ANAEROBIC DIGESTION OF FATS, OILS, AND GREASE TO GENERATE BIOGAS

BIOPOWER FEASIBILITY STUDY
REIPR 12226

Renewable Energy Incentive Program
New Jersey Clean Energy Program
c/o Conservation Services Group
75 Lincoln Highway, Suite 100
Iselin, NJ 08830

April 2013

PREPARED BY
BIRDSALL SERVICES GROUP
611 INDUSTRIAL WAY WEST
EATONTOWN, NEW JERSEY
07724

BIRDSALL SERVICES GROUP
ENGINEERS & CONSULTANTS

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ACKNOWLEDGMENTS

Birdsall Services Group, Inc. (BSG) acknowledges and thanks the New Jersey Clean Energy Program for the funding provided to conduct this study.

BSG acknowledges and thanks the Bergen County Utilities Authority (BCUA) Staff for their assistance in conducting this study. In particular, BSG is grateful to Mr. Eric Andersen, P.E., Chief Engineer/Director of Water Pollution Control Division, Mr. Walter Paul, Mr. Edward Switay, Plant Managers, Mr. David Hudspeth, Chief Sewage Plant Operator, and Mr. Riaz-Ul Hasan, Supervising Laboratory Technician.

BSG would like also to acknowledge the contribution of Russell Reid, the hauling company that delivered the FOG for the field pilot study.

1.0 EXECUTIVE SUMMARY

Food establishment services (FES) generate large amounts of grease products. Grease collected from grease traps installed in FES to separate it from wastewater is commonly termed trap grease or black grease, but will be herein referred to as FOG. Given its contamination with soap, solids, chemicals and high water content, FOG does not command a premium for use in animal feed products or biodiesel feedstock. Quantities of FOG generated in the study area were derived using Bergen County Census Data and a study conducted by the National Renewable Energy Laboratory (NREL) in thirty urban centers. Normalized to a per capita basis, the NREL study indicates that FOG from FSE is generated at a rate of 13 pounds/person/year.

A pilot study was conducted at the Bergen County Utility Authority (BCUA) wastewater treatment plant located in Little Ferry. . The pilot study indicated that the anaerobic co-digestion of FOG generate about 8.2 SCF biogas per gallon of FOG introduced into the anaerobic digester system.

The pilot program was successful as it demonstrated that (i) FOG co-digested with biosolids in the existing anaerobic digester can significantly boost the biogas production and (ii) the only encountered operational problem was linked to the presence of debris in the received FOG. A simple, field proven, low cost, and easy to implement solution is provided by BSG.

Utilization of biogas from the anaerobic digestion of FOG and biogas currently flared could be utilized to power an additional 1.4 MW combined heat and power engine. A financial analysis indicates that for a 1.4 MW combined heat and power engine and a FOG receiving facility, the required capital investment after incentives is about 4.5 million dollars with a simple payback time of 3 years.

With both positive environmental, renewable energy and financial benefits demonstrated though this study, BSG recommends that BCUA implement a full scale FOG receiving and processing program.

2.0 INTRODUCTION

Domestic and commercial food establishments generate large volumes of wastewater that contain significant amounts of fats, oil, and grease (FOG). FOG must be separated from wastewater prior to entering the sewage system, primarily because of its propensity to block municipal sewer lines and disrupt the effective operation of downstream treatment processes. Hence, grease separators (i.e. grease traps and interceptors) are installed between wastewater effluent points and the sewer system to allow FOG to be trapped in a chamber, while FOG-free (or reduced) water exits to the sewer.

The motivation for separating FOG from wastewater is not entirely associated with problems related to disposal in sewage systems. The recovered FOG can be used as a valuable renewable resource feedstock for its conversion to biogas.

The purpose of this project was to demonstrate that the co-digestion of FOG with biosolids in an existing wastewater anaerobic digester will boost the production of biogas, induce revenues, and identify potential operating problems. Next, the obtained results will be utilized to conduct a financial analysis to assess the viability of installing and operating a FOG receiving facility and an additional combined heat and Power (CHP) unit.

3.0 BROWN GREASE (FOG) SOURCES AND CHARACTERISTICS

In urban environments, FOG is produced at many locations, primarily where food is cooked, which includes residences and restaurants, but also at other large food preparation facilities and food or industrial processing plants. At restaurants, food preparation facilities, and certain industrial facilities, FOG is collected to prevent it from being discharged in large quantities to the sewers where blockages and other problems can occur. This study does not discuss the regulatory framework that prevents or minimizes grease discharges to municipal sewers, but such framework may exist or exists in urban locations in Bergen County. Many municipalities have ordinances prohibiting fats, oils and greases from being discharged to receiving sewer lines, and many of those same municipalities frequently experience problems in clogs and back-ups due to FOG deposits in their lines. Specifics of these regulatory programs vary considerably among municipalities and enforcement of such programs can also be quite variable.

Chemically, fats, oil, and grease (FOG) are all structurally lipids (Van Gerpen et al., 2004). At low temperatures, grease is largely congealed, creating a clotty mass. However, at warmer temperatures, it is more uniform and more easily "flowable". Oils are generally considered to be liquids, while greases are solid. Waste grease is categorized as "yellow" if it contains less than 15% free fatty acids (by weight) and categorized as brown grease if the FFA fraction is higher than 15%. The FOG classification based on FFA content is summarized in Table 1.

Table 1: FOG Classifications Based on FFA Content

Designation	Free Fatty Acid Content (%)
Virgin/neat/refined	< 1.5
High-quality yellow grease	< 5
Low-quality yellow grease	5 - 20
Brown grease	20 - 100

FOG collected from grease traps and interceptors has highly variable characteristics, as indicated by many studies on the subject and data collected (Li et al, 2002, and Suto et al, 2006). For instance, the total solids (TS) in collected FOG can vary from under 2 percent to over 15 percent. The material is acidic and the volatile solids-to-total solids (VS/TS) ratio is commonly in the range of 94 to 97 percent. It should be noted that FOG received at BCUA exhibited similar characteristic.

4.0 ANAEROBIC DIGESTION FOR ENERGY AND OTHER BENEFITS

Recently, the energy value of the brown grease has been recognized. The two main routes to convert brown grease to energy are its transformation to (1) biodiesel and (2) biogas.

Brown grease is not only a mix of lipid constituents; it is a differing mix from batch to batch and one restaurant from another. Due to the level of contaminants, such as food wastes and other particulates, chemicals, etc, FOG collected from grease traps is problematic in biodiesel production facilities as it requires numerous processing steps to remove water, malodorous compounds, particulates, and any compounds that could interfere with the synthesis reactions and reduce the biodiesel production yield. While converting yellow grease (e.g. used cooking oil) to biodiesel is a straight forward process, the main challenges when using brown grease as a feedstock are (1) overcoming the highly heterogeneous nature of brown grease, (2) pre-treatment and (3) managing the complications inherent in its higher free fatty acid content. All these steps add to the required initial investment and operating costs in converting brown grease to biodiesel.

In many wastewater treatment plants, anaerobic digestion is used to further treat the primary sludge and waste activated sludge (WAS) generated through the biological treatment of wastewater. Anaerobic digestion has several favorable characteristics that make it a growing treatment technology, especially when considering environmental impacts. It is an enclosed bioreactor where, under anaerobic conditions, microorganisms digest organic matter to produce biogas that consists of about 60% methane and 40% carbon dioxide. The biogas can then be utilized as energy feed stock to generate electricity and waste heat, to power equipment, and fulfill heating requirements for the plant, thereby reducing the wastewater treatment plant energy costs.

FOG can be co-digested with WAS in wastewater treatment plants equipped with anaerobic digesters. For high capacity wastewater treatment plants, the co-digestion process does not require concentrating the FOG stream. Generally, the entire grease-trap contents can be added directly to the digester after the removal of solid debris (straws, rags, plastic ware, etc.). When properly fed and anaerobically digested, FOG produces biogas at high production rate. The benefits of collecting FOG from food establishment services and further processing it as a co-substrate in anaerobic digesters include:

1. Increased biogas methane generation, along with energy and economic benefits;
2. Receiving FOG tipping fees
3. Minimizing sewer grease buildup and clogged sewers; and
4. Minimizing the problems with illegal disposal or landfill disposal of these wastes.

5.0 LITERATURE REVIEW ON THE ANAEROBIC CO-DIGESTION OF WASTE ACTIVATED SLUDGE AND BROWN GREASE

Through a literature search we have identified a number of peer-reviewed scientific publications on the co-digestion of FOG and waste activated sludge (biosolids). These research papers show remarkable potential for biogas production.

Co-digestion is a waste treatment method where different types of wastes are treated together. Co-digestion of wastewater produced biosolids with carbon-rich food wastes, such as FOG, has been used in industry due to its positive effect on biogas production (Zitomer and Adhikari, 2005); but the mixture is usually a function of availability and not based on knowledge of an optimal mixture (Gavala et al., 1996; Kübler et al., 2000)

Digesting materials with high-fat content increases methane yields due to the more negative oxidation state of the carbon in fats compared to proteins, carbohydrates, and urea (Jerger and Tsao, 1987). Cirne et al. (2007) have shown that digesting materials with high lipid content increases methane yield, which can result in a reduction in pH in the digester environment, especially if the slower growing methanogens cannot utilize the organic acids at the production rate of acetogenic bacteria; and Jeyaseelan and Matsuo (1995) reported an increase in digester efficiency. Ugoji (1997) reported that co-digestion of lipid-rich materials with waste activated sludge prevents the system from becoming overly acidic.

Kaboris et al. (2009) assessed the anaerobic biodegradability of a mix of municipal primary sludge (PS), thickened waste activated sludge (TWAS) and fat, oil, and grease (FOG) using semi-continuous feed, laboratory-scale anaerobic digesters operated at mesophilic (35 °C) and thermophilic (52 °C) temperatures. Addition of a large FOG fraction (48% of the total VS load) to a PS + TWAS mix, resulted in three times larger methane yield, 152 vs. 449 mL methane @ STP/g VS added at 35 °C and 2.6 times larger methane yield, 197 vs. 512 mL methane @ STP/g VS added at 52 °C. The high FOG organic load fraction was not inhibitory to the process. The results of the Kaboris et al study demonstrate the benefit of sludge and FOG co-digestion.

Davidson et al. (2008) measured the methane potential in batch laboratory tests, and the methane yield in continuous pilot-scale digestion. Co-digestion of brown grease (collected from grease traps) and sewage sludge was successfully performed both in laboratory batch and continuous pilot-scale digestion tests. The addition of brown grease to sewage sludge digesters was seen to increase the methane yield by 9–27% when 10–30% of brown grease (on VS-basis) was added. It was also observed that the brown grease increased the methane yield without increasing the sludge production.

Luostarinen et al. (2009) studied the feasibility of co-digesting grease trap sludge from a meat-processing plant and sewage sludge in batch and reactor experiments at 35 °C. Grease trap sludge had high methane production potential (918 m^3 per metric ton of VS added; that is 14.7 SCF/lb of VS added), but methane production started slowly. When mixed with sewage sludge, methane production started immediately and the potential increased with increasing grease trap sludge content. Semi-continuous co-digestion of the two materials was found feasible up to grease trap sludge addition of 46% of feed volatile solids (hydraulic retention time 16 days; maximum organic loading rate 3.46 kg VS/m^3-day). Methane production was significantly higher and no effect on the characteristics of the digested material was noticed as compared to digesting sewage sludge alone. At higher grease trap sludge additions (55% and 71% of feed volatile solids), degradation was not complete and methane production either remained the same or decreased.

Successful full-scale grease co-digestion operations in the U.S. include the East Bay Municipal Utilities District (Oakland, CA), the Fresno/Clovis Regional Water Recycling Facility (Fresno, CA), the City of Riverside (Riverside, CA), the Waco Metropolitan Area Sewerage District (Waco, TX), and the South Cross Bayou Wastewater Treatment Plant (Pinellas County, FL).

6.0 POTENTIAL BROWN GREASE FEED STOCK IN BERGEN COUNTY

In 1998, the National Renewable Energy Laboratory (NREL) conducted a study funded by the U.S. Department of Energy to collect and analyze data on urban waste grease resources in 30 randomly selected metropolitan areas in the United States. The metropolitan areas ranged in size from Bismarck, North Dakota (population 83,831) to Washington, DC (population 3,923,574). Two major categories of urban waste grease were considered in the study: (1) yellow grease feedstock collected from restaurants by rendering companies; and (2) grease trap wastes from restaurants, which can either be pumped into tank trucks for disposal or flow through municipal sewage systems into wastewater treatment plants.

The number of restaurants in most of the 30 metropolitan areas studied is quite consistent. It ranged from 1.1 to 1.9 restaurants per 1,000 people, and usually in the middle of this range, with a weighted average of 1.41 restaurants per 1,000 people. Cultural and dietary preferences greatly affect the amount of grease used in cooking. The amount of grease discarded from certain fast food restaurants is especially high. Despite significant local variations among neighborhoods' grease outputs, when entire metropolitan areas are considered, the quantities of grease were found reasonably consistent on a per capita (and a per restaurant) basis. The weighted average brown grease generation was estimated at 9,453 pound/year/restaurant. Generally, population of metropolitan area, state, or other geographic area is easier to obtain than the number of restaurants in that area. Regression analysis showed that restaurant grease collected from restaurants and restaurant grease traps could be predicted from both the number of restaurants (R-squared value of 0.908) and the number of people (R-squared value of 0.930) in a metropolitan area. For this reason, it is convenient to express the FOG generation in unit mass per capita. The weighted average FOG production was found to be 13 pound/year/person (R-squared value of 0.985). Therefore, FOG generation estimates, in a given service area can be computed from population data and FOG production rate.

Table A-1 in Appendix A presents the number of Food Service Establishments (FSE), population, and the number of FSE per 1,000 people by municipality in Bergen County. Population estimates were obtained from the 2010 Census population data. Food establishment services data were obtained from the New Jersey 2002 Economic Census data on accommodation and food services. Table A-1 indicates that there are about 2 restaurants per 1,000 people in Bergen County, which compares fairly well with national and regional data reported in NREL study cited above.

The potential brown grease generations in each municipality using the NREL production rate per capita are reported in Appendix A, Table A-2.

According to laboratory analyses performed on FOG delivered to BCUA during the month of May 2012, the weighted average of the solids content is about 8%, which corresponds to a FOG water content of 92%. Based on a generation rate of 13 lb/year/capita and a population of 905,116, the potential production of FOG in Bergen County is about 11.8 million pounds per year. Based on a water content of 92%; the annual volume of FOG that could potentially be pumped out of the FSE grease traps in Bergen County is estimated at 17.6 million gallons per year.

7.0 PILOT DEMONSTRATION STUDY

7.1 Description of the Pilot Demonstration Set-Up

As part of this project, BSG conducted a FOG to biogas pilot demonstration study at the BCUA Water Pollution Control Facility (WPCF) in Little Ferry, Bergen County, New Jersey. The WPCF is a public utility providing sewage disposal services a population of 575,205 from forty-seven (47) municipalities in Bergen County. It is a conventional activated sludge process with a rated capacity of 109 million gallons per day (MGD). The biological treatment process generates primary sludge (PS) and waste activated sludge (WAS). The combination of PS and WAS is herein referred to as biosolids. About 350,000 to 500,000 gallons of biosolids generated daily are fed into five (05) anaerobic digesters. The combined volumetric capacity of the 5 anaerobic digesters is about 4.86 million gallons (972,000 gallons each). One of the five anaerobic digesters at BCUA was used for the FOG co-digestion demonstration project.

A simplified block diagram of the pilot demonstration set-up is provided in Figure 1.

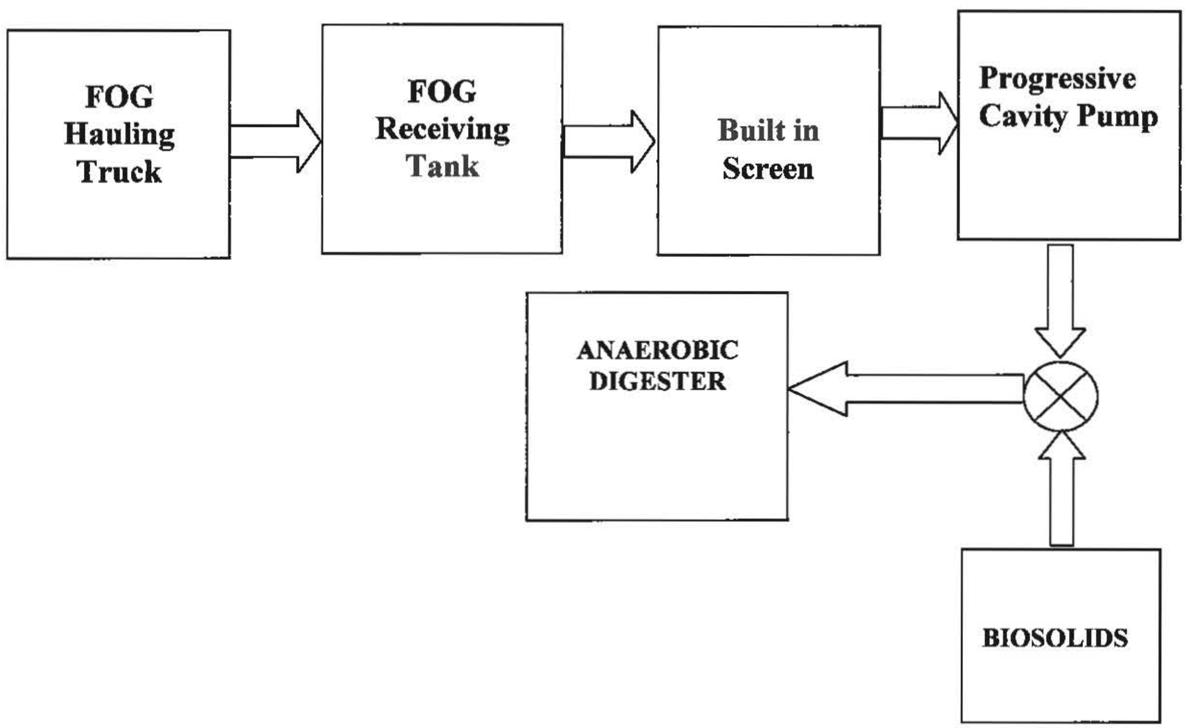

Figure 1: Block Diagram for FOG Processing Pilot Demonstration at the BCUA Facility

An existing, out of service dual underground stainless tank with a capacity of about 5,240 gallons each (total volume of 10,480 gallon) was utilized as the receiving tank for the FOG deliveries. In the past this tank was used to receive grease scum collected from the primary clarifiers. The pit is equipped with numerous piping component and heating elements which are not functional. At that time, the heat "melted "grease scum was fed to either Anaerobic Digester 1 or 2. This operational practice has been abandoned long ago. The pit is equipped with a built in screen aimed at retaining solids. A photograph of the grease pit is shown in Figure 2.

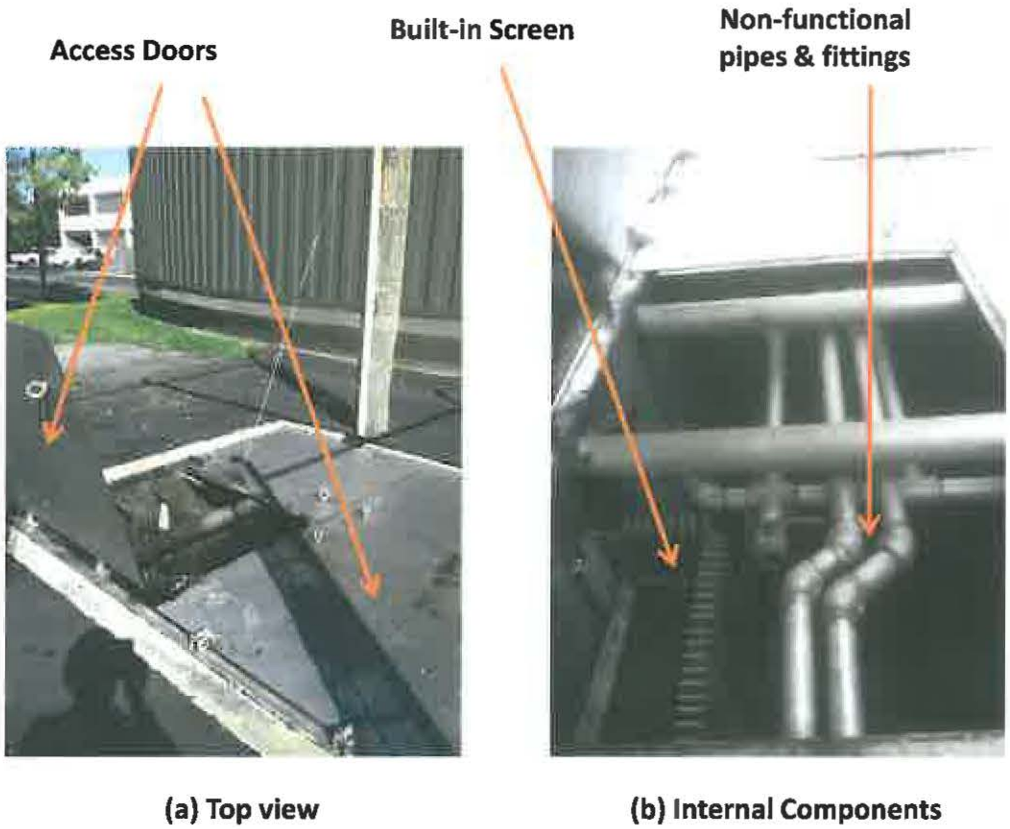

Figure 2: Photographs of the Grease Receiving Pit

The FOG collected from restaurant grease traps in Bergen County was delivered on site by the disposal company Russell Reid. On site, the FOG was discharged from the hauling trucks into the underground storage tank. A typical FOG delivery operation by Russell Reid (a local hauler) is illustrated in Figure 3.

Figure 3: Typical FOG Delivery Operation by Russell Reid

The FOG was fed to a dedicated anaerobic digester using a Moyno progressing cavity pump shown in Figure 4. When the plant biosolids were introduced into the dedicated anaerobic digester, the Moyno pump was started and the pumped grease was introduced simultaneously with the biosolids into the digester through the piping system shown in Figure 4.

(a) Anaerobic Digester

(b) FOG feed Pump

(c) Monyo Progressive Cavity Pump

(d) FOG feed point in Anaerobic Digester

Figure 4: FOG feeding Process from Grease Pit to dedicated Anaerobic Digester

7.2 Characterization of Delivered FOG

FOG collected by Russell Reid from restaurants Bergen County was fed to the grease pit described above. Samples of delivered FOG were routinely taken by BCUA personnel for analyses including total solids (TS), total volatile solids (TVS), pH and density. All these parameters were determined at the BCUA laboratory. FOG hauling trucks were weighted before and after the delivery. The volume of FOG delivered was computed based on the weight difference and the measured FOG density. Quantities and characteristics of FOG delivered by Russell Reid at BCUA for the month of May 2012 are summarized in Table 2.

Table 2: Fog Deliveries and Characterization

	FOG DELIVERIES			FOG CHARACTERISATION			
Date	Truck Weight In (Pounds)	Truck Weight Out (Pounds)	Net Weight Delivered (Pounds)	pH	TS (%)	TVS (%)	Specific gravity
5/1/2011	63,660	31,440	32,220	4.96	2.66	88	1.00857
5/2/2011	69,020	31,220	37,800				
5/3/2011	65,680	30,440	35,240	4.62	11.4	98	0.9872
5/7/2011	60,680	30,000	30,680	4.2	1.82	87	1.01058
5/8/2011	59,840	28,320	31,520				
5/9/2011	60,400	26,320	34,080	4.6	3.13	89	1.00157
5/10/2011	58,560	26,340	32,220				
5/14/2011	67,040	32,080	34,960	4.35	56.4	99	1.01966
5/15/2011	66,320	30,260	36,060				
5/16/2011	58,820	35,480	23,340	3.74	9.2	98	1.03545
5/17/2011	58,240	30,100	28,140	4.58	0.45	31.1	0.99756
5/21/2011	55,300	30,180	25,120	4.91	44	98.4	0.9782
5/22/2011	67,820	30,040	37,780				
5/24/2011	65,340	29,340	36,000	4.57	8.08	96.2	0.98807
5/25/2011	60,380	30,060	30,320	4.47	4.55	95.6	0.99168
5/29/2011				5.14	29.18	99.6	1.00743

Data presented in Table 2 were used to compute the average physical properties of FOG. The reported values are based, where appropriate, arithmetic averages or weighted average. Outliers such as, for example, the total solids reported on May 14 were not accounted for. The average FOG physical properties are as follows:

Table 3: Average Characteristics of FOG

Parameter	**Unit**	**Value**
Total Solids (TS)	%	8
Water Content	%	92
Total Volatile Solids/Total Solids (TVS/TS)	%	95
Specific Gravity (s.g)	-	1.0024
Density	lb/gal	8.36
pH	SU	Acidic (4 – 5)

The measured TVS/TS ratio is in excellent agreement with values reported in the literature

7.3 Effect of FOG Addition on Biogas Production

The additional volume of biogas produced in the anaerobic digester, as a result of FOG addition, cannot be measured directly by the flow meters. This is due to the fact that any spike in biogas production following FOG addition will be below the flow metering accuracy. In order to overcome this technical limitation, the total biogas produced during the month of May 2012 in the dedicated anaerobic digester fed with FOG and WAS was compared to the total biogas produced during the month of May 2011 (base line). Data gathered from the SCADA database are summarized in Appendix B, Table B-1. Biogas produced from the digestion of FOG is then computed by subtracting the measured biogas flow rate produced in Digester 1 (May 2012) to the baseline biogas production without FOG addition (May 2011).

These results indicate that the anaerobic co-digestion of 57,200 gallons of FOG resulted in an additional monthly biogas production of 469,263 SCF. This translates to a biogas production rate of 8.2 SCF per gallon of FOG. This observed value compares very well with the reported pilot results of FOG co-digestion at the Sacramento Municipal Utility District (SMUD) wastewater plant in California. In two pilot tests, SMUD reported biogas production rates of 4.5 and 7.3 SCF of biogas per gallon of FOG co-digested with biosolids.

The additional quantity of biogas generated by the addition of FOG in Anaerobic Digester 1 during the month of June 2012 was similarly computed by subtracting the total biogas produced in June 2012 from the June 2011 baseline. The data summarized in Appendix B, Table B-2, indicate that the addition of FOG in Anaerobic Digester 1 during the month of June 2012 resulted in an additional biogas production of 458,810 SCF very close to the results obtained during the previous month (May, 2012).

The pilot demonstration conducted at BCUA clearly indicates that addition of FOG as a co-substrate increases significantly biogas production.

1) The pilot program has demonstrated that FOG can easily be fed as a co-substrate to the existing anaerobic digesters at BCUA to generate additional biogas. The program has shown that the co-digestion of FOG results in the production of 8.2 SCF of biogas per gallon of FOG.

2) This biogas generation rate of 8.2 SCF per gallon of FOG introduced in the anaerobic digester as a co-substrate compares very well with the 7.3 SCF biogas per gallon of FOG obtained during pilot testing at the Sacramento Municipal Utility District (SMUD) wastewater plant in California

8.0 LEGAL

8.1 Permits, Approvals and Timelines

All required permits and approvals, and their timelines are provided below.

8.1.1 Local Zoning and/or Planning Board Land Use Approvals

The FOG will be at accepted by an already existing facility, and processed utilizing the wastewater and sludge treatment processes already in place. This project will require no new development, and uses space already inside the BCUA facility. No zoning or land use approval requirements are anticipated.

8.1.2 State Environmental Permits (i.e., Air and Water Emissions)

The processing of FOG as part of the intent to co-digest it with the stream of biosolids currently fed into the anaerobic digester will trigger some minor modifications to the following permits:

a. Air Permits - The facility-wide operating permit will need a "Minor modification" to the existing scenarios regarding using FOG as an additional feedstock to generate biogas. Since this new feedstock is anticipated to increase biogas production, all air permitting scenarios that reference biogas as a fuel source (flares, co-gen) will have to be modified to show the additional gas and anticipated increased run times and emissions. In addition, the anticipated addition of a new co-gen engine will require a "Major modification" of the Operating permit to reference a new significant source to be added to the facility inventory, along with a new set of emissions data.

The anticipated timeline for air permit modification will be about 4 months from the award of the new co-gen installation contract and selection of specific equipment (engine and emissions control equipment) for the project.

b. Solid Waste Management Plan - since this facility will be providing an alternative processing scenario to the County of Bergen's Solid Waste Management Plan, it is anticipated that an amendment to the plan may need to go through the approval process of the agency responsible for solid waste management and the County Freeholders. As BCUA is the agency responsible for managing solid waste planning in Bergen County, no difficulties are expected.

Anticipated timeline for Agency and freeholders' approval - three months from the inception of the project.

c. Water Permits and Sludge Management Plan - since this facility will be adding new materials with very high volatile solids content into the sludge, it is expected that the volume and constituents of the sludge will be only minimally altered. However BCUA will be required to amend its Sludge Management Plan, as required under the facility NJPDES permit. BCUA is the agency responsible for this plan, and no difficulties are expected.

The anticipated timeline for amending the sludge management plan and NJDEP approval will be about six months from the inception of the project.

8.1.3 NJDEP Sustainability Determination

This feedstock (fats, oil and grease) classifies as a Class I renewable per the applicable state regulations (N.J.A.C. 14:8-2.5(b)7). Accordingly, no sustainability determination is required.

8.1.4 Federal EPA Approval

No US EPA approval is required.

8.1.5 State or Federal Transportation Approvals for Feedstock Shipments

No Federal or State transportation approvals will be required. Existing licensed commercial haulers (i.e. Russell Reid) are already performing this transport, and will simply have the option of redirecting some of their collected FOG loads to the BCUA facility. The result will greatly reduce transportation mileage and costs compared to the system currently in existence.

8.2 Demonstration of compliance with EDC interconnection requirements

BCUA is, and has been for several years, a Customer-Generator from the existing biogas co-generation facility. As such, all interconnect requirements are in place, and have been maintained in accordance with the local EDC (PSE&G). All records for past inspections and installation are available for review at the facility.

8.3 Applicability of Legal Requirements Including but Not Limited To:

As a municipal utility authority, BCUA complies with all bidding requirements as set forth under N.J.S.A. 40A:11-1 et. seq.. In addition, BCUA complies with all other labor citations such as prevailing wage, non-discrimination, and all related requirements under the N.J.A.C. and N.J.S.A. for public bids from a public agency.

8.4 Applicants ability to complete the project within 18 months

Based on the above, compliance with all legal requirements will not adversely impact BCUA's ability to complete the project within 18 months from the date of approval.

9.0 TECHNICAL AND ECONOMIC ANALYSIS

The following analysis estimates, based on a reasonable quantity of FOG that could be delivered and processed by BCUA and the capture of biogas currently flared, the amount of electricity that could be generated on Site.

A parametric analysis is conducted where the main variable is the daily volume of FOG processed in the anaerobic digestion system. To accommodate operational constraints and existing size of gas collection piping and accessories, the maximum volume of FOG is about 42,000 gallons per day (maximum of 7 daily truck loads).

In 2012 and previous years, BCUA has flared an annual volume of biogas of about 119 million cubic feet. This flared biogas originates from the anaerobic digestion of WAS, a renewable energy. In the present analysis, this flared biogas and additional biogas produced by the co-digestion of FOG will be utilized as a renewable energy feed stock for electricity production. It should be noted that there are currently two 1.4 MW CHP units in operation at BCUA.

A parametric analysis showing the effect of the FOG processed as a co-substrate in the existing anaerobic digesters along with the recovery of currently flared biogas on the generation of electricity is summarized in Table 4. The analysis is based on the following assumptions:

a) Biogas composition from FOG co-digestion: 60% CH4 and 40% CO2
b) Biogas production from FOG: 8.2 SCF/gal
c) Capacity of FOG trucks: 6,000 gal
d) FOG acceptance schedule: 5 days/week
e) Energy content of Biogas: 600 BTU/SCF
f) Conversion thermal energy to electricity : 1 kWh per 10,600 BTU
g) Availability of CHP for electric generation: 85%
h) Currently flared biogas: 119.272 million ft^3/year

Table 4: Projected Electricity Generation from the captured flared biogas and addition biogas production from FOG processing

Biogas Flared (MM ft3	119.272	119.272	119.272	119.272	119.272	119.272
Energy flared (MM BTU/year)	71,563	71,563	71,563	71,563	71,563	71,563
FOG delivery (Trucks/day)	2	3	4	5	6	7
FOG volume (GPD)	12,000	18,000	24,000	30,000	36,000	42,000
FOG received (gal/year)	3,120,000	4,680,000	6,240,000	7,800,000	9,360,000	10,920,000
Biogas production from FOG (SCF)	25,584,000	38,376,000	51,168,000	63,960,000	76,752,000	89,544,000
Energy content FOG Biogas (MM BTU/year)	15,350	23,026	30,701	38,376	46,051	53,726
Total energy content of FOG and flared biogas (MM BTU/year)	86,914	94,589	102,264	109,939	117,614	125,290
Electricity produced (million kWh/year)	6.97	7.58	8.20	8.82	9.43	10.05
Electric Capacity (MW)	0.94	1.02	1.10	1.18	1.27	1.35
Size of CHP Engine (MW)	1	1	1.2	1.2	1.4	1.4

The above results show that by processing from 12,000 to 42,000 gallons per day of FOG, 5 days a week, along with capturing the currently flared biogas, BCUA could add a new CHP engine ranging from 1 to 1.4 MW. Such engine would be entirely run on renewable energy, that is waste activated sludge and FOG.

A parametric financial analysis accounting for revenues, O&M costs, capital costs, and financial incentives was conducted to determine the simple payback period.

The financial analysis is based on the following assumptions:

a) Electricity avoidance unit cost: $0.10/kWh
b) FOG receiving tipping fee: $0.12/gal
c) CHP O&M costs: $0.025/kWh
d) FOG processing O&M costs: 0.05/gal
e) CHP capital cost: $4,000/kW
f) FOG receiving facility: $30/(1,000 annual gal)
g) Engineering and construction management fees: 10% of capital expenditures.
h) CHP Incentives: $2,000/kW or 40% of CHP investment (whichever is lower)

The parametric financial analysis is summarized in Table 5. The results indicate that the net initial capital investment, depending on the volume of FOG, varies $3.1 to 4.6 million dollars and the simple payback period varies correspondingly from 4.2 to 3 years.

Table 5: Parametric financial analysis for the conversion of biogas from FOG and capture flared biogas from the acceptance and processing of FOG.

FOG Delivery (Truck loads/day)	2	3	4	5	6	7
FOG (Gallons/year)	3,120,000	4,680,000	6,240,000	7,800,000	9,360,000	10,920,000
Computed Electric Capacity (MW)	0.94	1.02	1.10	1.18	1.27	1.35
Selected Engine Size (MW)	1.0	1.0	1.2	1.2	1.4	1.4
Electricity generated (million kWh/year)	6.97	7.58	8.20	8.82	9.43	10.05
Annual Gross Revenues						
Electricity ($)	696,949	758,495	820,042	881,588	943,134	1,004,681
FOG Tipping Fee ($)	374,400	561,600	748,800	936,000	1,123,200	1,310,400
Sub-total Gross Revenues ($)	1,071,349	1,320,095	1,568,842	1,817,588	2,066,334	2,315,081
Annual O&M Costs						
CHP	174,237	189,624	205,010	220,397	235,784	251,170
FOG	156,000	234,000	312,000	390,000	468,000	546,000
Subtotal Annual O&M Costs	330,237	423,624	517,010	610,397	703,784	797,170
Net Revenues ($/year)	741,112	896,471	1,051,831	1,207,191	1,362,551	1,517,911
Capital Expenditures						
CHP Size (kW)	1,000	1,000	1,200	1,200	1,400	1,400
CHP ($)	4,000,000	4,000,000	4,800,000	4,800,000	5,600,000	5,600,000
FOG Receiving Facility ($)	93,600	140,400	187,200	234,000	280,800	327,600
Engineering & CM ($)	614,040	621,060	748,080	755,100	882,120	889,140
Subtotal	4,707,640	4,761,460	5,735,280	5,789,100	6,762,920	6,816,740
Financial Incentives						
Incentives (per kW)	2,000,000	2,000,000	2,400,000	2,400,000	2,800,000	2,800,000
Incentives @ 40% CHP Cost	1,600,000	1,600,000	1,920,000	1,920,000	2,240,000	2,240,000
Applied Incentive	1,600,000	1,600,000	1,920,000	1,920,000	2,240,000	2,240,000
Required Investment Capital Cost ($)	**3,107,640**	**3,161,460**	**3,815,280**	**3,869,100**	**4,522,920**	**4,576,740**
Simple Payback Period (Year)	**4.19**	**3.53**	**3.63**	**3.21**	**3.32**	**3.02**

10.0 CONCLUSION

This study shows that the anaerobic co-digestion of FOG collected from local restaurants in Bergen County has the potential of generating substantial revenues to BCUA through the collection of tipping fee and additional biogas generation from the existing BCUA anaerobic digesters. The acquisition of an additional 1.4 MW CHP will allow BCUA to process both biogas produced via the digestion of FOG and currently flared biogas. Furthermore, the implementation of this program has the potential to save local municipalities significant costs currently spent on maintenance and cleaning operations for FOG that currently builds up in sewer lines, causing backups and flooding. The full scale implementation of this project will make a positive environmental impact in the following areas:

a. Reduction in current greenhouse gasses (GHG) from existing operations. Currently, this waste material is incinerated, using an input of commercial natural gas to combust the material and drive off the associated water. The proposed system would biologically digest, rather than combust the waste, yielding methane biogas to be used for co-generation of heat and electricity.
b. Reduction in GHG emissions by utilizing a renewable energy and increasing the performance of the current BCUA digester gas–to-energy system.
c. Reduction in heavy truck miles travelled of hauling companies that collect and currently dispose of this waste stream in South Jersey and Pennsylvania.
d. Reduction of grease blockages of sewer lines in the local Municipalities serviced in Bergen County. Current economic conditions encourage restaurant owners to illegally dump waste grease into the sanitary system, or simply neglect or reduce necessary maintenance of grease traps. The addition of waste grease to these sanitary systems causes blockages that must be removed at significant cost to the Municipality, and blockages can cause wastewater back-ups, often into adjacent homes and basements.
e. Cost reductions to Municipalities for removing blockages, cost reductions to local businesses for the servicing of their grease traps, and fewer environmental releases and property damage.
f. BCUA will end up with an enriched sludge product to produce additional biogas (methane), which will then be run through the existing co-gen engines, resulting in an increase in onsite generated heat and electricity. The result is an increase in renewable energy for BCUA, and lowered demand from the electrical grid.
g. Total volume of FOG generated in the service area is about 17 million gallons per year. Eight (8) trucks per day of 6,000 gallons capacity will be needed to haul this maximum annual collected FOG. It should be noted that Joint Meeting currently accepts 2 to 7 trucks (6,000 gal capacity) of FOG daily.

With both positive environmental renewable energy and financial benefits, BSG highly recommends that BCUA implements a full scale FOG receiving and processing program.

11.0 REFERENCES

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12.0 APPENDIX A

Food Service Establishments Data and Potential Brown Grease Generation for Bergen County

Table A-1: Food Service Establishments Data for Bergen County

Source: US Census

Municipality	Population	Number of FSE	FSE/1000 people
Allendale	6,505	20	3.07
Alpine	1,849		
Bergenfield	26,764	44	1.64
Bogota	8,187	15	1.83
Carlstadt	6,127	22	3.59
Cliffside Park	23,594	44	1.86
Closter	8,373	32	3.82
Cresskill	8,573	13	1.52
Demarest	4,881	2	0.41
Dumont	17,479	21	1.20
East Rutherford	8,913	42	4.71
Edgewater	11,513	34	2.95
Elmwood Park	19,403	36	1.86
Emerson	7,401	25	3.38
Englewood	27,147	55	2.03
Englewood Cliffs	5,281	15	2.84
Fair Lawn	32,457	66	2.03
Fairview	13,835	24	1.73
Fort Lee	35,345	88	2.49
Franklin Lakes	10,590	9	0.85
Garfield	30,487	43	1.41
Glen Rock	11,601	18	1.55
Hackensack	43,010	111	2.58
Harrington Park	4,664	3	0.64
Hasbrouck Heights	11,842	29	2.45
Haworth	3,382	2	0.59
Hillsdale	10,219	13	1.27
Ho-Ho-Kus	4,078	6	1.47
Leonia	8,937	10	1.12
Little Ferry	10,626	26	2.45
Lodi	24,136	38	1.57
Lyndhurst	20,554	49	2.38
Mahwah	25,890	39	1.51
Maywood	9,555	17	1.78
Midland Park	7,128	15	2.10

Table A-1 (Continued): Food Service Establishments Data for Bergen County

Municipality	Population	Number of FSE	FSE/1000 people
Montvale	7,844	35	4.46
Moonachie	2,708	16	5.91
New Milford	16,341	21	1.29
North Arlington	15,392	25	1.62
Northvale	4,640	17	3.66
Norwood	5,711	13	2.28
Oakland	12,754	28	2.20
Old Tappan	5,750	9	1.57
Oradell	7,978	10	1.25
Palisades Park	19,622	53	2.70
Paramus	26,342	102	3.87
Park Ridge	8,645	13	1.50
Ramsey	14,473	52	3.59
Ridgefield	11,032	23	2.08
Ridgefield Park Village	12,729	19	1.49
Ridgewood Village	24,958	57	2.28
River Edge	11,340	15	1.32
River Vale	9,659	-	-
Rochelle Park	5,530	-	-
Rockleigh	531	-	-
Rutherford	18,061	32	1.77
Saddle Brook	13,659	28	2.05
Saddle River	3,152	6	1.90
South Hackensack	2,378	-	-
Teaneck	39,776	59	1.48
Tenafly	14,488	28	1.93
Teterboro	67	-	-
Upper Saddle River	8,208	7	0.85
Waldwick	9,625	26	2.70
Wallington	11,335	26	2.29
Washington Township	9,102	-	-
Westwood	10,908	30	2.75
Woodcliff Lake	5,730	11	1.92
Wood-Ridge	7,626	12	1.57
Wyckoff	16,696	20	1.20
TOTAL BERGEN COUNTY	**905,116**	**1,819**	**2.01**

Table A-2: Potential Brown Grease Generation in Bergen County's Municipalities

Municipality	Population	Grease Generation (Lbm/year)	FOG Volume (Gallons/year)
Allendale	6,505	84,565	126,792
Alpine	1,849	24,037	36,040
Bergenfield	26,764	347,932	521,668
Bogota	8,187	106,431	159,576
Carlstadt	6,127	79,651	119,424
Cliffside Park	23,594	306,722	459,880
Closter	8,373	108,849	163,202
Cresskill	8,573	111,449	167,100
Demarest	4,881	63,453	95,138
Dumont	17,479	227,227	340,690
East Rutherford	8,913	115,869	173,727
Edgewater	11,513	149,669	224,405
Elmwood Park	19,403	252,239	378,192
Emerson	7,401	96,213	144,256
Englewood	27,147	352,911	529,133
Englewood Cliffs	5,281	68,653	102,934
Fair Lawn	32,457	421,941	632,633
Fairview	13,835	179,855	269,664
Fort Lee	35,345	459,485	688,924
Franklin Lakes	10,590	137,670	206,414
Garfield	30,487	396,331	594,235
Glen Rock	11,601	150,813	226,120
Hackensack	43,010	559,130	838,326
Harrington Park	4,664	60,632	90,908
Hasbrouck Heights	11,842	153,946	230,817
Haworth	3,382	43,966	65,920
Hillsdale	10,219	132,847	199,183
Ho-Ho -Kus	4,078	53,014	79,486
Leonia	8,937	116,181	174,195
Little Ferry	10,626	138,138	207,116
Lodi	24,136	313,768	470,445
Lyndhurst	20,554	267,202	400,627
Mahwah	25,890	336,570	504,633
Maywood	9,555	124,215	186,240
Midland Park	7,128	92,664	138,935

Table A-2 (Continued): Potential Brown Grease Generation in Bergen County

Municipality	Population	Grease Generation (Lbm/year)	FOG Volume (Gallons/year)
Montvale	7,844	101,972	152,891
Moonachie	2,708	35,204	52,783
New Milford	16,341	212,433	318,509
North Arlington	15,392	200,096	300,012
Northvale	4,640	60,320	90,440
Norwood	5,711	74,243	111,315
Oakland	12,754	165,802	248,593
Old Tappan	5,750	74,750	112,076
Oradell	7,978	103,714	155,502
Palisades Park	19,622	255,086	382,461
Paramus	26,342	342,446	513,443
Park Ridge	8,645	112,385	168,503
Ramsey	14,473	188,149	282,099
Ridgefield	11,032	143,416	215,029
Ridgefield Park	12,729	165,477	248,106
Ridgewood	24,958	324,454	486,467
River Edge	11,340	147,420	221,033
River Vale	9,659	125,567	188,268
Rochelle Park	5,530	71,890	107,788
Rockleigh	531	6,903	10,350
Rutherford	18,061	234,793	352,034
Saddle Brook	13,659	177,567	266,233
Saddle River	3,152	40,976	61,437
South Hackensack	2,378	30,914	46,351
Teaneck	39,776	517,088	775,290
Tenafly	14,488	188,344	282,392
Teterboro	67	871	1,306
Upper Saddle River	8,208	106,704	159,986
Waldwick	9,625	125,125	187,605
Wallington	11,335	147,355	220,935
Washington Township	9,102	118,326	177,411
Westwood	10,908	141,804	212,612
Woodcliff Lake	5,730	74,490	111,686
Wood-Ridge	7,626	99,138	148,642
Wyckoff	16,696	217,048	325,429
TOTAL Bergen County	**905,116**	**11,766,508**	**17,641,990**

13.0 APPENDIX B

Effect of FOG Co-Digestion on Biogas Production
Pilot Study Results and Analysis

Table B-1: Biogas Production from Anaerobic Digester 1 at BCUA for the Months of May 2011 and May 2012

Date	Biogas May 2011 (SCF)	Biogas May 2012 (SCF)	Sludge Feed May 2011 (1,000 Gal)	Sludge Feed May 2012 (1,000 Gal)	Ration (SCF/Gal) May 2011	Ration (SCF/Gal) May 2012
5/1	117,800	130,369	81	105	1.46	1.24
5/2	127,400	112,301	68	100	1.86	1.12
5/3	137,800	168,540	85	96	1.62	1.76
5/4	129,600	149,141	92	86	1.40	1.74
5/5	135,400	153,481	78	83	1.74	1.84
5/6	141,413	162,145	76	91	1.86	1.78
5/7	146,700	152,042	83	87	1.77	1.75
5/8	137,077	152,353	79	101	1.75	1.50
5/9	141,700	134,108	71	87	2.00	1.54
5/10	160,296	180,796	84	118	1.92	1.54
5/11	164,379	160,016	84	97	1.95	1.64
5/12	161,909	165,012	79	86	2.06	1.92
5/13	129,047	155,013	84	94	1.53	1.65
5/14	151,702	155,012	93	103	1.64	1.50
5/15	147,859	155,013	94	108	1.58	1.44
5/16	139,656	170,017	73	107	1.91	1.58
5/17	151,897	170,014	95	91	1.60	1.87
5/18	154,518	165,014	105	90	1.47	1.83
5/19	154,114	165,012	93	81	1.66	2.03
5/20	162,940	175,014	74	93	2.21	1.88
5/21	148,868	170,011	82	95	1.81	1.78
5/22	143,217	170,011	83	85	1.73	2.01
5/23	147,620	170,013	86	88	1.71	1.94
5/24	160,079	170,014	100	89	1.59	1.92
5/25	157,667	170,010	95	101	1.66	1.69
5/26	155,263	185,014	93	107	1.67	1.74
5/27	154,053	185,015	94	111	1.64	1.66
5/28	159,070	175,013	96	92	1.67	1.90
5/29	149,028	160,011	98	87	1.52	1.83
5/30	136,989	165,014	94	77	1.45	2.14
5/31	141,227	165,010	105	81	1.35	2.03
TOTAL	**4,546,285**	**5,015,548**	**2,696**	**2,917**	**1.69**	**1.72**

Table B-2: Biogas Production from Anaerobic Digester 1 at BCUA for the Months of June 2011 and June 2012

Date	Biogas June 2011 (SCF)	Biogas June 2012 (SCF)	Sludge Feed June 2011 (1,000 Gal)	Sludge Feed June 2012 (1,000 Gal)	Ratio (SCF/Gal) June 2011	Ratio (SCF/Gal) June 2012
6/1	155,844	180,011	107	101	1.45	1.78
6/2	165,091	180,010	94	114	1.76	1.57
6/3	159,075	180,008	85	106	1.87	1.70
6/4	131,150	165,011	73	89	1.79	1.86
6/5	136,719	189,630*	94	114	1.46	1.66*
6/6	157,987	175,328*	102	106	1.56	1.66*
6/7	165,397	162,686*	126	98	1.31	1.66*
6/8	159,390	164,094*	130	99	1.22	1.66*
6/9	158,777	171,128*	124	103	1.28	1.66*
6/10	170,012	125,474*	126	76	1.35	1.66*
6/11	173,443	170,010	99	94	1.76	1.82
6/12	163,998	170,008	93	102	1.77	1.66
6/13	158,977	165,010	89	86	1.79	1.92
6/14	153,722	140,008	90	97	1.71	1.44
6/15	160,079	170,010	87	91	1.84	1.87
6/16	155,008	180,011	105	94	1.48	1.91
6/17	160,009	170,007	102	89	1.56	1.91
6/18	150,007	165,008	91	108	1.64	1.53
6/19	135,004	165,007	73	103	1.86	1.61
6/20	145,010	160,009	87	110	1.66	1.46
6/21	155,006	170,009	107	96	1.45	1.78
6/22	160,008	180,008	115	114	1.40	1.58
6/23	160,009	190,013	124	120	1.30	1.58
6/24	165,008	190,014	121	121	1.37	1.57
6/25	160,007	165,008	97	106	1.64	1.56
6/26	140,004	170,010	92	108	1.52	1.57
6/27	130,005	185,010	101	98	1.29	1.88
6/28	145,005	180,013	102	118	1.42	1.52
6/29	155,009	175,014	93	111	1.67	1.58
6/30	155,006	145,006	100	99	1.56	1.46
TOTAL	**4,639,757**	**5,098,567**	**3,025.62**	**3,069.92**	**1.53**	**1.66**

* Calculated values because Biogas flow rate reported by SCADA system were not realistic.