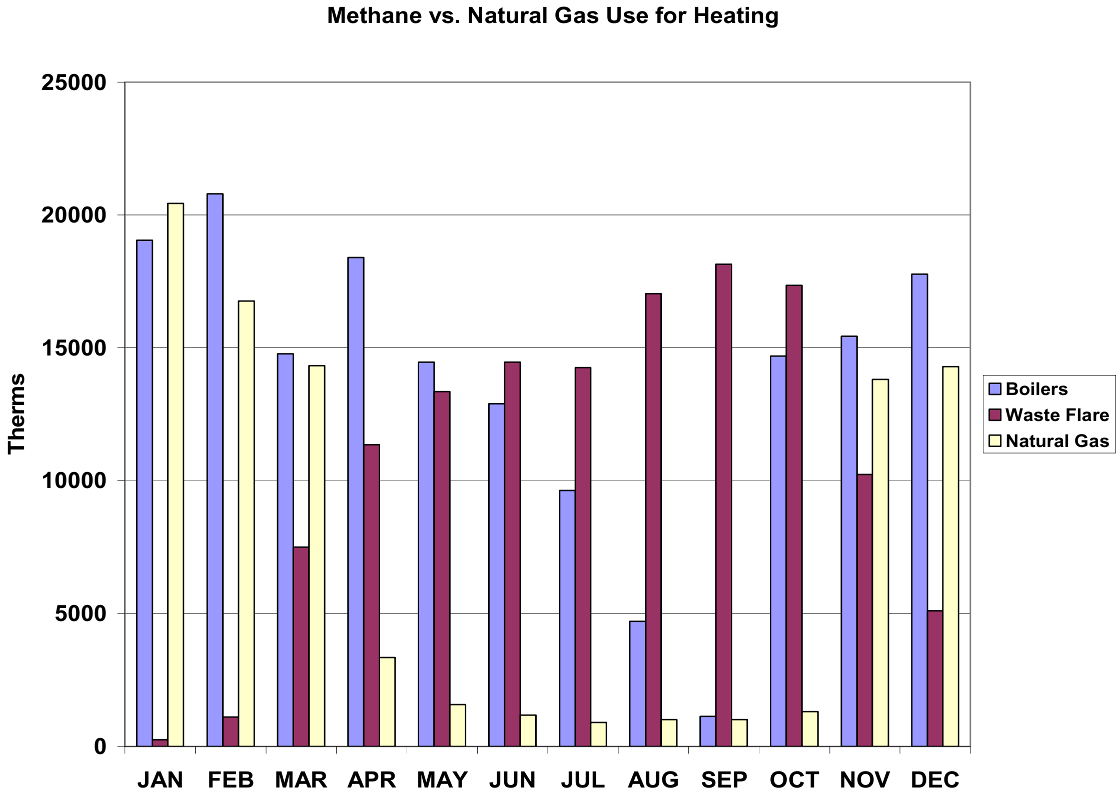

Figure 3.2. Comparison of Methane Gas vs. Natural Gas Use at DWRF

Figure 3.2 shows the trend of methane being used for heating during the winter months and being supplemented by natural gas to meet the heating needs of the plant. The warmer months shows that methane is primarily flared into the atmosphere and natural gas use is relatively small. For 2010, methane gas produced an estimated 163,706 therms for the DWRF boilers and natural gas produced 89,938 therms. The percentage of heating accomplished by boilers using methane gas was calculated to equal 64.54%. Additionally, the percentage of methane produced that was flared equaled 44.29%.

3.3.3. Estimating Monetary Value of Natural and Methane Use at DWRF

Using the rate structure for natural gas (in therms) provided in Chapter 3.2.3 along with 2010 DWRF methane and natural gas use (in therms) provided in Tables 3.12 and 3.13, the estimated cost for natural gas use, savings associated with methane use for heating, and the value of the flared methane gas at DWRF could be calculated. The estimated cost of natural gas use in 2010 at DWRF is provided in Table 3.14.

Table 3.14 Estimated 2010 DWRF Natural Gas Cost

Nat. Gas Use	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010
Cost ($)	$14,572	$11,960	$10,233	$2,436	$1,180	$891
Nat. Gas Use	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
Cost ($)	$699	$773	$772	$989	$9,862	$10,203
2010 Total Natural Gas Cost = $64,576						

As noted previously, this estimation for natural gas cost was made using the new rate structure. If DWRF could reduce their 12 month natural gas use to less than 50,000 therms (or 5000 dekatherms), they would qualify under the commercial – small gas service rate schedule. This rate schedule does not have a capacity charge which is a significant amount of the natural gas cost in the commercial – large gas service rate schedule. Instead of paying $7.14 per dekatherm under the commercial – large gas service rate schedule, DWRF could pay $6.59 per dekatherm under the commercial – small gas service rate schedule. They would need to reduce their 12 month usage by approximately 40,000 therms (or 4000 dekatherms). DWRF would need to improve and possibly add boilers to improve their heating efficiency and capacity along with looking into technologies to store methane gas for colder months.

The 2010 total and monthly cost savings associated with utilizing methane gas to fuel their boilers is provided in Table 3.15 below.

Table 3.15. Estimated 2010 DWRF Methane Boiler Use Savings

Methane Boiler Use	**Jan 2010**	**Feb 2010**	**Mar 2010**	**Apr 2010**	**May 2010**	**Jun 2010**
Savings ($)	$13,522	$14,765	$10,484	$13,064	$10,263	$9,154
Methane Boiler Use	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
Savings ($)	$6,387	$3,337	$799	$10,426	$10,961	$12,619
2010 Total Methane Boiler Use Savings = $116,231						

Based on Table 3.15, DWRF saves over $100,000 a year by using methane gas produced from their anaerobic digesters to fuel their boilers used for heating. This is significantly more than the estimated cost of natural gas use in 2010 at DWRF. However, due to the variability of heating needs based on outside air temperatures and weather, DWRF produces excess methane gas that has monetary value that they cannot use. The monetary value associated with methane gas flared into the atmosphere in 2010 at DWRF is provided in Table 3.16.

Table 3.16. Estimated 2010 DWRF Flared Methane Value

Methane Flared	**Jan 2010**	**Feb 2010**	**Mar 2010**	**Apr 2010**	**May 2010**	**Jun 2010**
Value ($)	$181	$783	$5,330	$8,057	$9,479	$10,269
Methane Flared	**Jul 2010**	**Aug 2010**	**Sep 2010**	**Oct 2010**	**Nov 2010**	**Dec 2010**
Value ($)	$10,122	$12,098	$12,884	$12,317	$7,268	$3,627
2010 Total Methane Flared Value = $92,416						

DWRF in 2010 flared methane gas with an estimated heating value of $92,416 based on therms that this methane gas could produce. This issue is prevalent in wastewater treatment plants with anaerobic digestion systems throughout the United States. The cost to put in infrastructure to transport biogas from the anaerobic digesters to potential users in the vicinity of the plant is high. In Colorado, the Littleton/Englewood WWTP, located Southwest of Denver, did transport biogas to users in the vicinity of the plant to generate revenue. However, the costs associated with transporting the biogas eventually outweighed the revenue generated and the Littleton/Englewood WWTP stopped transporting biogas in favor of flaring the gas into the atmosphere. For DWRF to try to find a market for their excess biogas to generate revenue would be difficult. The city of Fort Collins would need to invest a large amount of money in either pipelines or some other form of gas transportation along with finding potential buyers.

DWRF should look into the possibility of purchasing a methane gas storage bladder or a similar technology. If DWRF can store methane gas from the warmer months and use that gas to offset natural gas use in the winter months, then they can significantly reduce the costs associated with natural gas use. This would require adding to the infrastructure of the plant and a large capital investment but could provide a payback in possibly 10-15 years. DWRF personnel are currently looking at ways to use the biogas produced from their anaerobic digesters more efficiently to reduce their natural gas use and amount of biogas flared at the plant. By optimizing boiler operations, they should be able to improve on the percentage of heating fueled by methane gas in the future.

3.4. SAVINGS ON ELECTRICITY COSTS FROM ENERGY GENERATION TECHNOLOGIES

Utilizing the electric rate structure and data provided in Tables 3.4 and 3.5 in Chapter 3.2.4., the savings associated with the use of various energy generation technologies to produce electricity for plant use utilizing anaerobic digester biogas can be calculated. Table 3.7 in Chapter 3.2.5 provides the NREL energy generation technology analysis data that will be used to size the various technologies based on biogas available as fuel.

For the NREL analysis, a 30 MGD WWTP serving 300,000 was used as an example. A plant operating at this capacity can produce an estimated 110 million SCF/year of biogas from their anaerobic digesters (Remick, 2009). DWRF serves a large portion of the approximately 150,000 residents of Fort Collins and typically operates at a wastewater inflow of 11-12 MGD, but receive solids from the Mulberry WRF for treatment in the DWRF anaerobic digesters which increase the biogas production. In 2010, DWRF produced approximately 49 million SCF of methane from their anaerobic digesters. Using the conversion rate of methane comprising 65% of biogas, DWRF produced approximately 75 million SCF of biogas in 2010. In the table below, the values associated with the NREL analysis are provided along with those values scaled to model DWRF’s 2010 biogas production. The efficiency of each technology is incorporated in the analysis.

Table 3.17. NREL Energy Generation Technology Analysis (derived from Remick, 2009)

110M SCF biogas per year (NREL) / 75M SCF biogas per year (DWRF)				
Technology	**UTC Fuel Cell**	**FCE Fuel Cell**	**Micro- turbine**	**Recip. engine**
Capacity supported by biogas*	880 kW / 600 kW	1,100 kW / 750 kW	570 kW / 389 kW	470 kW / 320 kW
Energy produced MW-hr/yr	7,700 / 5,250	9,150 / 6,239	5,000 / 3,409	4,110 / 2,802
Capital costs $/kW	$4,500	$4,300	$3,840	$2,870
Total Capital Cost	$3.96M / $2.7M	$4.73M / $3.23M	$2.19M / $1.49M	$1.35M / $918K
* Assumes full use of biogas without regard to generator unit size				

Table 3.17 provides information on the option of DWRF utilizing all of their biogas towards fueling energy generation technology for electricity production. At this time that is not feasible but evaluating how much return they could get on utilizing flared biogas to power an energy generation technology would be a reasonable alternative.

3.4.1. Utilization of DWRF Flared Biogas for Electricity Generation

In 2010, DWRF flared approximately 21.7 million SCF of methane which equates to 33.4 million SCF of biogas using the conversion of methane comprising 65% of digester gas. For this analysis, the four energy generation technologies will be evaluated to provide perspective. The microturbine would be the preferred energy generation technology if DWRF are approved for a grant that will help offset the purchase cost of the microturbine. However, they may be able to apply for a grant for one of the other energy generation technologies thus making it worth evaluating all of them. The table below displays the results of setting the amount of biogas available for use by the various energy generation technologies equal to the amount of biogas flared at DWRF during 2010.

Table 3.18. Electricity Generation Analysis Utilizing 2010 DWRF Flared Biogas

33.4M SCF biogas flared per year (DWRF)				
Technology	**UTC PAFC**	**FCE MCFC**	**Microturbine**	**Recip. engine**
Capacity supported by biogas*	267 kW	334 kW	173 kW	143 kW
Energy produced MW-hr/yr	2,338	2,778	1,518	1,248
Capital costs $/kW	$4,500	$4,300	$3,840	$2,870
Total Capital Cost	$1.20M	$1.44M	$665K	$410K
* Assumes full use of biogas without regard to generator unit size				

In order to provide an estimate on how much DWRF can save per month and annually on electric costs utilizing the various technologies, the energy produced (in MW-hr/yr) by each technology needed to be converted to a monetary value based on the 2012 DWRF electric rate structure. The amount of energy produced from the four technologies in kW-hr/month is provided in Table 3.19.

Table 3.19. Monthly Electricity Production from Various Technologies Utilizing DWRF Flared Biogas

Technology	UTC PAFC	FCE MCFC	Microturbine	Recip. engine
Electricity Produced (kWh/ month)	194,833	231,500	126,500	104,000

Table 3.19 provides an estimation of the monthly power production from DWRF flared biogas. Due to the monthly variation of biogas use at DWRF, the actual power production would not be spread evenly for the year. For the months with lower flared biogas the energy generation technology would be run for much shorter periods of

time producing less than the estimated monthly power production and for warmer months the energy generation technology would produce more than the estimated monthly power production. However, since the total amount of biogas used for the year remains unchanged, using the monthly electricity production in Table 3.19 is suitable and will be verified later.

In this analysis, consumption will be analyzed which is the energy costs for summer and winter along with the demand reduction of the coincident peak and facilities distribution demands. The average savings per month and annual savings on electric costs for the four energy production technologies based on the 2012 DWRF electric rate structure and results are presented in Table 3.20.

Table 3.20. Average Monthly and Yearly Savings for Utilization of DWRF Flared Biogas to Produce Electricity

Technology	UTC PAFC	FCE MCFC	Micro-turbine	Recip. Engine
Savings (summer) / month (% Savings)	$10,391 (21.12%)	$12,572 (25.55%)	$6,742 (13.70%)	$5,553 (11.29%)
Savings (non-summer) / month (% Savings)	$9,707 (19.73%)	$11,717 (23.82%)	$6,299 (12.80%)	$5,187 (10.54%)
Total Yearly Savings (% Savings)	$118,538 (20.08%)	$143,164 (24.25%)	$76,914 (13.03%)	$63,341 (10.73%)

The results in Table 3.20 are the average savings DWRF could achieve from various energy producing technologies utilizing excess biogas that is not applied to heating. The percentage in parenthesis for each technology indicates the percentage of savings when compared to the electric costs provided in Table 3.5. Due to the monthly variation of biogas production, a more in-depth analysis utilizing the actual monthly data for electricity use in 2011 at DWRF was completed to provide a more accurate picture of savings on a monthly basis. Table 3.21 provides the electricity production on a monthly basis based on flared biogas.

Table 3.21. Monthly Power Production for Energy Generation Technologies

Date	DWRF Energy (kWh)	UTC PAFC (kWh)	FCE MCFC (kWh)	Micro-turbine (kWh)	Recip. Engine (kWh)
1-Dec-11	910,000	4,566 (0.50%)	5,425 (0.60%)	2,965 (0.33%)	2,437 (0.27%)
1-Nov-11	971,600	19,805 (2.18%)	23,532 (2.59%)	12,859 (1.41%)	10,571 (1.16%)
1-Oct-11	938,000	134,734 (14.81%)	160,090 (17.59%)	87,479 (9.61%)	71,920 (7.90%)
1-Sep-11	985,600	203,689 (22.38%)	242,023 (26.60%)	132,250 (14.53%)	108,727 (11.95%)
1-Aug-11	904,400	239,626 (26.33%)	284,723 (31.29%)	155,583 (17.10%)	127,910 (14.06%)
1-Jul-11	929,600	259,603 (28.53%)	308,459 (33.90%)	168,553 (18.52%)	138,573 (15.23%)
1-Jun-11	985,600	255,898 (28.12%)	304,057 (33.41%)	166,148 (18.26%)	136,596 (15.01%)
1-May-11	946,400	305,846 (33.61%)	363,405 (39.93%)	198,578 (21.82%)	163,257 (17.94%)
1-Apr-11	980,000	325,693 (35.79%)	386, 988 (42.53%)	211,464 (23.24%)	173,852 (19.10%)
1-Mar-11	938,000	311,370 (34.22%)	369,969 (40.66%)	202,165 (22.22%)	166,206 (18.26%)
1-Feb-11	1,016,400	183,723 (20.19%)	218,299 (23.99%)	119,286 (13.11%)	98,069 (10.78%)
1-Jan-11	1,022,000	91,700 (10.08%)	108,957 (11.97%)	59,538 (6.54%)	48,949 (5.38%)
TOTAL		2,336,251 (20.27%)	2,775,927 (24.08%)	1,516,867 (13.16%)	1,247,069 (10.82%)

In Table 3.21, the percentage in parenthesis represents the monthly amount of electricity production each technology would provide at DWRF based on the 2011 power production. The total values at the bottom of the table represent the power production for each technology in kWh for the year. In Table 3.18, the value of electricity production for each technology is reported in MWH/yr. These values can be compared to those reported in Table 3.21 for the year. On average, the values in Table 3.21 are 2 MWH/yr lower than those reported in Table 3.18. This difference is less than 0.5% and is relatively insignificant.

The monthly savings can be calculated using the monthly electricity production and the demand reduction for coincident peak and facilities distribution based on the capacity (in kW) of each energy generation technology. The monthly and annual savings generated from each technology is provided in Table 3.22 below.

Table 3.22. Monthly Savings for Energy Generation Technologies

Date	UTC PAFC (kWh)	FCE MCFC (kWh)	Micro-turbine (kWh)	Recip. Engine (kWh)
1-Dec-11	$3,067	$3,827	$1,987	$1,642
1-Nov-11	$3,599	$4,459	$2,333	$1,926
1-Oct-11	$7,610	$9,224	$4,937	$4,067
1-Sep-11	$11,067	$13,375	$7,180	$5,914
1-Aug-11	$12,385	$14,942	$8,037	$6,618
1-Jul-11	$13,119	$15,813	$8,513	$7,009
1-Jun-11	$11,839	$14,249	$7,683	$6,324
1-May-11	$13,582	$16,320	$8,814	$7,255
1-Apr-11	$14,274	$17,143	$9,264	$7,625
1-Mar-11	$13,774	$16,549	$8,940	$7,358
1-Feb-11	$9,320	$11,256	$6,047	$4,980
1-Jan-11	$6,108	$7,440	$3,962	$3,266
TOTAL	$119,743	$144,595	$77,696	$63,984

The total savings reported in Table 3.22 can be compared to the total savings reported in Table 3.20. On average, there is a $1000 difference in savings which equates to less than a 1% difference in the values. Thus, it can be safely assumed that the average values for monthly and annual power production and monthly and annual savings reported in Tables 3.19 and 3.20 are representative and can be used in an economic analysis. Since the annual savings associated with each technology utilizing DWRF monthly data was determined in Table 3.22, the yearly savings will be used for the economic analysis to follow.

3.5. ECONOMIC ANALYSIS OF PURCHASING AN ENERGY GENERATION TECHNOLOGY

Following the methods and procedures to conduct the economic analysis of purchasing an energy generation technology fueled by biogas detailed in Chapter 3.2.7, the analysis was completed. Data was used from Tables 3.18 thru 3.22 to complete the analysis for the various cases.

3.5.1. Economic Analysis for Electricity Generation

The initial analysis was conducted only using the various technologies to produce electricity. The pertinent data for the economic analysis for electricity generation for the best case scenario is provided in Table 3.23 below.

Table 3.23. Economic Analysis of Electricity Generation with DWRF Flared Biogas (Best Case)

Parameter	UTC PAFC	FCE MCFC	Microturbine	Recip. Engine
Production (kWh)	2,338,000	2,778,000	1,518,000	1,248,000
Capacity (kW)	267	334	173	143
1st Year Savings	$119,743	$144,595	$77,696	$63,984
20 Year Savings	$2,909,440	$3,513,278	$1,887,808	$1,554,643
Initial Capital Cost	$1,141,567	$1,358,288	$450,687	$208,312
20 Year Capital Cost	$2,271,476	$2,702,706	$896,773	$414,498
1st Year O & M Cost	$86,291	$102,530	$24,331	$16,094
20 Year O & M Cost	$2,096,642	$2,491,220	$591,167	$391,047
20 Year Cost	$4,368,118	$5,193,926	$1,487,940	$805,545
20 Year Revenue/Deficit	**$1,458,678**	**$1,680,647**	**$399,868**	**$749,098**

As Table 3.23 shows, purchasing a microturbine or reciprocating engine would be financially viable while both fuel cells would cause DWRF to lose money over the 20 year period. Due to their high capital and O & M costs and the results from the best case option, fuel cells are effectively eliminated from consideration for use for energy generation at DWRF.

To illustrate and determine the payback period on the microturbine and reciprocating engine, a cumulative cash flow chart was created. This chart shows in what year DWRF can expect to payback the cost of the technology and begin to see a profit on their investment. The cumulative cash flow chart is shown in Figure 3.3 for the best case options for the microturbine and reciprocating engine.

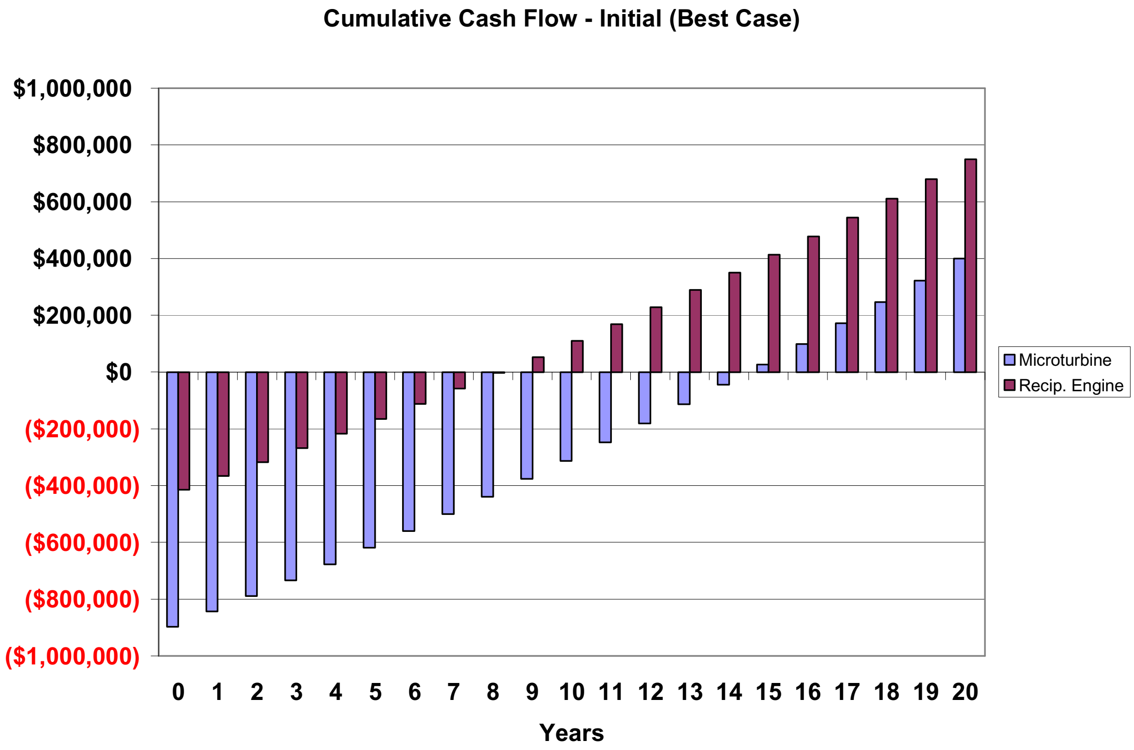

Figure 3.3. Cumulative Cash Flow for Electric Generation with DWRF Flared Biogas (Best Case)

In Figure 3.3, the total capital cost for the 20 years is the start point in year 0. Each year after that point, the yearly savings and O & M costs are incorporated into the cash flow. For the reciprocating engine, DWRF can expect to payback the cost in 9 years. From that point on, DWRF will be netting a profit on their investment. For the microturbine, DWRF can expect to payback the cost in 15 years. Both technologies would provide DWRF with a positive return on their investment over the 20 year period with the reciprocating engine providing a larger return due to the lower capital cost.

The same analysis was completed for the base case option which represents the average capital and O & M cost associated with each technology. The results of this analysis are provided in Table 3.24 and Figure 3.4 below.

Table 3.24. Economic Analysis of Electric Generation with DWRF Flared Biogas – Base Case

Parameter	Microturbine	Recip. Engine
Production (kWh)	1,518,000	1,248,000
Capacity (kW)	173	143
1st Year Savings	$77,696	$63,984
20 Year Savings	$1,887,808	$1,554,643
Initial Capital Cost	$559,055	$312,817
20 Year Capital Cost	$1,112,401	$622,439
1st Year O & M Cost	$37,009	$27,820
20 Year O & M Cost	$899,217	$675,963
20 Year Cost	$2,011,618	$1,298,402
20 Year Revenue/Deficit	**$123,810**	**$256,241**

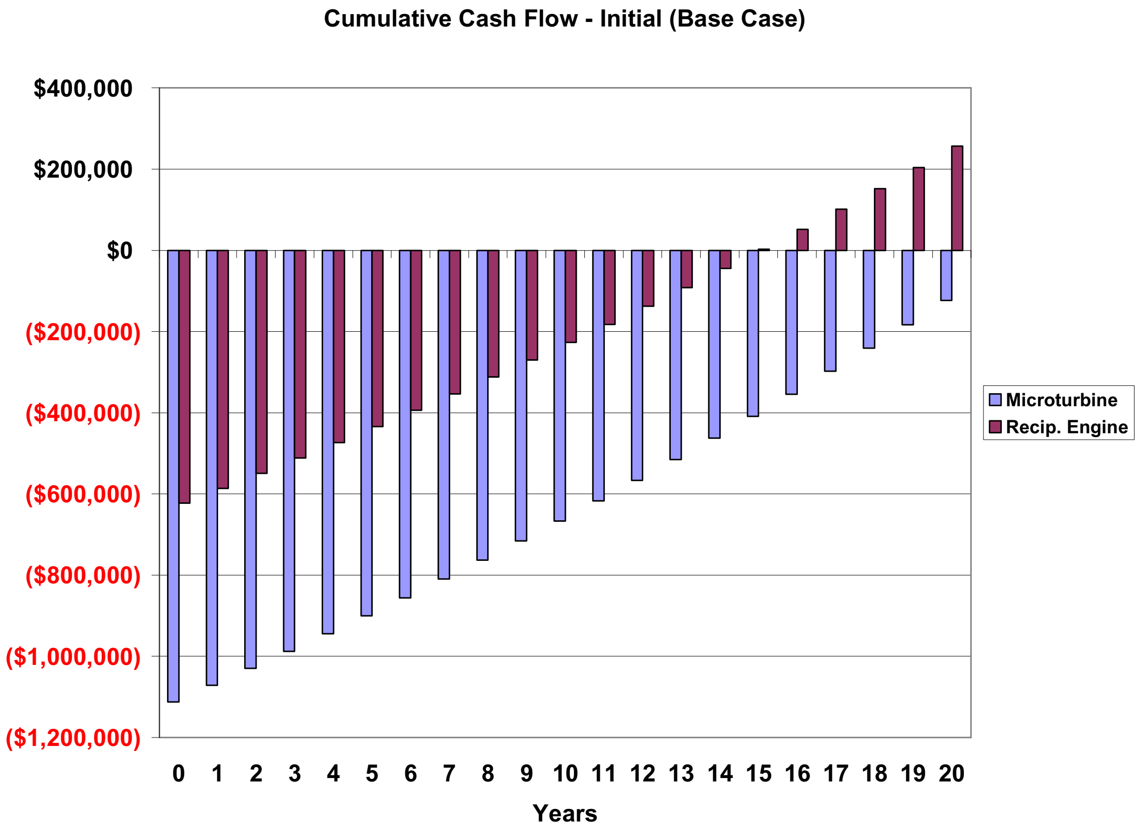

Figure 3.4. Cumulative Cash Flow for Electric Generation with DWRF Flared Biogas (Base Case)

As shown in Table 3.24 and Figure 3.4, only the reciprocating engine technology would provide a return on investment for DWRF over the 20 year period. The payback on the reciprocating engine would begin in year 15. With only a net return of $256,241 on the reciprocating engine, this option may not be economically viable.

The analysis on the worst case option was conducted with high capital and O & M costs. The results for this analysis are provided in Table 3.25 and Figure 3.5.

Table 3.25. Economic Analysis of Electric Generation with DWRF Flared Biogas (Worst Case)

Parameter	Microturbine	Recip. Engine
Production (kWh)	1,518,000	1,248,000
Capacity (kW)	173	143
1st Year Savings	$77,696	$63,984
20 Year Savings	$1,887,808	$1,554,643
Initial Capital Cost	$710,769	$442,701
20 Year Capital Cost	$1,414,280	$880,881
1st Year O & M Cost	$52,857	$51,792
20 Year O & M Cost	$1,284,280	$1,258,409
20 Year Cost	$2,698,560	$2,139,291
20 Year Revenue/Deficit	**$810,752**	**$584,648**

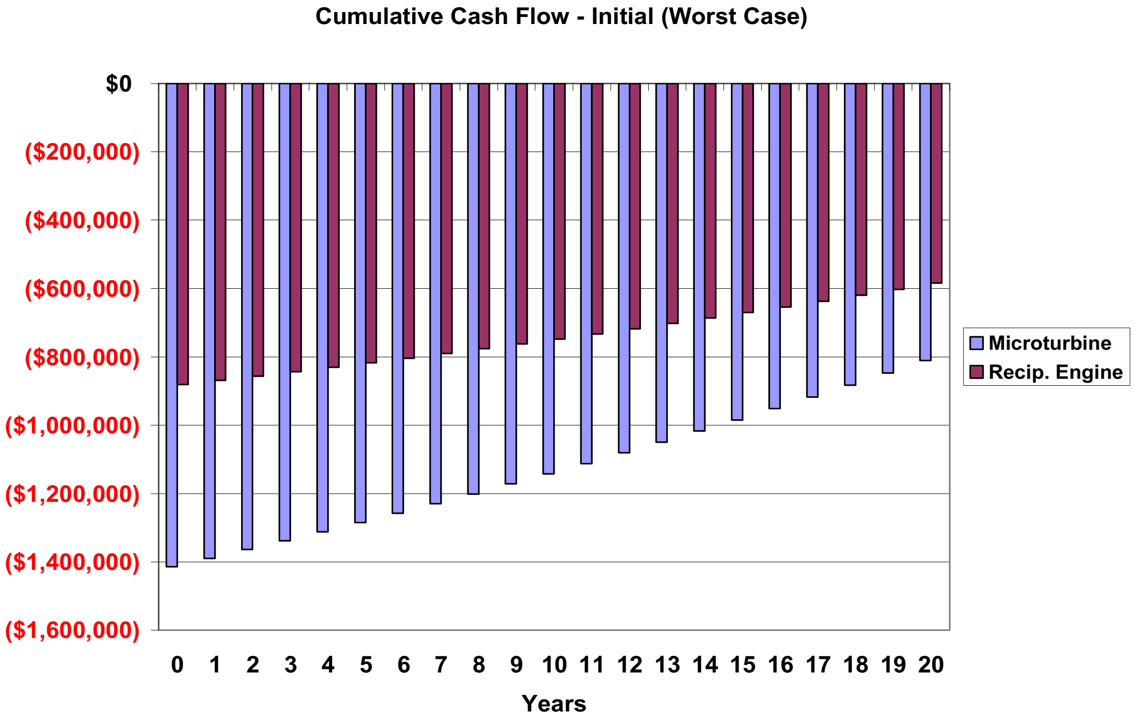

Figure 3.5. Cumulative Cash Flow for Electric Generation with DWRF Flared Biogas (Worst Case)

For the worst case option, neither technology will provide DWRF with a return on investment when evaluating the electricity production only. Thus at the worst case capital and O & M costs, DWRF should not invest in either energy generation technology based on the economic analysis for electricity generation.

3.5.2. Economic Analysis for Electricity and Heating Generation

As outlined in Chapter 3.2.5, the energy generation technologies produce electricity and heat that can be recovered and utilized to meet a variety of heating needs. The low end values of the electric heat rate for a microturbine and reciprocating engine found in Table 3.6 in Chapter 3.2.5 were used to determine the therms per year that both could produce. The results of the heating production for the microturbine and the reciprocating engine are provided in Table 3.26.

Table 3.26. Annual Heating Production of Microturbine and Reciprocating Engine

	Microturbine	**Recip. Engine**
Electric Heat Rate (Btu/kWh)	13,080	8,022
Electric Production (kWh)	1,518,000	1,248,000
Therms/year	198,554	100,115

The natural gas used at DWRF in 2010 produced 89,938 therms for heating needs (shown in Table 3.13). Both the microturbine and the reciprocating engine would produce enough therms to eliminate the need for natural gas. The estimated cost of the natural gas use reported in Table 3.14 was estimated to equal $64,576. If this annual heating savings is extrapolated out over 20 years with a 2% inflation rate, the total savings in replacing natural gas with heat produced from a microturbine or reciprocating engine equals $1.57 million. In order to replace natural gas use for heating with recovered heat from an energy generation technology, infrastructure needs to be added to DWRF. The infrastructure will include pipes, heat exchangers, valves, and other equipment to transport the recovered heat to be utilized for heating needs. An estimate of $100,000 for heating infrastructure additions was made and added to the initial capital cost of the energy generation technology. The net benefit of utilizing an energy generation technology that can provide enough heat to replace natural gas use for heating is shown in the table below.

Table 3.27. Net Benefit of Utilization of Flared Biogas for Energy Generation (Heating and Electricity)

Options	20 Year Costs (Microturbine / Recip. Engine)	20 Year Savings (Microturbine / Recip. Engine)	Net Benefit (Microturbine / Recip. Engine)
Best Case	$1,686,919 / $1,004,523	$3,456,835 / $3,123,670	**$1,769,916 / $2,119,146**
Base Case	$2,210,597 / $1,497,381	$3,456,835 / $3,123,670	**$1,246,238 / $1,626,289**
Worst Case	$2,897,539 / $2,338,269	$3,456,835 / $3,123,670	**$559,296 / $785,400**

This significantly improves the economics for all cases and makes this a very economically viable project to undertake. The payback period on the microturbine is 12 years and the payback period on the reciprocating engine is 8 years for the base case scenario. The cumulative cash flow chart for the base case is provided below to demonstrate the significant returns that DWRF can attain on their investment.

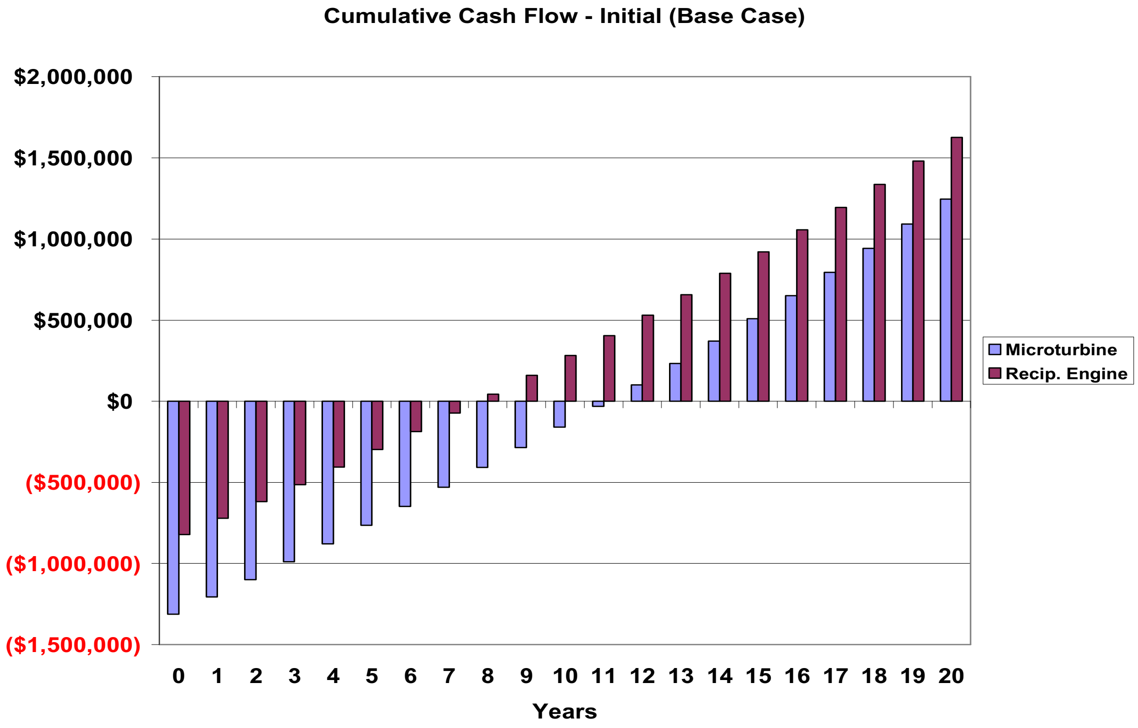

Figure 3.6. Cumulative Cash Flow for Energy Generation with DWRF Flared Biogas (Heating and Electricity)

Due to the difficulty of estimating costs associated with adding infrastructure for the use of recovered heat from the energy generation technologies, a sensitivity analysis was conducted. The cost for heating infrastructure addition was varied from $50,000 to $500,000. The base case scenario was used in the analysis with only the heating infrastructure costs being varied. The results of the sensitivity analysis for heating infrastructure addition costs are shown in Figure 3.7 for both the microturbine and reciprocating engine.

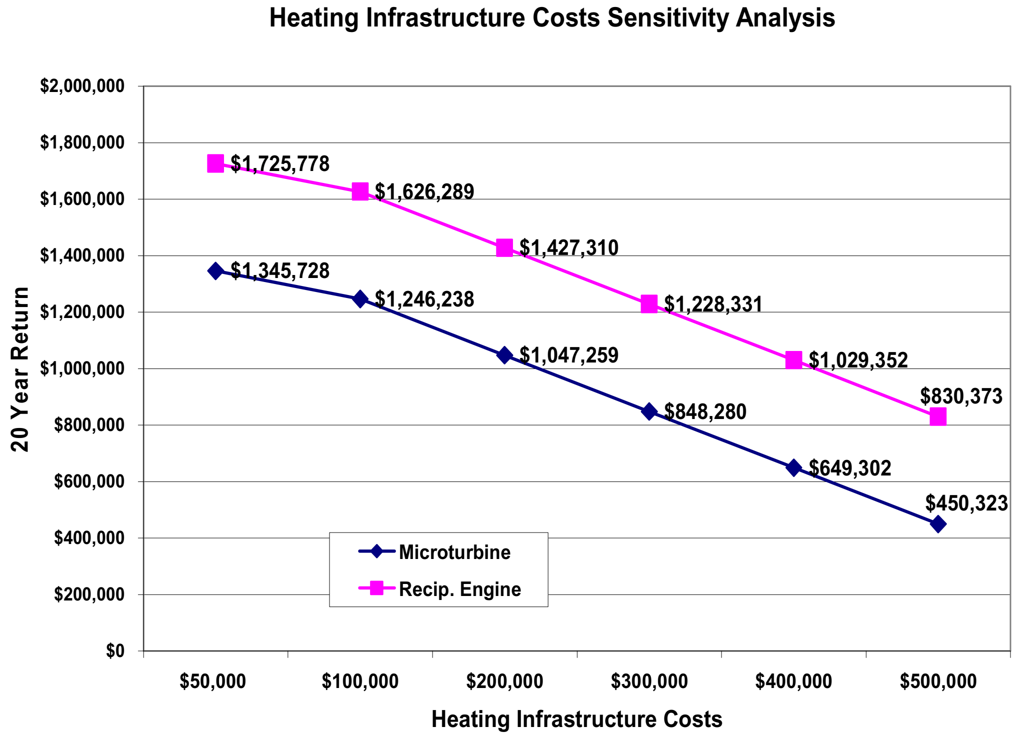

Figure 3.7. Heating Infrastructure Costs Sensitivity Analysis

The sensitivity analysis in Figure 3.7 shows the decrease in return on investment at the end of the 20 year period as heating infrastructure costs increase. However, even at an extremely high cost of $500,000 for heating infrastructure addition, both energy generation technologies produce a positive return on investment over a 20 year period.

When utilizing an energy generation technology that can produce both electricity and heat, the economics are favorable for DWRF to purchase a microturbine or reciprocating engine and using flared biogas as fuel. Additionally, if DWRF applies and receives grant money to subsidize the capital cost of a microturbine or even a reciprocating engine, then DWRF could reap even more savings. Based on the economic analysis of utilizing flared biogas as a fuel for an energy generation technology, the results show good promise in DWRF investing in a technology and seeing a significant return on their investment.

3.6. ECONOMIC ANALYSIS OF FOOD WASTE ADDITION AT DWRF

With the addition of food waste to their anaerobic digesters, DWRF can increase their biogas production as shown in Chapter 2. This biogas can in turn be used to fuel energy generation technologies as shown previously in this chapter. Since all heating needs at DWRF can be accomplished by a microturbine or reciprocating engine using only flared biogas, the additional biogas will only be utilized to produce electricity for plant use. Thus, further savings on heating will not be generated with increased biogas production unless additional biogas can be sold on the open market.

3.6.1. Results of Various Amounts of Food Waste Addition on Electricity Generation

As more biogas is produced at DWRF, an energy generation technology can produce more electricity and heat. 33.4 million SCF of flared biogas at DWRF in 2010 will be used as the baseline amount of biogas that can be used for energy generation. The additional amount of biogas produced from adding various amounts of food waste will be added to this baseline amount to complete an economic analysis. The daily increase in biogas production attributed to various amounts of food waste was reported earlier in Tables 2.8 thru 2.10.

For the 800 lbs/day of food waste from the Ram’s Horn Dining Facility, no further processing is required thus building a food waste processing facility would not be needed. The issue lies in where to add the food waste in the DWRF treatment process which was described in detail in Chapter 2.2.5. At this time, DWRF does not have a viable location in their treatment process to add the food waste. Any option discussed in Chapter 2.2.5 would either be labor intensive or require additional infrastructure. A comparison was made between the net benefit of utilizing DWRF flared biogas as a fuel versus the net benefit of utilizing both DWRF flared biogas and the increased biogas produced from adding 800 lbs/day of food waste over a 20 year period. For the microturbine, approximately $38,629 was added to the savings with the increased biogas production over 20 years. For the reciprocating engine, approximately $30,411 was added to the savings with the increased biogas production over 20 years. These amounts are very minimal and do not justify the possible costs incurred with accepting 800 lbs/day of food waste from the CSU Ram's Horn Dining Facility.

An economic analysis of adding 5 tons/day of food waste was completed utilizing the capital and O & M costs associated with building a food waste diversion program and food waste processing facility. The increased biogas produced from the added food waste was applied to electricity generation utilizing a microturbine or reciprocating engine. Due to the increased amount of biogas produced from the food waste, the capacity (in kW) and electricity production (in kWh/yr) of the microturbine and reciprocating engine both increased. This increased the savings in regards to electricity generation. The results of the economic analysis for the best case option with 5 tons/day of food waste added are provided in the table below.

Table 3.28. Economic Analysis of Energy Generation with DWRF Flared Biogas and 5 tons/day of Food Waste Addition (Best Case)

Parameter	Microturbine	Recip. Engine
Increase Gas Production (ft^3/yr)	8,993,235	8,993,235
Production (kWh)	1,926,965	1,583,965
Capacity (kW)	220	181
1st Year Electricity Savings	$98,512	$81,055
20 Year Electricity Savings	$2,393,590	$1,969,423
1st Year Heating Savings	$64,576	$64,576
20 Year Heating Savings	$1,569,027	$1,569,027
20 Year Total Savings	$3,962,617	$3,538,450
Technology Capital Cost	$672,279	$363,864
20 Year Technology Capital Cost	$1,337,694	$724,013
1st Year Technology O & M Cost	$30,885	$20,427
20 Year Technology O & M Cost	$750,434	$496,318
FW Facility Capital Cost	$2,448,110	$2,448,110
20 Year FW Facility Capital Cost	$4,871,222	$4,871,222
1st Year FW Facility O & M Cost	$1,613	$1,613
20 Year FW Facility O & M Cost	$39,190	$39,190
20 Year Total Cost	$6,998,540	$6,130,743
20 Year Revenue/Deficit	**$3,035,923**	**$2,592,294**

With 5 tons of food waste added per day to the DWRF anaerobic digesters, DWRF would take a significant net loss on their investment in a food waste processing facility. The capital cost of the facility along with the various other associated costs detailed in Table 3.10 would be too large for DWRF to overcome in a 20 year period.

An economic analysis was completed with 15 tons/day of processed food waste added to the DWRF anaerobic digesters for the best case option. The cumulative cash flow chart below illustrates the results of the analysis.

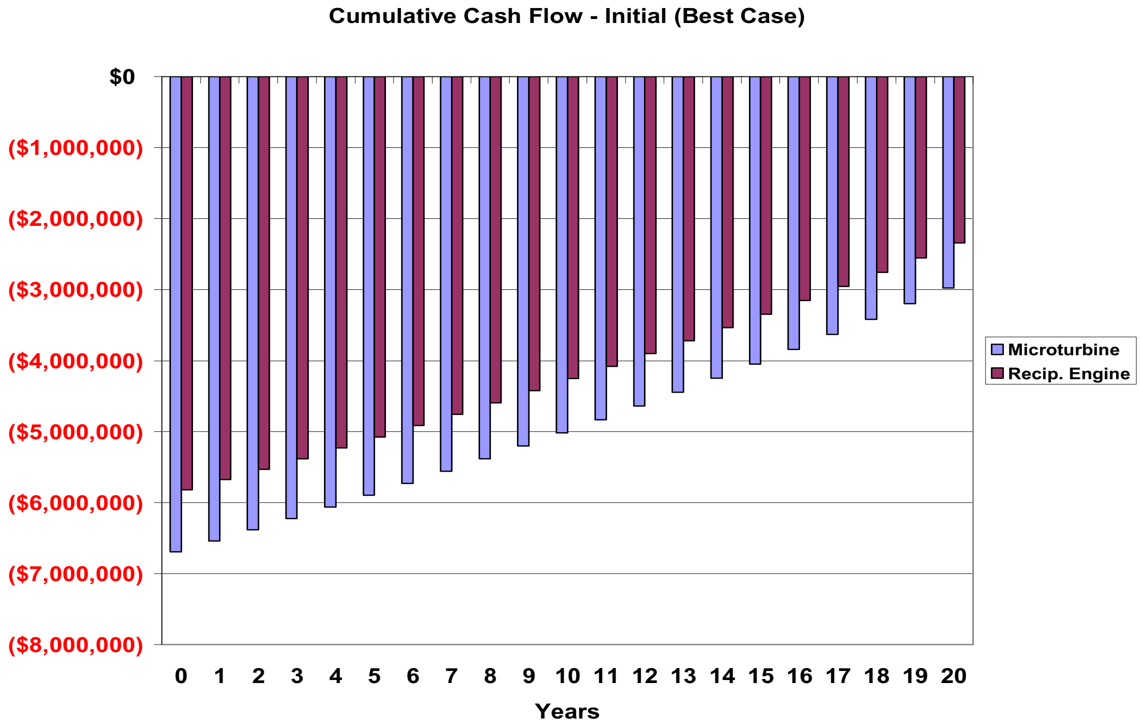

Figure 3.8. Cumulative Cash Flow for Energy Generation with DWRF Flared Biogas and 15 Tons/Day of Food Waste Addition (Best Case)

Figure 3.8 shows that over a 20 year timeframe, DWRF would not attain a return on their investment in a food waste facility. With the microturbine as the energy production technology, DWRF would lose $2,974,795. With the reciprocating engine as the energy production technology, DWRF would lose $2,342,944. Thus, unless DWRF could reduce the costs associated with a food waste processing facility, a program and facility to process 15 tons/day of food waste would not be economically viable.

An economic analysis was completed utilizing 25 tons/day of food waste added to the DWRF anaerobic digesters for the best case option. This amount of food waste represents the high end amount of food waste that the city of Fort Collins could collect in a day. The EBMUD facility in Oakland, CA processes approximately 20 tons/day of food waste with plans to increase that amount over the next few years. The cumulative cash flow chart for this economic analysis is provided below.

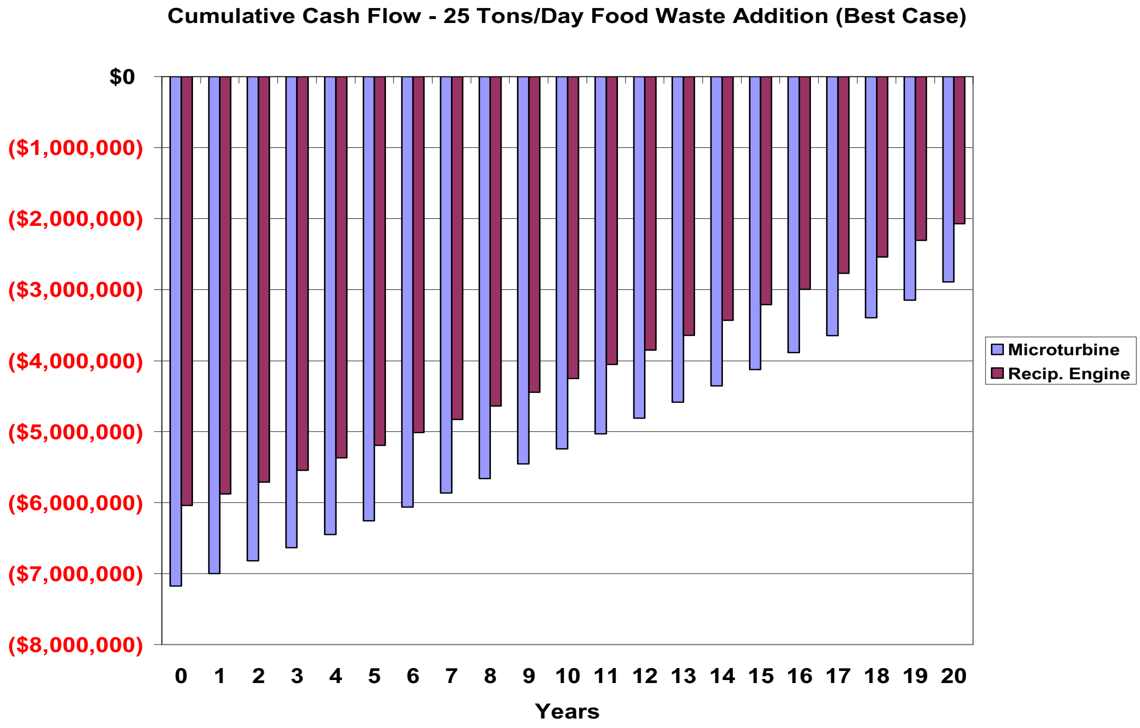

Figure 3.9. Cumulative Cash Flow for Energy Generation with DWRF Flared Biogas and 25 Tons/Day of Food Waste Addition (Best Case)

Even with 25 tons/day of food waste added, DWRF would not see a return on their investment in a food waste diversion program and food waste processing facility. With a microturbine, DWRF would lose $2,888,825 over a 20 year period. With a reciprocating engine, DWRF would lose $2,068,749 over a 20 year period. The loss over a 20 year period for 25 tons/day of food waste addition as compared to the loss over a 20 year period for 15 tons/day of food waste addition is decreasing. However, without reducing costs associated with a food waste diversion program and processing facility, adding 25 tons/day of food waste would not be economically viable.

Using 15 tons/day of food waste added, an analysis was completed to determine the capital cost of the food waste processing facility and program that would provide a positive return on investment for a 20 year period. The cumulative cash flow chart for this scenario is presented in Figure 3.10.

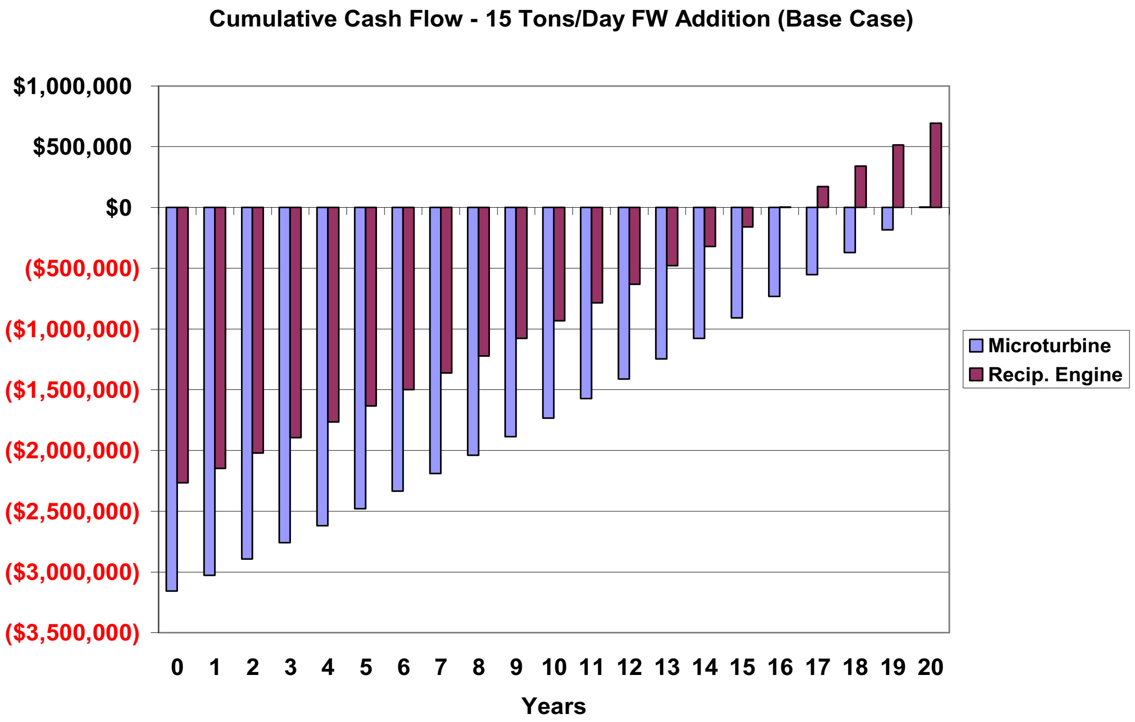

Figure 3.10. Cumulative Cash Flow for Energy Generation with DWRF Flared Biogas, 15 Tons/Day of Food Waste Addition, and $475K Capital Cost for Food Waste Processing Facility (Base Case)

The capital cost of the food waste processing facility was set at $475,000 for the base case option with 15 tons per day of food waste added to the DWRF anaerobic digesters. For the microturbine, the payback on the capital costs occurs in year 20 with a positive return of $4,354 for the 20 year period. For the reciprocating engine, the payback on the capital costs occurs in year 18 with a positive return of $692,939 for the 20 year period. Additionally, if the food waste facility capital cost was $775,000, then for the reciprocating engine the return on investment would be just under $100,000 for the 20 year period. This analysis provides an estimate on what the capital costs for a food waste processing facility needs to be for DWRF to make a return on their investment over a 20 year period. It is highly unlikely that DWRF could attain capital costs that low for a full scale food waste processing facility and diversion program, thus, economically it is unfeasible to move ahead with the food waste diversion program at this time.

Even though the food waste diversion program is economically feasible at this time there are positive economic aspects to the program. Specifically, savings on electricity costs significantly rise as the amount of food waste added increases while the marginal cost of a food waste diversion program does not significantly increase as more food waste is added. In Figure 3.11 below, the annual savings on electricity costs are shown for various amounts of food waste added.

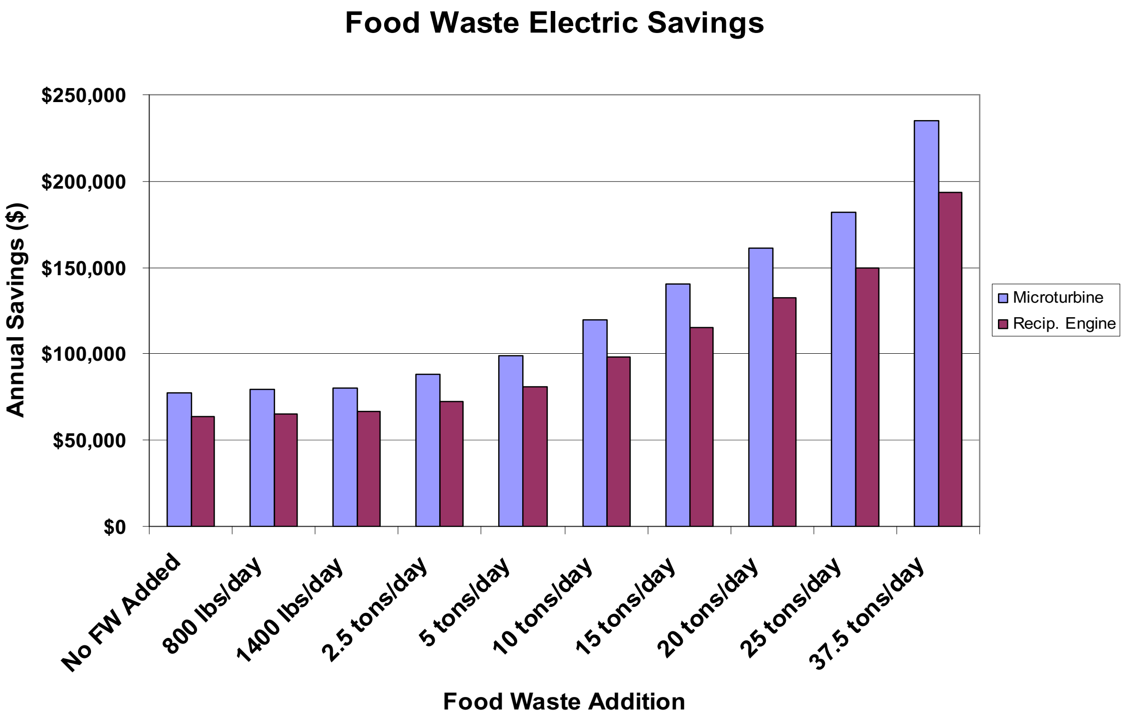

Figure 3.11. Electric Savings for Various Amounts of Food Waste Addition

With no food waste added, the annual savings on electricity is around $79,000 per year for a microturbine. When 15 tons of food waste is added per day, the savings on electricity increases by over $60,000. With the maximum amount of food waste added, the annual electricity savings almost triples to around $233,000.

The marginal cost increase for the base case option was evaluated. Beginning with 800 lbs of food waste added per day, the 20 year total cost (both capital and O & M for energy generation technology and food waste facility and program) were compared. Figure 3.12 shows the comparison of the 20 year total costs for the various amount of food waste added.

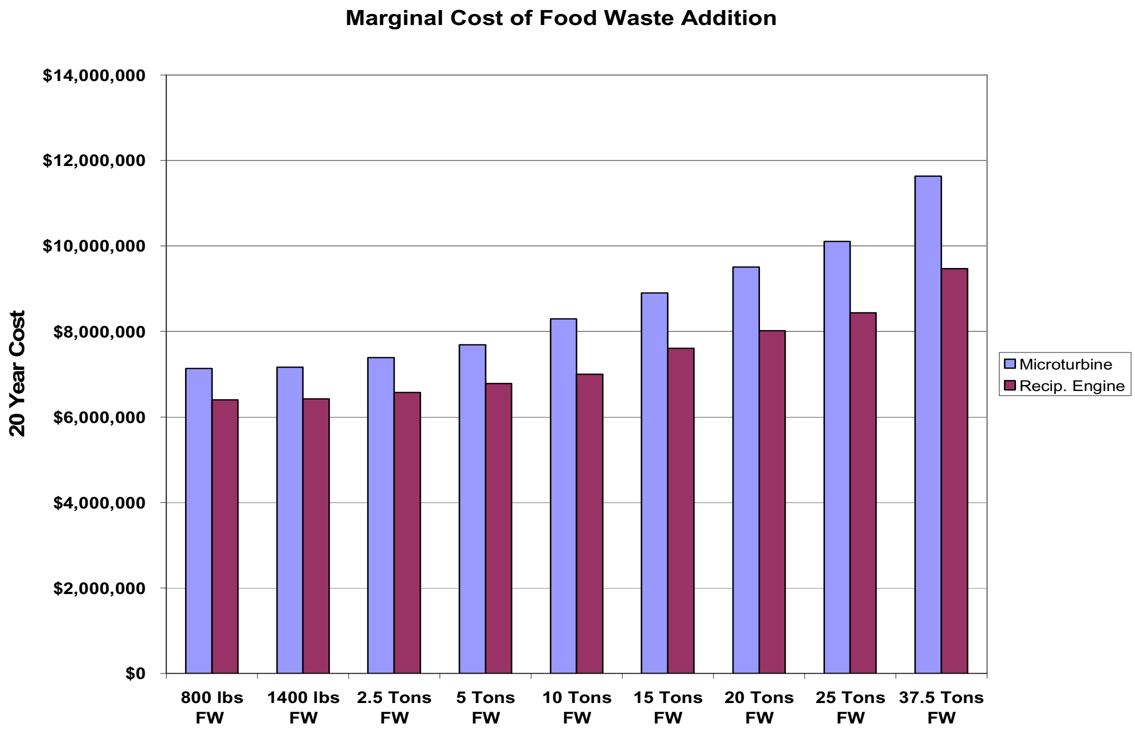

Figure 3.12. Marginal Cost of Food Waste Addition

The increase in cost as food waste addition per day increase does not increase at a significant rate. The marginal cost increase of food waste addition was calculated by using 800 lbs per day of food waste added as a baseline. Additionally, the electricity savings increase was also calculated using 800 lbs per day of food waste as a baseline for comparison. The results of this comparison are shown in Figure 3.13.

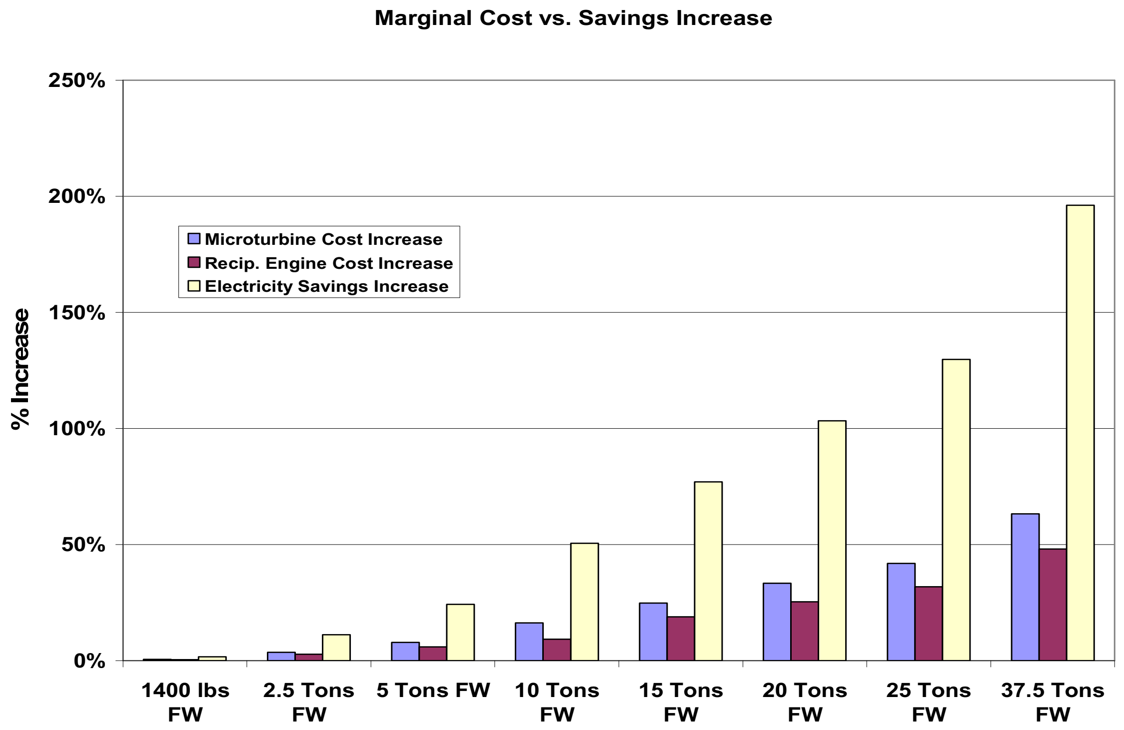

Figure 3.13. Marginal Cost vs. Electricity Savings Increase Comparison

Figure 3.13 shows that the savings in electricity costs increases at a much larger rate than the cost associated with the various amounts of food waste addition. Thus, as more food waste is added, the savings increase steadily becomes much greater than the increase in cost. This shows that implementing a food waste diversion program on a larger scale would be more cost effective and is a positive economic aspect.

3.7. TRIPLE BOTTOM LINE ANALYSIS OF FOOD WASTE ADDITION AT DWRF

3.7.1. Economic Factors of TBL Analysis

An economic analysis was completed in the previous section on food waste addition to the DWRF treatment process. Previous to that, an economic analysis was completed on utilizing an energy generation technology with DWRF flared biogas as the fuel source. Procuring a microturbine or reciprocating engine to create energy (both electricity and heat) at DWRF with only DWRF flared biogas as a fuel source is very financially viable. The savings over a 20 year period produced from electricity generation coupled with the heat generation of either technology to replace the need for natural gas for heating purposes could range from an estimated $1 million to $2.5 million. This represents a significant return on investment over a 20 year period.

With the USEPA, US Department of Energy (DOE), and various other agencies pushing for government, public, and private entities to improve on sustainability and resource conservation, many grants and low interest loans are being offered to spur these organizations to invest in technologies to enhance sustainability in the future. Currently, DWRF are in the application process for a grant for the purchasing of a microturbine for energy generation. The Colorado Governor's Energy Office (GEO) provided a contracted team from Systems, Resources, and Applications (SRA) International to investigate the economic viability of purchasing an energy generation technology for DWRF. Analyzing only the electricity generation portion of the technologies, they found a reciprocating engine to be an economically viable option for DWRF. If DWRF actively pursues a grant or another government subsidy that is being offered for an energy generation technology, the savings and return on investment will significantly increase and make it very worthwhile.

The economic analysis of adding a food waste diversion program utilizing the DWRF anaerobic digesters would not bring a net return on investment over a 20 year period. The capital costs presented in the analysis for a food waste diversion program and food waste processing facility represented costs similar to those incurred at the EBMUD WWTP and CMSA WWTP when implementing their programs. Additionally, other expenses and costs were determined from information provided by the EPA. There exist possibilities for DWRF to reduce the capital costs associated with the program and food waste processing facility. Specifically, in regards to the food waste processing facility, the DODA urban organics processing unit being tested by A1 Organics in Colorado may be a stand alone technology that could process food waste to create a consistent anaerobic digestion feedstock. Furthermore, EBMUD received grants and funding from USEPA to implement their food waste diversion project. DWRF should actively pursue grants and funding from either USEPA or from state level agencies to help offset some of the costs of the food waste diversion project. However, even with lower capital costs for a food waste processing facility and grants and subsidies, DWRF most likely would not be able to make a food waste diversion program viable at this time.

3.7.2. Environmental Factors of TBL Analysis

The environmental factors and impacts of implementing a food waste diversion program in the Fort Collins area utilizing the DWRF anaerobic digesters are significant. With just the use of DWRF flared biogas for energy generation, DWRF will greatly reduce their energy needs by using renewable energy they produce from biogas generated in their anaerobic digesters.

An innovative project that has begun in Fort Collins is the “FortZED” project. The “FortZED” project, or the Fort Collins Zero Energy District, was started by a $6.3 million grant from the US Department of Energy and $5 million in local support to turn the Colorado State University campus and most of the downtown area of Fort Collins into a net zero energy district (FortZED website, 2009). The project is looking at various methods to incorporate renewable energy technologies to create an area that operates at a net zero energy usage. Even though DWRF falls outside of the footprint of the "FortZED" project, utilizing flared biogas to power a microturbine or reciprocating engine would support this local initiative and demonstrate the commitment of the city of Fort Collins to a sustainable future.

The EPA reports that food waste is the second largest category of MSW sent to landfills in the United States, accounting for approximately 14% of the waste stream. More than 34 million tons of food waste is sent to landfills in the US each year. Only 3% of food waste is currently being diverted from landfills. The Larimer County Landfill projects that at its current rate, the landfill will remain open for the next 20 years. At that point, the landfill will reach its capacity and need to be close down.

The Larimer County Solid Waste Department purchased land north of Fort Collins in 2006 as a potential future landfill site. This site is further from the city of Fort Collins then the current landfill location. If DWRF can accept 15 tons/day of food waste to be processed and sent to their anaerobic digesters, this would divert 5,475 tons of food waste from the Larimer County landfill a year. This would be a significant amount of MSW diverted from the landfill and prolong the life of the landfill. The Larimer County Solid Waste Department is investigating options and technologies to become more efficient at waste disposal along with energy generation. Thus, with that extra time associated with diverting food waste from the landfill, there may not be a need to open a new landfill.

Another significant environmental benefit of diverting food waste from the landfill and utilizing it as a feedstock for the DWRF anaerobic digesters is the reduction of greenhouse gas emissions and flaring of methane into the atmosphere. Methane gas is a prevalent by-product of food waste biodegradation at landfills. As mentioned previously, methane gas is significantly more potent as a greenhouse gas then carbon dioxide (another by-product of food waste biodegradation) and may harm the atmosphere. The Larimer County landfill has implemented a technology to flare some of the landfill gas (LFG) produced and also are trying to field a technology to utilize landfill gas for energy generation. The EPA Waste Reduction Model (WARM) provides an estimate in metric tons of carbon dioxide equivalent (MTCO2E), metric tons of carbon equivalent (MTCE), and units of energy (million BTU) that food waste diversion from landfills can produce. The results of diverting 15 tons of food waste a day from the Larimer County landfill are provided in the table below.

Table 3.29. Greenhouse Gas Emissions Reduction and Energy Savings Utilizing the EPA WARM

Greenhouse Gas Emissions Reduction and Energy Savings			
LFG Use	**MTCO2E (Daily / Annual)**	**MTCE (Daily / Annual)**	**Million BTU (Daily / Annual)**
LFG Flared	7 / 2,497	2 / 681	8 / 2,885
LFG Recovered for Energy	5 / 1,817	1 / 495	1 / 333

The EPA determined the average passenger vehicle emits 5.1 MTCO2E per year. Flaring of methane gas is a low cost option to get rid of the gas that is used all over the world. As has been shown, methane gas can be utilized for energy production which results in savings. The greenhouse gas emissions reduction by diverting 15 tons of food waste daily from the Larimer County landfill (if the landfill only flares their LFG) equates to taking 490 passenger vehicles off of the road for a year. This would be a tremendous environmental benefit of taking on a food waste diversion project at DWRF.

3.7.3. Social Factors of TBL Analysis

Social factors can provide both a positive and negative effect on the morale and feeling of a community. A food waste diversion project in Fort Collins would provide a positive impact on the community. Citizens of Fort Collins pride themselves on being good stewards of the environment and of natural resources. A food waste diversion project would help to further this pride. The city of Fort Collins wants to be at the forefront in environmental stewardship and in utilizing renewable energy generation technologies. The positive publicity that a project like this would receive would help further the community's drive and commitment in this area.

This project would provide accessibility and convenience to the food waste suppliers. Many restaurants, supermarkets, and other large food waste generators are actively trying to divert food waste from landfills through composting in Fort Collins. However, many of these composting programs are reaching capacity and this food waste diversion program would be able to accommodate a much larger amount of food waste. Undoubtedly, DWRF and the city of Fort Collins will be able to find willing suppliers of food waste to support this program. DWRF can make it accessible by providing containers for food waste and organizing the pickup of food waste at the supplier's location. If the project proves to be a success, the city of Fort Collins could look into a residential food waste collection program which would give an opportunity for all citizens to participate in the program.

The opportunity to involve local food waste generators in a food waste diversion program would be offered to the largest producers of food waste first. This information should be provided relatively soon from a separate Fort Collins solid waste stream survey being conducted as discussed earlier. It makes sense to offer the opportunity to the largest producers of food waste first and then work down. The end goal would be to offer the opportunity to participate in the food waste diversion program to all commercial and industrial generators of food waste to ensure an equitable implementation of the program. Depending on the amount of interest from commercial and industrial food waste producers, the city of Fort Collins and DWRF may not have enough capacity initially to accept all that are interested in participating. However, a food waste diversion program can continue to grow over time (as demonstrated by the EBMUD food waste diversion program) and should be able to include all entities that are interested in participating.

By reducing costs associated with energy use at DWRF along with generating some revenue from a food waste diversion project, wastewater rates may be positively impacted for the customers. A WWTP needs to generate revenue from user rate fees to cover operating expenses along with saving money for future infrastructure improvements and upgrades on technology. By implementing a program that can generate savings and revenue, DWRF can pass the savings on to their customers by keeping their rates relatively steady and low while still being able to invest in infrastructure improvements and technological upgrades. This would provide a great social benefit to the residents of Fort Collins.

4. SUMMARY AND CONCLUSIONS

Food waste diversion and its subsequent use in municipal wastewater treatment plant's anaerobic digestion systems is an emerging trend in solid waste management and renewable energy generation. The benefits of a food waste diversion program provide numerous positive impacts economically, environmentally, and socially. Included with the analysis of a food waste diversion program at DWRF was an analysis of possibilities for renewable energy generation and savings associated with it.

4.1. FOOD WASTE CHARACTERIZATION AND EVALUATION OF DWRF ANAEROBIC DIGESTER CAPACITY FOR FOOD WASTE ADDITION

Samples of CSU Ram's Horn Dining Facility food waste were characterized to determine its viability as a feedstock for the DWRF anaerobic digesters. The total solids percentage and volatile solids fraction of the total solids of the food waste were determined and found to be similar to other types of food waste reported in literature.

A statistical analysis to determine sample mean, sample variance and sample standard error along with sample size determination calculations were completed. This analysis helped to provide statistical information and confirm the precision and accuracy of the simple random sampling plan used.

Data for the 2010 DWRF anaerobic digesters was provided for analysis to determine the operating capacity of the anaerobic digesters. Three loading rates (solids, hydraulic, and organic) were analyzed with the solids loading rate determined to be limiting. With the anaerobic digesters operating at approximately 58% capacity according to solids loading, the anaerobic digesters have significant capacity for food waste addition. It was determined that three anaerobic digesters could support the addition of 37.5 tons of food waste a day. This is a significant amount and much more than DWRF could receive at the inception of a food waste diversion program.

Calculations were made for various amounts of food waste added to the anaerobic digesters to determine the effects on key parameters such as solids reduction in the digesters, pounds of volatile solids destroyed, digester biogas production, and residual solids production. The effects on all key parameters proved to be positive and confirmed food waste as a viable and desired feedstock for an anaerobic digestion system.

4.2. ECONOMIC AND TRIPLE BOTTOM LINE ANALYSIS OF ENERGY GENERATION FROM DWRF BIOGAS

To determine the efficacy of a food waste diversion program utilizing the DWRF anaerobic digesters, a thorough and rigorous economic and triple bottom line analysis needed to be conducted. Utilizing information calculated in Chapter 3 along with information provided by DWRF on methane and natural gas use and costs for electricity and heating the analysis was completed.

Using 2010 data for methane and natural gas use at DWRF, the savings associated with using methane gas to operate boilers for heating, the cost of natural gas use for heating, and the monetary value of flared methane gas for heating were calculated. It was determined that DWRF accomplished approximately 65% of their heating needs in 2010 using methane gas generated from their anaerobic digesters. DWRF should look to optimize their boiler use to increase their heating through methane gas as 44% of the methane gas produced from the digesters was flared in 2010. DWRF should also investigate the various methane and biogas storage technologies that are available. Due to heating varying based on seasonal weather factors, they are not able to fully utilize all of the biogas the anaerobic digesters produce.

The utilization of DWRF digester biogas to fuel various energy generation technologies was explored. If the biogas that is flared cannot be used for heating at DWRF, it can be used to produce electricity for the plant. Using data from the EPA and NREL, an economic analysis was conducted based on the savings associated with electricity generation these technologies could produce. For the best case option, a microturbine or reciprocating engine technology fueled by DWRF flared biogas would provide a return on investment and savings over a 20 year period.

These energy generation technologies also can provide heating for various plant processes while producing electricity. Both microturbine and reciprocating engine technology can provide enough heating while producing electricity from flared biogas to eliminate the need for natural gas. Over a 20 year period, this results in savings of $1.57 million in heating costs. Combining the heating and electricity generation a microturbine or reciprocating engine technology provides, DWRF would gain a return on investment and savings which makes the procurement of one of these technologies very favorable.

The addition of various amounts of food waste provided an increase in digester biogas that can be used to attain greater savings on energy generation. However, DWRF would need to spend a significant amount on capital costs to start a food waste diversion program with a food waste processing facility. The best option for DWRF would be to emulate the EBMUD WWTP food waste treatment process in Oakland, CA or purchase a stand alone food processing unit like the DODA urban organics processing unit being tested in Colorado. A high end estimate on the cost of implementing a food waste diversion program with associated equipment was approximately \$2.5 million. An economic analysis was completed to determine the revenue generated or deficit as a result in the implementation of a food waste diversion program in Fort Collins utilizing the DWRF anaerobic digesters. It is not economically viable for DWRF to receive the 800 lbs/day of food waste from CSU due to minimal increase in gas production. At 25 tons/day of food waste, DWRF would still not be close to seeing a profit on the purchase of a microturbine or reciprocating engine. If DWRF could receive grants or subsidies to reduce the cost of implementing a food waste diversion program or keep capital costs associated with this program below \$475,000, then DWRF would see a return on their investment over a 20 year period. However, this capital cost is extremely low and practically unfeasible to attain thus making a food waste diversion program not economically viable at this time.

The triple bottom line analysis provided many positive impacts economically, environmentally, and socially. Specifically, the reduction in greenhouse gas emissions and the reduction in solid waste going to the Larimer County landfill would be significant. Fort Collins prides itself on being a ‘green’ community and taking the initiative on environmental stewardship and renewable energy generation. A food waste diversion program would help to bolster these areas.

4.3. RECOMMENDATIONS

The economic analysis of procuring an energy generation technology fueled by biogas at DWRF is very favorable. This study supports the initial viability of utilizing an energy generation technology to produce electricity and heating for various plant needs. DWRF should make inquiries to various energy generation technology manufacturers to get quotes on capital and O & M costs associated with their technologies. This cost data can be compared to the economic analysis completed in this study to verify savings and the economic viability of energy generation at DWRF. Additionally, DWRF should investigate further the purchase of a methane gas storage technology. A methane gas storage technology may provide DWRF with the ability to better optimize their boiler operations for heating.

DWRF should not begin a food waste diversion program in the near future due to it not being economically viable at this time. There are positive environmental and social impacts of a food waste diversion program, but the financial loss associated with starting a program is too large for DWRF. DWRF and the city of Fort Collins should reevaluate the economic feasibility of a food waste diversion program in 5-10 years. If energy costs rise and capital costs associated with a food waste diversion program are lower in the future, it may be economically viable.

Some other factors besides rising energy costs and lower capital costs for a food waste diversion program that could positively impact the viability are limited landfill capacity, local and state government policy incentives for a food waste diversion program, and increased tipping fees for landfills.

Larimer County projects another 15-20 years on the operating life of the Larimer County landfill before reaching capacity. If this projection is amended shortening the operating life of the landfill, then a food waste diversion program becomes more viable. Also, if the city of Fort Collins and Larimer County decide to use the land purchased north of Fort Collins for a future landfill for another purpose, then a food waste diversion program becomes more attractive to extend the life of the current landfill. Currently, there is no indication of the landfill projected operating life being shortened or the land for the future landfill being used for another purpose but it would be worth monitoring over the next few years.

Both local governments and the Colorado state government are actively looking for ways to become more sustainable. To spur innovation and action towards sustainability, there may be government policy incentives and grants that can help subsidize projects improving sustainability. A food waste diversion program would definitely promote sustainability. The state of Colorado are providing incentives and grants for project supporting sustainability and most likely will continue to do so in the future. DWRF and the city of Fort Collins needs to stay alert and aware of new state incentives and grants that they may be able to tap into to make a food waste diversion program more viable.

Finally, tipping fees at the Larimer County landfill and in the state of Colorado are generally lower than most of the rest of the United States. If over the next few years tipping fees begin to rise, then DWRF could charge more for a tipping fee for a food waste diversion program to increase revenue. This would improve the economics of a food waste diversion program. However, unless the tipping fee increases significantly over the next few years, the food waste diversion program will not become economically viable on revenue from tipping fees alone.

4.4. FURTHER WORK NEEDED

Further work is needed in trying to qualify and quantify food waste in providing BOD for the DWRF secondary treatment process. If DWRF does place a priority on trying to utilize food waste as a carbon source for their secondary treatment processes, then further analysis is needed in how to process and where to add food waste in the overall DWRF treatment process to attain the desired results. For enhanced methane production in the DWRF anaerobic digesters, it makes the most sense to process the food waste into a slurry and feed it directly to the anaerobic digesters. This would provide no benefit to adding BOD to the secondary treatment processes to achieve nutrient removal. DWRF can utilize the food waste from the CSU Ram's Horn Dining Facility to run some experiments to try to determine the BOD addition that results from adding food waste at various locations in the treatment process.

The completion of the testing on the DODA urban organics processing unit and subsequent final report by A1 Organics and CDPHE should provide valuable information on this food waste processing technology. If demonstrated to be a viable option for processing raw food waste, then this technology might provide a less expensive option on processing food waste and thus be worth procuring to start a food waste diversion program. DWRF should review this report thoroughly to determine if it would be beneficial into evaluating the DODA urban organics processing unit to process food waste.

The solid waste stream survey being conducted by Clements Environmental Group will provide crucial information on the largest generators of food waste in the Fort Collins area. These food waste generators would be the prime organizations and businesses to be part of a food waste diversion program. This information will also help to quantify the amount of food waste generated in Fort Collins on a daily, weekly, and monthly basis. From that data, it can be determined if enough food waste is generated in

Fort Collins to justify a food waste diversion program. Observing trends and data on food waste generation provided by the EPA and other organizations, Fort Collins should easily generate enough food waste on a daily basis to justify a food waste diversion program.

Further work can be completed on whether DWRF should procure and utilize a biogas storage technology. Information for various storage technologies would need to be collected such as volume of storage and length of storage time. DWRF flares excess biogas in the summer month and with storage the flared biogas from summer months could be used in winter months to augment biogas produced from the anaerobic digesters. Data for methane and natural gas use for the past 6 years is available for an analysis into the feasibility and viability of a biogas storage technology at DWRF.

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6. APPENDIX A – DWRF ANAEROBIC DIGESTERS CAPACITY CALCULATION SPREADSHEET

5 days worth of data is shown in this appendix to provide further insight into the process of determining DWRF anaerobic digesters capacity and also the effect of adding various amounts of food waste. Columns in white represented data provided by DWRF and columns in yellow represented data the author calculated using the equations discussed in Chapter 2.2. The author was provided with data for the 365 days in 2010 and made calculations for each day. An average for each column was determined and used to represent the associated parameter. These values were reported in Chapters 2.5 and 2.6.

DATE	PRIMARY SLUDGE MGD*	PRIMARY SLUDGE %TS*	PRIMARY SLUDGE %VS*	Thickened WAS to DIGS Gal/day	THICKENED WAS TO DIGS MGD*	THICKENED WAS TO DIGS %TS*	THICKENED WAS TO DIGS %VS	Max Food Waste Added (lbs VS/day)	800 lbs Added (lbs VS/day)
01/01/10	**0.0393**	4.25	87.5	25300	**0.025**	4.57	82.5	17356.05	167.59
01/02/10	**0.0395**	4.25	87.5	25700	**0.026**	4.57	82.5	17168.24	167.59
01/03/10	**0.0398**	4.25	87.5	26500	**0.027**	4.57	82.5	16823.65	167.59
01/04/10	**0.0399**	4.25	87.5	26300	**0.026**	4.57	82.5	16855.52	167.59
01/05/10	**0.0417**	4.18	86.4	25100	**0.025**	4.57	82.5	17047.51	167.59

DATE	1400 lbs Added (lbs VS/day)	2.5 Tons Added (lbs VS/day)	5 Tons Added (lbs VS/day)	10 Tons Added (lbs VS/day)	15 Tons Added (lbs VS/day)	20 Tons Added (lbs VS/day)	25 Tons Added (lbs VS/day)	Max Food Waste Added (lbs/day)
01/01/10	293.29	1047.45	2094.89	4189.78	6284.67	8379.56	10474.45	82849.43
01/02/10	293.29	1047.45	2094.89	4189.78	6284.67	8379.56	10474.45	81952.94
01/03/10	293.29	1047.45	2094.89	4189.78	6284.67	8379.56	10474.45	80308.02
01/04/10	293.29	1047.45	2094.89	4189.78	6284.67	8379.56	10474.45	80460.16
01/05/10	293.29	1047.45	2094.89	4189.78	6284.67	8379.56	10474.45	81376.63

DATE	800 lbs Added (lbs/day)	1400 lbs Added (lbs/day)	2.5 Tons Added (lbs/day)	5 Tons Added (lbs/day)	10 Tons Added (lbs/day)	15 Tons Added (lbs/day)	20 Tons Added (lbs/day)	25 Tons Added (lbs/day)	Max Weight of Dry Solids (lbs/day)	800 lbs Added (lbs/day)	1400 lbs Added (lbs/day)
01/01/10	799.99	1400.03	5000.02	10000.00	20000.00	29999.99	39999.99	49999.99	18980.80	183.28	320.75
01/02/10	799.99	1400.03	5000.02	10000.00	20000.00	29999.99	39999.99	49999.99	18775.42	183.28	320.75
01/03/10	799.99	1400.03	5000.02	10000.00	20000.00	29999.99	39999.99	49999.99	18398.57	183.28	320.75
01/04/10	799.99	1400.03	5000.02	10000.00	20000.00	29999.99	39999.99	49999.99	18433.42	183.28	320.75
01/05/10	799.99	1400.03	5000.02	10000.00	20000.00	29999.99	39999.99	49999.99	18643.39	183.28	320.75

DATE	2.5 Tons Added (lbs/day)	5 Tons Added (lbs/day)	10 Tons Added (lbs/day)	15 Tons Added (lbs/day)	20 Tons Added (lbs/day)	25 Tons Added (lbs/day)	Food Waste MGD	800 lbs Added MGD	1400 lbs Added MGD	2.5 Tons Added MGD	5 Tons Added MGD	10 Tons Added MGD
01/01/10	1145.51	2291.00	4582.00	6873.00	9164.00	11455.00	0.0097	0.0001	0.0002	0.0006	0.0012	0.0024
01/02/10	1145.51	2291.00	4582.00	6873.00	9164.00	11455.00	0.0096	0.0001	0.0002	0.0006	0.0012	0.0024
01/03/10	1145.51	2291.00	4582.00	6873.00	9164.00	11455.00	0.0094	0.0001	0.0002	0.0006	0.0012	0.0024
01/04/10	1145.51	2291.00	4582.00	6873.00	9164.00	11455.00	0.0095	0.0001	0.0002	0.0006	0.0012	0.0024
01/05/10	1145.51	2291.00	4582.00	6873.00	9164.00	11455.00	0.0096	0.0001	0.0002	0.0006	0.0012	0.0024

DATE	15 Tons Added MGD	20 Tons Added MGD	25 Tons Added MGD	DIGESTER PRODUCT %TS	DIGESTER PRODUCT %VS	VS IN (lbs VS/day)	VS IN (w/ Max FW) (lbs VS/day)	VS IN (800 lbs FW) (lbs VS/day)	VS IN (1400 lbs FW) (lbs VS/day)
01/01/10	0.0035	0.0047	0.0059	1.82	71.7	20143.95	37155.10	20308.21	20431.41
01/02/10	0.0035	0.0047	0.0059	1.82	71.7	20331.76	37158.84	20496.02	20619.22
01/03/10	0.0035	0.0047	0.0059	1.82	71.7	20676.35	37165.68	20840.61	20963.81
01/04/10	0.0035	0.0047	0.0059	1.82	71.7	20644.48	37165.05	20808.74	20931.94
01/05/10	0.0035	0.0047	0.0059	1.83	71.7	20452.49	37161.24	20616.75	20739.95

DATE	VS IN (2.5 Tons FW) (lbs VS/day)	VS IN (5 Tons FW) (lbs VS/day)	VS IN (10 Tons FW) (lbs VS/day)	VS IN (15 Tons FW) (lbs VS/day)	VS IN (20 Tons FW) (lbs VS/day)	VS IN (25 Tons FW) (lbs VS/day)	VS OUT (lbs VS/day)	VS OUT (w/ Max FW) (lbs VS/day)
01/01/10	21170.59	22197.21	24250.47	26303.73	28357.00	30410.26	7022.85	8081.34
01/02/10	21358.39	22385.02	24438.28	26491.54	28544.80	30598.06	7088.08	8135.11
01/03/10	21702.99	22729.61	24782.87	26836.13	28889.39	30942.65	7207.66	8233.68
01/04/10	21671.11	22697.74	24751.00	26804.26	28857.52	30910.78	7196.79	8224.75
01/05/10	21479.12	22505.75	24559.01	26612.27	28665.53	30718.79	7297.14	8341.84

DATE	VS OUT (800 lbs FW) (lbs VS/day)	VS OUT (1400 lbs FW) (lbs VS/day)	VS OUT (2.5 Tons FW) (lbs VS/day)	VS OUT (5 Tons FW) (lbs VS/day)	VS OUT (10 Tons FW) (lbs VS/day)	VS OUT (15 Tons FW) (lbs VS/day)	VS OUT (20 Tons FW) (lbs VS/day)	VS OUT (25 Tons FW) (lbs VS/day)
01/01/10	7033.07	7040.73	7086.73	7150.61	7278.37	7406.13	7533.89	7661.65
01/02/10	7098.30	7105.96	7151.96	7215.84	7343.60	7471.36	7599.12	7726.88
01/03/10	7217.88	7225.55	7271.54	7335.42	7463.18	7590.94	7718.70	7846.46
01/04/10	7207.01	7214.68	7260.67	7324.55	7452.31	7580.07	7707.83	7835.59
01/05/10	7307.41	7315.11	7361.33	7425.51	7553.89	7682.27	7810.65	7939.03

DATE	Solids Reduction (%)	Solids Reduction (w/ Max FW) (%)	Solids Reduction (800 lbs FW) (%)	Solids Reduction (1400 lbs FW) (%)	Solids Reduction (2.5 Tons FW) (%)	Solids Reduction (5 Tons FW) (%)	Solids Reduction (10 Tons FW) (%)	Solids Reduction (15 Tons FW) (%)
01/01/10	65.14	81.10	65.42	65.63	66.83	68.36	71.04	73.30
01/02/10	65.14	80.92	65.42	65.62	66.81	68.34	71.00	73.24
01/03/10	65.14	80.61	65.42	65.62	66.79	68.29	70.92	73.14
01/04/10	65.14	80.64	65.41	65.62	66.79	68.29	70.92	73.15
01/05/10	64.32	80.36	64.61	64.82	66.03	67.58	70.29	72.58

DATE	Solids Reduction (20 Tons FW) (%)	Solids Reduction (25 Tons FW) (%)	Digester Gas Production (ft^3/day)	Digester Gas Production (w/ Max FW) (ft^3/day)	Digester Gas Production (800 lbs FW) (ft^3/day)	Digester Gas Production (1400 lbs FW) (ft^3/day)	Digester Gas Production (2.5 Tons FW) (ft^3/day)
01/01/10	75.23	76.91	157,453	361,587	159,424	160,903	169,773
01/02/10	75.17	76.83	158,924	360,849	160,895	162,374	171,244
01/03/10	75.05	76.71	161,624	359,496	163,595	165,074	173,944
01/04/10	75.06	76.72	161,372	359,619	163,343	164,822	173,692
01/05/10	74.54	76.25	157,864	358,369	159,835	161,314	170,184

DATE	Digester Gas Production (5 Tons FW) (ft^3/day)	Digester Gas Production (10 Tons FW) (ft^3/day)	Digester Gas Production (15 Tons FW) (ft^3/day)	Digester Gas Production (20 Tons FW) (ft^3/day)	Digester Gas Production (25 Tons FW) (ft^3/day)	Increase in gas production (w/ Max FW) (%)	Increase in gas production (800 lbs FW) (%)
01/01/10	182,092	206,732	231,371	256,010	280,649	129.65	1.25
01/02/10	183,563	208,202	232,842	257,481	282,120	127.06	1.24
01/03/10	186,263	210,903	235,542	260,181	284,820	122.43	1.22
01/04/10	186,011	210,651	235,290	259,929	284,568	122.85	1.22
01/05/10	182,503	207,142	231,782	256,421	281,060	127.01	1.25

DATE	Increase in gas production (1400 lbs FW) (%)	Increase in gas production (2.5 Tons FW) (%)	Increase in gas production (5 Tons FW) (%)	Increase in gas production (10 Tons FW) (%)	Increase in gas production (15 Tons FW) (%)	Increase in gas production (20 Tons FW) (%)	Increase in gas production (25 Tons FW) (%)
01/01/10	2.19	7.82	15.65	31.30	46.95	62.59	78.24
01/02/10	2.17	7.75	15.50	31.01	46.51	62.01	77.52
01/03/10	2.13	7.62	15.24	30.49	45.73	60.98	76.22
01/04/10	2.14	7.63	15.27	30.54	45.81	61.07	76.34
01/05/10	2.19	7.80	15.61	31.22	46.82	62.43	78.04

DATE	Solids Destroyed (lbs VS/day)	Solids Destroyed (w/ Max FW) (lbs VS/day)	Solids Destroyed (800 lbs FW) (lbs VS/day)	Solids Destroyed (1400 lbs FW) (lbs VS/day)	Solids Destroyed (2.5 Tons FW) (lbs VS/day)	Solids Destroyed (5 Tons FW) (lbs VS/day)	Solids Destroyed (10 Tons FW) (lbs VS/day)	Solids Destroyed (15 Tons FW) (lbs VS/day)
01/01/10	13,121	30,132	13,285	13,409	14,148	15,174	17,228	19,281
01/02/10	13,244	30,071	13,408	13,531	14,270	15,297	17,350	19,403
01/03/10	13,469	29,958	13,633	13,756	14,495	15,522	17,575	19,628
01/04/10	13,448	29,968	13,612	13,735	14,474	15,501	17,554	19,607
01/05/10	13,155	29,864	13,320	13,443	14,182	15,209	17,262	19,315

DATE	Solids Destroyed (20 Tons FW) (lbs VS/day)	Solids Destroyed (25 Tons FW) (lbs VS/day)
01/01/10	21,334	23,387
01/02/10	21,457	23,510
01/03/10	21,682	23,735
01/04/10	21,661	23,714
01/05/10	21,368	23,422