© IWA Publishing 2013
105

Water Practice & Technology Vol 8 No 1
doi: 10.2166/wpt.2013.012

An economic analysis of energy generation and food waste diversion for enhanced biogas production at a colorado wastewater treatment facility

Cristian A. Robbins[a] and Sybil Sharvelle[b]

[a] Department of Geography & Environmental Engineering, United States Military Academy, 745 Brewerton Road, West Point, New York 10996. E-mail: cristian.robbins@usma.edu

[b] Department of Civil & Environmental Engineering, Colorado State University, 1372 Campus Delivery, Fort Collins, Colorado 80523. E-mail: sybil.sharvelle@colostate.edu

Abstract

Food waste diversion to enhance biogas production for energy generation in municipal wastewater treatment plants (WWTPs) is an emerging trend in the United States. Using an interested WWTP in Fort Collins, Colorado a study was completed to determine the efficacy and viability of implementing a food waste diversion program utilizing food waste as a feedstock in their existing anaerobic digesters to enhance biogas production. The results of the study concluded that a food waste diversion program would result in a loss of approximately $2.5 million over a 20 year period making the program unfeasible currently. However, the use of excess biogas produced in the plant's anaerobic digesters from the processing of the municipal solid waste stream (MSW) to fuel a reciprocating engine energy generation technology would result in an estimated return on investment of $1.63 million, and an estimated return on investment of $1.25 million for a microturbine energy generation technology over the same 20 year time period. Changes to multiple variables in the economic analysis such as higher energy costs and higher landfill tipping fees could result in a more positive outlook for a future food waste diversion program in Northern Colorado. This study can be used by other WWTPs in the US and other countries as a model to determine the initial economic feasibility of a food waste diversion program in their area. WWTPs in locations with greater costs associated with energy and tipping fees than those reported in this study may find a food waste diversion program economically viable and beneficial.

Key words: Codigestion, Energy Generation, Enhanced Biogas Production, Food Waste Diversion

INTRODUCTION

Food waste diversion from landfills for beneficial uses is an emerging trend in the United States (U.S.) with great potential. European countries have been diverting food waste since the mid-1990s and now have over 200 operating anaerobic digestion plants of commercial scale with a majority of those plants utilizing the organic fraction of the municipal solid waste (MSW) stream as feedstock (IEA, 2008). These plants use a variety of wet and dry anaerobic digestion systems and also are not exclusively located at municipal wastewater treatment plants (WWTPs). The organic fraction of the MSW stream used as feedstock included food waste but also yard trimmings and manure. Adoption of anaerobic digestion for MSW management has been slower in the US due to the large initial capital cost associated with starting a diversion program aimed at utilizing the organic fraction of MSW for energy generation (East Bay Municipal Utility District, 2008). In Europe, land is scarcer as compared to the United States and thus landfill capacity is becoming a significant issue. As the US population continues to rise and competing requirements for land use increase, landfill space will become costlier and thus may lead to solid waste diversion programs. European municipalities have been actively trying to become economically sustainable and utilizing waste to generate energy is a method they have been implementing since the mid-1990s.

In the United States, the East Bay Municipal Utility District (EBMUD) WWTP in Oakland, CA is the largest plant with a food waste diversion program (USEPA 2009). 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. As energy prices continue to increase, and municipalities are looking toward environmentally sustainable approaches for managing resources, there is a growing interest in WWTPs accepting MSW to boost biogas production in existing anaerobic digesters.

A food waste diversion program utilizing anaerobic digesters at a WWTP would include a collection system along with a processing system as the food waste cannot be added directly to the anaerobic digesters without some initial processing. The EBMUD WWTP utilizes a solids handling company that collects food waste from local businesses and transports it to a material recovery facility (MRF) where the food waste is sorted to remove contaminants (such as plastics) and then shredded to a small size (Central Marin Sanitation Authority 2010). The food waste is transported to the WWTP where it goes through final processing. The food waste processing system at the WWTP begins in a slurry tank where the food waste is added to water to create an approximately 10% solids content mixture for ease of pumping. The food waste slurry goes through a rock trap/grinder and paddle finisher to remove any contaminants such as rocks, metals, grit, and other material that is not readily biodegradable while also further reducing the size of material (Central Marin Sanitation Authority 2010). Finally, the food waste feedstock is pumped into the anaerobic digester to be converted into biogas.

Environmental benefits such as reducing the amount of food waste that is sent to landfills and reducing greenhouse gas emissions are very appealing to municipalities. Additionally, the financial benefits of utilizing the enhanced biogas production to help heat and power the plant and subsequent reduction in energy costs and potential to sell excess biogas for revenue is very appealing. While MSW diversion to WWTP anaerobic digesters sounds like an attractive alternative, municipalities are unsure of the economics associated with such a project. A case study for the City of Fort Collins, Colorado was conducted here. The WWTP used in this study processes a wastewater flow of 11 million gallons per day (MGD) (41,635 m^3 per day) and uses preliminary treatment (bar screens & grit chambers), primary treatment (primary clarifiers), secondary treatment (activated sludge with secondary clarifiers), and disinfection to treat the influent wastewater to an acceptable standard. Also, the Fort Collins WWTP uses anaerobic digesters to process sludge from the treatment process. A process schematic is provided to show the treatment process and of note the biotowers depicted in the diagram are currently not being utilized (Figure 1).

An aerial view of the Fort Collins WWTP along with a picture of the anaerobic digesters are shown below (Figures 2 and 3).

The maximum daily loading rates for the anaerobic digesters at the Fort Collins, Colorado WWTP are presented below for background and were used for analysis to determine the amount of food waste addition possible for the anaerobic digesters (Table 1).

While results from this study are specific to the western US region, the approach is widely applicable. Key factors affecting economics, such as energy cost and capital investment, were evaluated. Additionally, an approach to estimate food waste addition based on anaerobic digester performance data is presented.

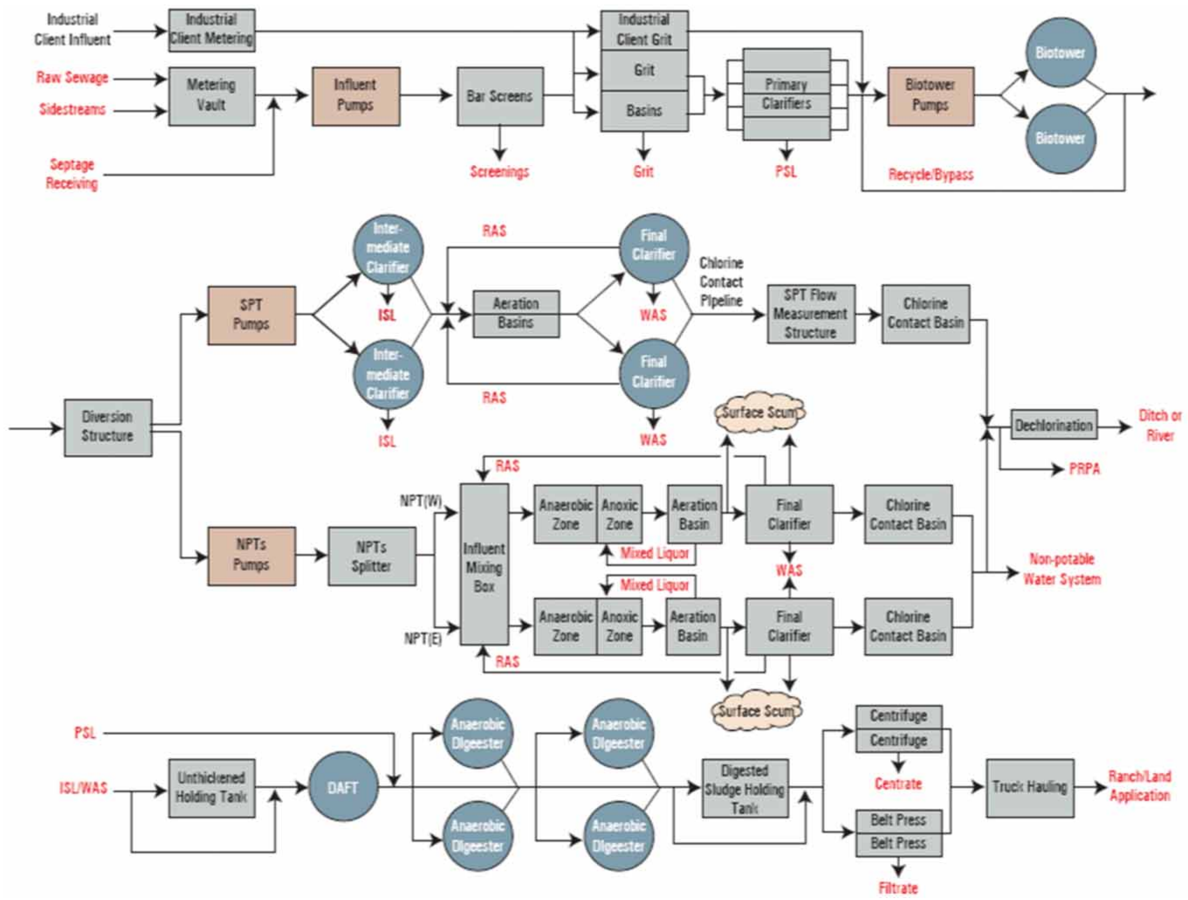

Figure 1 | Process flow schematic of fort Collins, Colorado WWTP.

METHODS

Food Waste Characterization

Colorado State University (CSU) offered to provide processed food waste from their Ram's Horn Dining Facility to a Fort Collins, Colorado WWTP for their use as an anaerobic digestion feedstock. A Somat close-coupled waste pulping systems are used in the kitchens to process pre- and post-consumer food waste. 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 364 kilograms (800 pounds) per day of processed food waste to the WWTP.

Samples of CSU food waste were collected and tested for Chemical Oxygen Demand (COD) concentrations, Total Solids (TS) percentage, and the Volatile Solids (VS) to TS ratio of the food waste. These parameters would provide data for characterization of CSU food waste. The VS/TS ratio provided the volatile solids content of the solids material of the food waste which represents the fraction that would biodegrade in an anaerobic digester producing biogas. The key parameters of TS and VS/TS were compared to other food waste characterization studies (Zhang *et al*. 2007). Two samples per week were collected over a five week period from November 2011 to December 2011 to provide 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 a representative characterization of

Figure 2 | Aerial view of fort Collins, Colorado WWTP.

Figure 3 | Fort Collins, Colorado WWTP anaerobic digesters.

the variability of food waste quality. The food waste is relatively homogenous with concentrations not expected to cycle with seasons and long term trends are not expected to exist. Finally, sample size calculations were made to determine if enough samples were taken (Robbins 2012).

Table 1 | Fort Collins, Colorado WWTP anaerobic digesters loading rates

Loading Rates	Max Daily Loading Rates
Solids	37,500 lbs VS/day (17,046 kg VS/day)
Hydraulic	186,900 gallons/day (704 m^3/day)
Organic	0.15 lbs VS/ft^3 d (2.41 kg VS/m^3 d)

Analysis of anaerobic digesters operating capacity

The Fort Collins, Colorado WWTP used in this study processed 11 million gallons a day (MGD) of wastewater and the anaerobic digesters received primary sludge from the primary clarifiers along with waste activated sludge from a secondary treatment process that included an activated sludge process with a secondary clarifier.

An analysis of the operating capacity of the Fort Collins WWTP anaerobic digesters was conducted using hydraulic, solids, and organic loading rates. Determining the operating capacity of the anaerobic digesters allowed for comparison to the maximum loading rates and thus determination of the maximum amount of food waste addition to the digesters. Four anaerobic digesters are operated with each having a maximum operating volume of 3,316 m^3. The anaerobic digesters are classified as mesophilic, high rate digesters which are common throughout WWTPs in the US. Calculations were made using only three anaerobic digesters to provide a factor of safety for a digester that may go offline for maintenance in addition to a possible increase of wastewater flow into the WWTP in the future which in turn would result in increased sludge loading to the anaerobic digesters.

After an estimate of the anaerobic digesters operating capacity was completed, an estimate of the maximum amount of food waste addition was determined. The average amount of VS added to the anaerobic digesters was the limiting loading capacity (maximum daily solids loading rate) minus the average daily limiting loading (2010 daily solids loading rate). The average TS percentage and average VS/TS ratio for the food waste from the characterization study was used to convert solids loading from kg VS of food waste per day to kg of food waste per day. The maximum amount of food waste (in kg 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 kg/day).

Estimated biogas production

The estimated biogas production as a result of using various amounts of food waste feedstock was an important parameter that needed to be determined. To determine the expected gas production from the food waste, the amount of digested sludge (in kg VS/day) that exited the anaerobic digesters needed to be calculated. In the 2010 anaerobic digester data, the daily TS% and VS/TS ratio concentrations were given for digested sludge. The amount of VS that exited the anaerobic digesters daily was calculated using the equation presented below:

$$\mathrm{kgVS}/d = (Q_{\mathrm{primary}} + Q_{\mathrm{WAS}} + Q_{\mathrm{FW}}) * 8.34 * \mathrm{TS\%} * \frac{\mathrm{VS}}{\mathrm{TS}}$$

Q_{primary} = Primary sludge flow rate
Q_{WAS} = Waste activated sludge flow rate
Q_{FW} = Food waste flow rate

(developed from Central Marin Sanitation Authority 2008).

This calculation allowed for the VS reduction in the digesters to be determined.

Estimating the VS reduction within the anaerobic digesters allowed for an estimate of the anaerobic digester biogas production. The kg of VS destroyed was calculated to determine the digester biogas production. Total digester biogas production can be estimated from the percentage of VS reduction. Typical values vary from 0.75 to 1.12 m^3 (12 to 18 ft^3) of digester biogas produced per kg (lb) of VS destroyed (Tchobanoglous & & Burton 1991). To provide a conservative estimate of biogas production, 0.75 m^3/kg (12 ft^3/lb) VS destroyed was applied.

Economic analysis

Using data calculated for added digester gas production as a result of food waste addition, an economic analysis to determine feasibility of implementing energy generation and food waste diversion was completed. Finding key economic breakpoint values on where the project would see a positive return on investment was important throughout the analysis.

The enhanced biogas production from the food waste in the digesters needed to be monetized. A thorough economic analysis was completed and a key component of that analysis was the estimated biogas and associated biogas production from various amounts of food waste added. Beginning with the 364 kg (800 lbs) of food waste per day, multiple iterations were completed with varying amounts of food waste added. Of note, the characterized food waste's TS% and VS/TS ratio were used to represent all food waste. These values may change depending on the source and type of food waste used as discussed previously.

Finally, depending on the type of food waste treatment process used, there may be losses of VS associated with the processing of the waste. These losses were not accounted for during the iterative process to determine biogas production based on food waste addition amounts. It was 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 than the specified amount to ensure that the amount of food waste required makes it to the digesters due to losses.

Economic analysis of using flared biogas as fuel source for energy generation

An economic analysis of purchasing and operating three types of energy generation technologies (fuel cells, microturbines, and internal combustion reciprocating engines) was completed and then expanded to include additional biogas produced from various amounts of food waste added to the digesters. Using 2009 capital and O & M cost data from the National Renewable Energy Laboratory (NREL) and cost data from the EPA Combined Heat and Power (CHP) Partnership converted into current dollars using a Gross Domestic Product (GDP) deflator along with flared biogas as a fuel source, the various technologies were evaluated (Remick 2009 and USEPA 2008). The Molten Carbonate Fuel Cell (MCFC) and Phosphoric Acid Fuel Cell (PAFC) were immediately eliminated from consideration due to the capital cost for each being too large. Using the Fort Collins 2012 electric rate structure, cost savings for using the excess biogas produced at the plant for electricity generation was determined (City of Fort Collins 2011).

A 20 year analysis of savings versus costs of utilizing an energy generation technology at the plant was conducted. Capital and O & M costs were typically reported as a range so three cases were developed: best, base, and worst (these values are shown in Table 2). The best case scenario used the low end reported costs, the worst case scenario used the high end reported costs, and the base case scenario used the general median reported costs.

Finally, before completion of the analysis, the heating component of energy generation technologies needed to be factored into the analysis. Energy generation technologies produce waste heat during electricity generation that can be recovered and applied to meet heating needs. The electric heat

Table 2 | Capital and O & M costs ranges for energy generation technologies (in 2011 Dollars)

Technology	Best Case (Capital – O & M)	Base Case (Capital – O & M)	Worst Case (Capital – O & M)
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

rate (in Btu per kWh produced) reported by the EPA CHP Partnership for microturbines and reciprocating engines provided an estimate on how much heat could be generated and applied to meet heating needs throughout the WWTP. Furthermore, infrastructure needed to be added to the plant to bring the heat (mostly in the form of steam) to where it was required to replace natural gas use. An estimate of $100,000 in capital costs to upgrade infrastructure for heating was made for the analysis and a sensitivity analysis was completed ranging from $50,000 to $500,000 to determine the effect of various upgrade costs.

Economic analysis of food waste diversion program

After completion of an economic analysis utilizing only flared biogas, an economic analysis incorporating a food waste diversion program was completed. The addition of 13.64 tonnes (15 tons) per day of food waste was set as a reasonable baseline for a food waste diversion program after evaluating other current or projected US food waste diversion programs. A food waste separation facility (either at a solid waste transfer facility or at the plant) needed to be constructed along with a food waste treatment facility (at the plant) in order to turn raw food waste into a viable anaerobic digestion feedstock. Another factor added into this economic analysis was landfill tipping fees. In the Northern Colorado area, landfill tipping fees are around $20 per short ton. However, when compared to other US regions, this tipping fee was relatively low. For example, in California, it was common to see tipping fees that exceed $100 per short ton. Utilizing cost data reported in the EPA's Co-digestion Economic Analysis Tool (CoEAT) and from the Central Marin Sanitation Authority (CMSA) food waste to energy facility pre-design report, an estimate on how much it would cost to implement a food waste diversion program utilizing anaerobic digesters and Fort Collins food waste was completed (CMSA 2010) .

RESULTS

Food waste characterization

The CSU food waste compared favorably to other food waste characterization studies with the TS percentage determined to be approximately 23% and the VS/TS ratio at approximately 91%. In literature, typical food wastes had a TS percentage reported from approximately 10–30% and a VS/TS ratio ranging between 90 and 95% (Zhang *et al*. 2007). Food waste collected from CSU was typical of other food waste quality reported in the literature (sampling data shown in Table 3). For further analysis, the CSU food waste was used to represent food waste in the Fort Collins area and depending on the source and type of food waste used estimations that follow could vary. However, the CSU food waste provided a good starting point for the analysis.

Analysis of anaerobic digesters

Capacity. Using 2010 anaerobic digester data (provided in Table 4), the limiting factor based on the three rates was determined to be the solids loading rate (Table 5).

Table 3 | CSU Ram's horn dining facility food waste characterization data

Sample	Sample Date	TS (%)	VS/TS (%)
1	8-Nov-11	17.72	87.00
2	8-Nov-11	23.11	85.91
3	15-Nov-11	29.61	96.74
4	15-Nov-11	28.02	95.44
5	29-Nov-11	11.26	93.83
6	29-Nov-11	25.27	89.54
7	6-Dec-11	20.22	91.08
8	6-Dec-11	26.56	86.13
9	13-Dec-11	23.42	94.32
10	13-Dec-11	23.89	94.44

Table 4 | 2010 Anaerobic digester data for fort Collins, Colorado WWTP

Month	Q_{IN} (m^3 / d)	Q_c (d)	VS$_{IN}$ (kg VS / d)	VS$_{OUT}$ (kg VS / d)	VS Reduct. (%)	Biogas Produced (m^3)
January	245.4	54.99	8,488	3,120	63.25	4,015
February	290.6	46.21	10,788	3,855	64.27	5,185
March	309.1	43.16	11,054	4,127	62.66	5,180
April	304.5	44.12	11,299	3,773	66.60	5,628
May	254.0	54.63	10,058	3,308	67.11	5,048
June	255.9	52.27	10,243	3,348	67.31	5,156
July	231.5	58.14	8,960	3,153	64.81	4,343
August	229.8	57.78	8,617	3,216	62.68	4,039
September	242.2	54.83	10,026	3,399	66.10	4,956
October	255.1	52.05	10,293	3,608	64.95	5,000
November	257.6	51.62	9,861	3,568	63.82	4,706
December	235.3	56.74	9,007	3,009	66.59	4,485
AVERAGE	259.3	52.21	9,891	3,457	65.01	4,812

The situation in Fort Collins is common in many municipalities where a large portion of the anaerobic digester capacity is not being utilized and thus could accommodate an additional feedstock. With the determination of the limiting loading rate and the operating capacity of the anaerobic digesters the theoretical maximum amount of food waste that can be added was calculated.

Using the methodology described earlier and the information presented in Table 2, the maximum amount of raw food waste that could be added to the anaerobic digesters daily is 34 tonnes (37.5 tons).

Table 5 | Loading rates and associated operating capacities

Loading Rates	Max Daily Loading Rates	2010 AD Daily Loading Rates	AD Operating Capacity
Solids (kg VS/day)	17,045	9,891	58.03%
Hydraulic (m^3/day)	708	259	36.60%
Organic (VS/m$^3 \cdot$ d)	2.41	1.0	41.30%

Estimated biogas production

Without any food waste addition, the average daily VS reduction in the digesters was approximately 65%. With 4.55 tonnes (5 tons) per day food waste added the VS reduction would increase to an estimated 68%. With the maximum amount of 34 tonnes per day food waste added the VS reduction would increase to an estimated 80%. This projected increase in solids reduction would occur due to the high VS content of food waste and demonstrates why food waste would be a viable and valuable anaerobic digestion feedstock.

Notable increases in digester gas production begin to be shown when 4.55 tonnes/day of food waste is added (Figure 4). At this point, gas production estimates increased by over 15%, which equated to approximately 700 m^3/day (approximately 25,000 ft^3/day) of extra digester gas for use in the plant. An increase of biogas production of 45% occurred at the 13.64 tonnes/day (15 tons/day) increase point and an increase of 75% occurred at the 22.72 tonnes/day (25 tons/day) increase point. At the maximum amount of food waste addition, there is an increase of 117%.

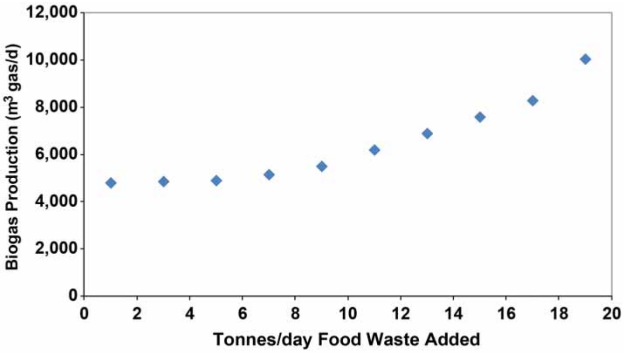

Figure 4 | Digester biogas production results.

Economic analysis of using flared biogas as a fuel source for energy generation

Biogas from anaerobic digesters fueled boilers to provide heat for the WWTP. WWTP personnel stated that they covered approximately 60% of their plant heating using biogas and a seasonal variation existed for the biogas need. In the winter there was not enough methane to support the plant's heating needs while in the summer there was excess biogas. For almost all WWTPs with seasonal variation, this would be a common problem in trying to beneficially use biogas from the anaerobic digesters. This spurred interest in looking at energy generation technologies to further beneficially use excess biogas.

To supplement their biogas fueled boilers for heating, natural gas boilers and heating units were utilized. Data for the plant's monthly use of biogas for heating and flaring along with natural gas use was provided (shown in Figure 5). Natural gas was primarily used in the colder winter months for heating with the majority of biogas produced from the digesters being used in the boilers. During the warmer months, the majority of biogas from the digesters was flared.

For natural gas, the Fort Collins WWTP pays approximately $0.71 per therm (lower than the national average of $0.87 per therm as reported by the Energy Information Administration (EIA)). Using the amount of therms determined in Figure 5, an estimation of costs, savings, and value related to natural gas and biogas use for heating was completed (shown in Table 6).

The Fort Collins WWTP in 2010 paid approximately $64,576 for natural gas to fuel their boilers when not enough biogas was being produced. However, they generated a savings of $116,231 for 2010 by utilizing excess biogas produced in their anaerobic digesters to fuel heat boilers. Additionally,

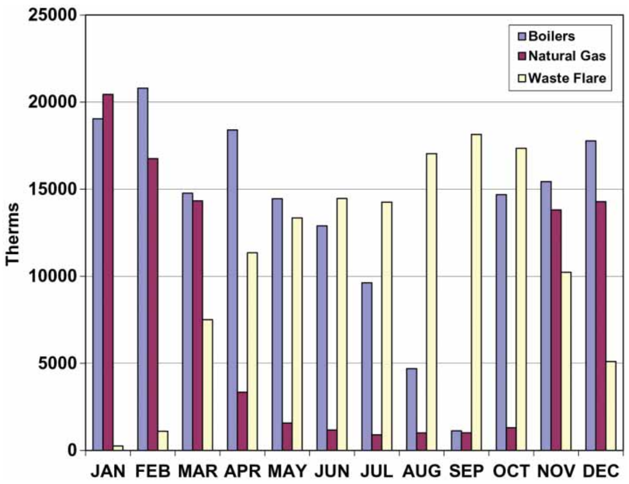

Figure 5 | Comparison of biogas use vs. natural gas use at a fort Collins, Colorado WWTP in 2010.

Table 6 | Costs, savings, and value of natural gas and biogas use

Type	Costs/Savings/Value	@ National Average	% Increase
Natural Gas Use	$64,576	$78,783	22%
Biogas as Fuel	**$116,231**	**$141,802**	
Flared Biogas	**$92,416**	**$112,748**	

the Fort Collins WWTP flared biogas valued at $92,416 into the atmosphere due to no viable storage option at the WWTP. When applying the national average for natural gas, the cost of natural gas use and savings associated with biogas use increase by 22%.

The initial savings analysis of using excess biogas for electricity generation resulted in the microturbine providing annual savings of approximately $78,000 and the reciprocating engine providing annual savings of approximately $64,000. Energy costs in the Northern Colorado area in general are lower than energy costs in other regions in the US and thus it can be assumed savings as a result of using excess biogas in other US regions would be greater than those reported here.

Both technologies produce enough therms of heat to replace natural gas used for heating at the plant based on their electric heat rate and the amount of electricity that was estimated to be produced annually. The additional savings in regards to heating costs along with the costs associated to heating infrastructure upgrades were factored in to further the economic analysis. In addition, the following assumptions were made to complete the economic analysis:

- 20 year loan at a 3.5% interest rate (typical for municipalities) would be taken out to cover all capital costs associated with adding an energy generation technology at the plant.
- 2% inflation rate applied to both annual costs and savings which created a cost and savings escalator for the 20 year period.
- Gross Domestic Product (GDP) deflator was used to bring costs (in 2008 dollars) to 2011 dollars (equation shown below).

GDP deflator = (Nominal GDP / Real GDP) × 100 (Robbins 2012)

A cumulative cash flow for the 20 year lifetime of the project was developed (Figure 6) utilizing the information presented earlier and with the assumptions listed above.

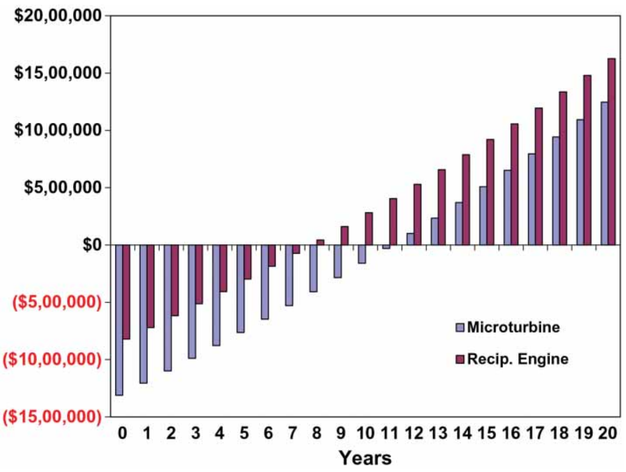

Figure 6 | Cumulative cash flow for energy generation with flared biogas with annualized capital costs and annual O & M costs (heating and electricity).

A further breakdown of costs and savings associated with the above cumulative cash flow are shown in tabular format below (Table 7) and for supporting calculations refer to Robbins 2012.

Table 7 | Breakdown of costs and savings associated with Figure 6

Parameter	Microturbine	Recip. Engine
Annual Savings (on electricity and heating)	$142,272	$128,560
Purchase Cost of Technology	$695,055	$412,817
Capital Cost over 20 Year Lifetime	$1,311,380	$821,418
Annualized Capital Cost	$65,569	$41,071
Annual O & M Cost	$37,009	$27,820
Total Annual Costs	$102,578	$68,891
Total 20 Year Savings	$3,456,835	$3,123,670
Total 20 Year Costs	$2,210,597	$1,497,381
20 Year Return	$1,246,238	$1,626,289

Both a microturbine and reciprocating engine used for energy generation with flared biogas as a fuel source results in a return on investment over the 20 year period. The reciprocating engine produces less power and thus has less annual savings but with lower capital and O & M costs provides a larger return on investment than the microturbine. The cumulative cash flow chart in Figure 3 shows results for the base case, but even with the worst case scenario both technologies provide a return on investment of over $500,000 for the 20 year time period.

Economic analysis of food waste diversion program

In order to evaluate the economic feasibility of a food waste diversion program, an estimate needed to be made to determine the cost of a full scale food waste diversion program utilizing the anaerobic digesters at the Fort Collins WWTP. As discussed previously, the USEPA CoEAT was used along with the CMSA food waste to energy facility pre-design report to develop a cost estimate for the food waste diversion program (Table 8).

The total capital cost of $2,448,110 associated with a food waste processing operation shown above was used in the economic analysis of a food waste diversion program. The increased biogas production due to the added 13.64 tonnes per day of food waste would bring an initial annual savings

Table 8 | 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 or $/0.093 m^2)	$100	1,000	$100,000
Odor Control System	$85,000	1	$85,000
H_2S Scrubber Tank	$5,000	1	$5,000
H_2S Scrubber Media	$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
Fats, Oils, Grease (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	

increase on electricity generation of approximately $20,000 for the microturbine and approximately $17,000 for a reciprocating engine compared to utilizing only excess biogas at the WWTP. The same values for inflation and interest rates and other economic parameters as the previous economic analysis with flared biogas were used and a 20 year economic analysis was completed using the increased energy savings from food waste addition and the total capital cost of a food waste processing operation (Figure 7).

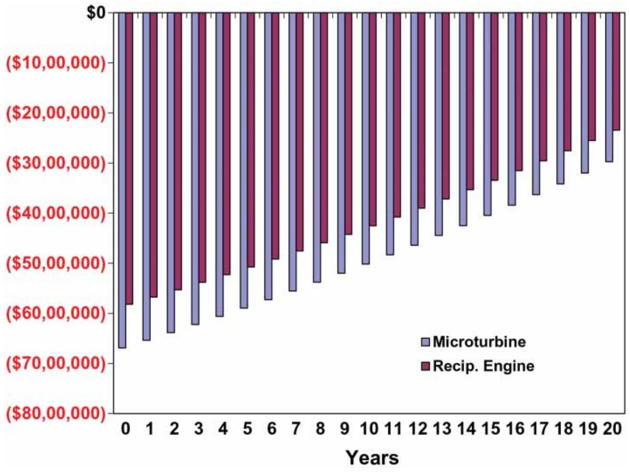

Figure 7 | Cumulative cash flow for energy generation with flared biogas and 13.64 tonnes/day of food waste addition with annualized capital costs and annual O & M costs (best case).

The results of the economic analysis of 13.64 tonnes per day of food waste were not favorable to a food waste diversion program being economically feasible. Even for the best case scenario, the estimated capital cost of approximately $2.5 million to begin a food waste diversion program utilizing both a food waste separation and processing facility would be too large to overcome. Both technologies would lose an estimated $2.5–3.5 million over 20 years. In order for both technologies to provide a return on investment over 20 years, the initial capital costs associated with a food waste diversion program would need to be less than $475,000.

Economic factors to improve feasibility

Increase in certain costs related to energy, fees, and maintenance along with decreases in capital and O & M costs for technologies could change the outlook for a food waste diversion project. A comparison was made between the marginal cost of a food waste diversion program and the savings associated with it (shown in Figure 8).

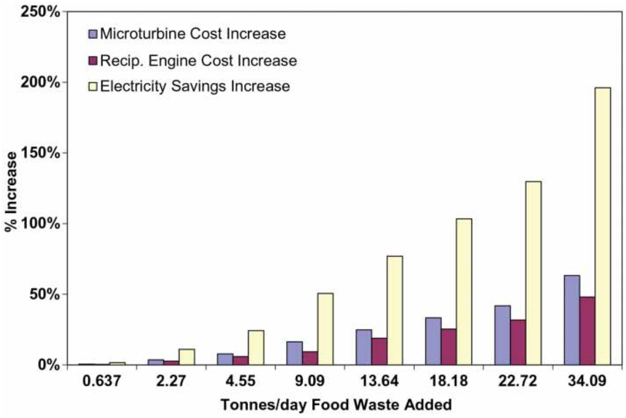

Figure 8 | Marginal cost vs. savings increase.

As more food waste is added to the anaerobic digesters, the savings substantially outpaces the marginal cost of the diversion program. Typically, the savings are 3 to 4 times greater than the cost associated with the diversion program which indicates that in certain areas of the country, a food waste diversion program can be economically feasible.

In regards to electricity costs, the Fort Collins area has substantially cheaper rates than other areas in the US. An electric rate schedule typically has an energy charge ($/kWh), a coincident peak demand charge, and a distribution facilities demand charge. The latter two charges fluctuate based on the monthly demand placed on the electricity provider. The Energy Information Administration (EIA) listed the July 2012 national average as $0.1010 per kWh for commercial users. The Fort Collins WWTP average energy charge for 2012 was $.0358 per kWh which is substantially lower than the national average. When using the national average for energy charge, the electricity savings for the microturbine increases from approximately $78,000 to $177,000 per year and the savings for the reciprocating engine increases from $64,000 to $146,000 per year. For the base case, this results in a net return on investment over the 20 year period of $3.67 million for the microturbine and $3.62 million for the reciprocating engine without a food waste diversion program (this represents a $2 million increase when compared to calculations made with the lower energy rates). With a food waste diversion program at 13.64 tonnes/day added, the net return on investment, the electricity savings for the microturbine increases from approximately $140,300 to $320,500 per year and the savings for the reciprocating engine increases from approximately $115,400 to $263,500 per year. For the base case, this results in a net return on investment over the 20 year period of $456,200 for the microturbine and $365,000 for the reciprocating engine ($3.25 million increase for the microturbine and $2.5 million increase for the reciprocating engine when compared to calculations made with the lower energy rates). This demonstrates that a food waste diversion program can be viable at energy costs similar to the US national average. As the energy costs increase, the microturbine will provide a better value than the reciprocating engine due to production efficiency.

CONCLUSIONS

The use of flared biogas to generate electricity and additional heat utilizing a microturbine or reciprocating engine is economically viable and feasible for numerous WWTPs. The flared biogas is a commodity not being beneficially used and turning the resource into energy would benefit WWTPs economically. With only using the excess biogas produced in the anaerobic digesters, the WWTP used in this study would achieve an estimated $1.6 million return on investment over a 20 year time period utilizing a reciprocating engine energy generation technology and an estimated $1.2 million return on investment over the same time period utilizing a microturbine energy generation technology. With the implementation of a food waste diversion program, the capital cost for a food waste processing operation would be approximately $2.5 million which would result in a net loss on investment of approximately $2.5 to $3.5 million when utilizing the same technologies over the same 20 year time period. While the cost for a food waste diversion for this project rendered it unfeasible, such a program can become economically feasible at energy rates at or above the national average. However, there exist many variables in regards to costs of energy and also costs associated with collecting and processing food waste that can cause a significant fluctuation on the economic analysis of any food waste diversion program. These costs need to be vetted thoroughly before any WWTP decides to pursue a food waste diversion program.

REFERENCES

2009 F2E Work Plan Food Waste to Energy Facility Predesign 2010 *Central Marin Sanitation Authority*. San Rafael, CA, USA.
Anaerobic Digestion of Food Waste – Final Report 2008 East Bay Municipal Utility District, Oakland, CA, USA.
Catalog of CHP Technologies 2008 *United States Environmental Protection Agency Combined Heat and Power Partnership*. Washington, DC, USA.
Central Marin County Commercial Food-to-Energy Program 2011 *Central Marin Sanitation Authority*. San Rafael, CA, USA.
City of Fort Collins 2012 Electric Rates 2011 *City of Fort Collins Ordinances 142 and 166*. Fort Collins, CO, USA.
Co-Digestion Economic Analysis Tool (CoEAT) 2010 *United States Environmental Protection Agency*. Washington, DC, USA.
Colorado PUC Number 6 Gas Rates 2011 *Public Service Company of Colorado*. Denver, CO, USA.
Methane Capture Feasibility Study 2008 *Central Marin Sanitation Authority*. San Rafael, CA, USA.
Monthly Energy Review January 2012 *2012 United States Energy Information Administration*. Washington, DC, USA.
Operating Anaerobic Digestion Plants of Commercial Scale List 2008 *International Energy Agency*. Paris, France.
Robbins, C. 2012 *Food Waste Diversion for Enhanced Methane Gas Production at the Drake Water Reclamation Facility*. Colorado State University, Fort Collins, CO, USA.
Remick, R. 2009 Fuel Cells on Biogas. 2009 Michigan Water Environment Association's Biosolids and Energy Conference. Michigan, USA.
Tchobanoglous, G. & Burton, F. 1991 *Wastewater Engineering: Treatment, Disposal, and Reuse*. 2nd Edn., Metcalf & Eddy.
Turning Food Waste into Energy at the East Bay Municipal Utility District 2009 *United States Environmental Protection Agency*. Washington, DC, USA.
Zhang, R., Mashad, H., Hartman, K., Wang, F., Liu, G., Choate, C. & Gamble, P. 2007 Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technology* **98**, 929–935.