California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Anaerobic Digestion of Food Waste to Create Biomethane Renewable Natural Gas

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We would like to thank the management and project team at the California Energy Commission for the project funding and continuous support during the various phases of the implementation for this project.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's Clean Transportation Program Investment Plan, updated annually. The CEC issued PON-11-601, Biofuels Production Facilities, to provide funding for the development of new, California-based biofuel production facilities that can sustainably produce low carbon transportation fuels. In response to PON-11-601, the recipient submitted an application which was proposed for funding in the CEC's Notice of Proposed Awards October 5, 2012. The agreement was executed as ARV-12-021 on December 15, 2012 in the amount of $1,211,370.

ABSTRACT

The Inland Bio-Energy food waste-to-energy processing facility located in Chino, California has been in operation since 2012. It is the first, and currently one of the largest, dedicated food waste digester projects in the State of California. The digesters at the site are part of the Solids Handling Facilities owned by the Inland Empire Utility Agency. These digesters were initially operated for the treatment of cow manure from the neighboring feedlot. When the manure digestion process was decommissioned, Inland Empire Utility Agency contracted with Inland Bio-Energy to restart and modify the facility for food waste digestion and power production with renewable natural gas. Inland Bio-Energy installed new digester mixing systems using hydraulic pump mixing, a new digestate treatment consisting of a "Centrisys" dewatering centrifuge, and a new dissolved air flotation system for solids removal from the centrate prior to discharge to the Santa Ana River Interceptor. The food waste pre-treatment hammer mill and bio-separator were also installed at the materials recovery facility in Fontana, California. The goals of this project are two-fold: 1) to maximize production of renewable biogas and generated power; and 2) to provide a site for local waste haulers to transfer organic wastes and divert them from landfills.

Keywords: California Energy Commission, ES Engineering, IEUA, Inland Bioenergy, biogas, biomethane, anaerobic digestion, CNG upgrade, Burrtec, renewable energy, methane, waste-to-energy, pilot project, refuse collection fleet, alternative energy, waste-derived fuels, bioenergy, resource recovery, internal combustion engine.

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EXECUTIVE SUMMARY

The Inland Bio-Energy food waste anaerobic digester facility in Chino, California has been in operation since 2012. Recent regulations in California require an increasing amount of organics diversion from landfills to reduce greenhouse gas emissions and to promote the production of renewable energy. These regulations are driving the market for both dedicated digestion of food waste and co-digestion of organics with wastewater residuals. Inland Bio-Energy is the first, and currently one of the largest, dedicated food waste digester projects in the state of California. ES Engineering, Inc. has been contracted by Inland Bio-Energy to operate and maintain the anaerobic digestion facility.

Pre-treatment of Food Waste

During the last years of full-scale digester operations, the project used mechanical pre-treatment systems, which is a hammer mill and bio-separators. This equipment was used to reduce the size of fruit and vegetable food waste from grocery stores. After manual pre-sorting and removal of plastic foils and large contaminants, the pre-treatment equipment is essential at the materials recovery facility to generate the "BioSlurry" (a mixture of organic waste that forms a slurry), which is then hauled to Inland Bio-Energy in 5,000-gallon tanker trucks.

In addition, the Inland Bio-Energy site has found other liquid substrates that combine the highest biogas production potential with the lowest operating costs. These substrates were found to be sugary juices or syrup concentrates delivered in bulk tanker load.

Biogas Yields

The process control was based on using chemical oxygen demand to provide a biogas output, which was consistent for the operation of the cogeneration system. The ratio of biogas per pound of chemical oxygen demand was monitored and used as a predictive tool. The biogas yield was a function of the volatile suspended solids and chemical oxygen demand. The yield ranged from 13 to 18 cubic feet of biogas per pound of chemical oxygen demand added. This translates to a daily production of 100,000 of biogas just from food waste BioSlurry, which was around 25,000 gallons per day with an average solids concentration of around 10 percent.

Digestate Treatment Equipment

The dewatering equipment was essential in meeting the discharge limits for the final effluent disposal to the regional Santa Ana River Interceptor, which discharges to the Orange County Sanitation District.

The costs for the chemical in the dewatering systems and dissolved air flotation are a function of the food waste chemical charges (divalent versus monovalent cationic molecules). The costs for the chemicals were determined to be significantly higher than in municipal wastewater plants (based on a dollars per dry ton of biosolids). For the future, the operations team is looking for alternative means of sludge disposal by finding beneficial uses for the digestate as liquid fertilizers.

Digester Mixing

The mixing system installed as part of the CEC grant was efficient in keeping the solid in suspension to produce an ideally mixed digestate that promotes a close contact between substrates and microorganisms in the seed sludge to break down the organics.

The hydraulic residence time in the digesters was between 20 and 30 days. The solids from the discharge of the dewatering unit were returned to the digesters as return activated sludge to avoid wash-out of microorganisms.

Project Not Completed

Two pieces of equipment essential to processing and using renewable natural gas as a transportation fuel were not installed as originally specified in the grant agreement. The biogas upgrading system to compressed natural gas was not completed due to significant delays in the South Coast Air Quality Management District air permit application for the compressed natural gas upgrading system. South Coast Air Quality Management District required changes in the permitting process by requiring a facility wide Title V permit amendment rather than the Research Permit that had originally been designated. The permit applications for Authority to Construct and Permit to Operate from the South Coast Air Quality Management District were initially estimated to take at least six to eight months due to the effect of the current EPA status of the Inland Empire Utilities Agency sites (i.e., Title V). ES Engineering initiated the permit application on September 2015 and was reviewed and submitted through the Inland Empire Utilities Agency as the facility owner on October 2015. South Coast Air Quality Management District requested additional detailed information on the compressed natural gas upgrading equipment in order to complete their review. However, the equipment vendor was reluctant to provide any more information without a valid purchase order.

Changes in ownership of the Inland Bio-Energy project and financial issues and the lease terms with Inland Empire Utilities Agency lead to a halt of the design and installation of the upgrading system. The priority for the Inland Empire Utility Agency was to use the biogas for generation of renewable electricity to become energy independent from the grid. Subsequently, the renewable natural gas fuel dispensing equipment was not installed either.

In 2017, ES Engineering requested termination of the project grant due to their inability to complete the project as originally designed. The CEC and ES Engineering reached a Settlement Agreement whereby the CEC canceled the grant, authorized payment of $791,042 out of the original $1.2 million grant, and allowed the Inland Empire Utilities Agency to retain title and use of the digester equipment that was purchased and installed with CEC funds. ES Engineering exceeded their match requirement by paying over $2.1 million in private funds, which was higher than the $1,449,500 match amount specified in the grant agreement.

CHAPTER 1: Food Waste Diversion Through Biogas Generation

Problem Statement

The Inland Bio-Energy (IBE) food waste anaerobic digester facility in Chino, California has been in operation since 2012. Recent regulations in California require an increasing amount of organics diversion from landfills to reduce greenhouse gas (GHG) emissions and to promote the production of renewable energy. These regulations are driving the market for both dedicated digestion of food waste and co-digestion of organics with wastewater residuals.

The goal of this Project was to demonstrate that the existing anaerobic digester facility designed to handle cow manure or liquid food waste could be combined with a new food waste pre-processing system to create biomethane gas that could be used as a low carbon transportation fuel. This project was designed to allow up to 300 tons per day (TPD) of solid food waste to be diverted from the landfill. The biogas was intended to be used as a source of low carbon biomethane gas with a portion being cleaned, purified and compressed to transportation-grade renewable natural gas for use in refuse collection trucks.

Goals of the Agreement

The goals of the project were to design and install a solid food waste processing system to remove contaminants, to reduce the food waste particle size, and to screen and blend the food waste material based on the substrates energy content prior to introduction into the anaerobic digestions (ADs). This technology has demonstrated that certain types of organics from grocery stores (depending on the input materials up to 100,000 tons/year of solid food waste) can be diverted from the landfill by using existing AD facility and associated infrastructures to create biomethane for conversion into compressed natural gas (CNG) fuel.

Objectives of the Agreement

The objectives of the Project include the following:

- Receive and characterize food waste feedstock from Burrtec, a local solid waste company. This includes visual inspection of the feedstock, field measurements, and lab testing.
- Purchase and install pre-processing equipment to pre-treat the food waste before delivery to the digesters.
- Operate the existing AD equipment at the site using the solid food waste processed through the new food waste processing system.
- Set up a portable, proven gas treatment technology at the Inland Empire facility that can convert the biogas into biomethane and CNG fuel for use in heavy-duty engines.
- Operate pilot scale biogas treatment system to create low carbon biomethane CNG for heavy-duty refuse collection vehicles.

- Conduct a test of fueling heavy-duty refuse collection vehicles using the pre-landfill low carbon biomethane CNG.
- Refurbish the second digester at the Inland Empire Utilities Agency (IEUA) site to allow the required increase in gas production to meet commercial fueling amounts required by Burrtec.
- Operate and maintain the dissolved air flotation (DAF) solids removal system so that biogas can be produced.
- Conduct upgrades to the food waste receiving area including receiving tanks and pumps.
- Conduct upgrades to the effluent treatment area including solids dewatering.

Public Private Partnership of Stakeholders and Project Partners

A unique aspect of this project is the public-private partnership between the Inland Empire Utility Agency (a wastewater treatment agency), which is the owner of the assets, and a private wastewater treatment system operator Environ Strategy (ES Engineering, Inc.) in collaboration with the waste hauler Burrtec Waste Industries. The subcontractors and project partners in this demonstration project were Landia, Inc. for the digester mixing system, DODA USA, Inc. for the food waste processing equipment, Centrisys for the digestate dewatering system as well as DMT Clear Gas Solutions, LLC (DMT) for the biogas to CNG upgrading system.

Planned versus Actual Project Activities

In total, ES Engineering completed 10 of the 12 specified tasks in the grant agreement.

Task 1: Agreement management. Completed.

Task 2: Evaluate capacity of the existing AD equipment. Completed.

Task 3: Characterize the solid food wastes identified to supply the digesters. Completed.

Task 4: Design and install pre-treatment equipment that can process the new solid food waste stream. Completed.

Task 5: Commission and operate pre-treatment equipment supplied by DODA USA. Completed.

The pre-treatment system with the DODA USA equipment achieved the expected throughput. The mixing system is able to provide the additional size reduction with the chopper pumps and the adequate mixing in the digesters by hydraulic mixing and one turn-over per hour.

Task 6: Purchase, install and operate biogas clean-up equipment. This task was not completed.

The biogas upgrading system to CNG was not completed due to significant delays in the South Coast Air Quality Management District (SCAQMD) air permit application for the CNG upgrading system. This was due to a change from a Research Permit application to a facility wide Title V permit amendment. ES Engineering's permit applications to receive Authority to Construct and Permit to Operate from the SCAQMD was initially estimated to take at least six to eight months due to the effect of the current EPA status of the IEUA sites (i.e., Title V). Consequently, this has caused delays in issuing equipment purchase orders to vendors because of the uncertainty in the SCAQMD permit review. ES Engineering initiated the permit application on September 2015; it was reviewed and submitted through the IEUA as the facility owner on October 2015. On February 2016, SCAQMD requested additional detailed information on the CNG upgrading equipment in order to complete their review. However, the equipment vendor was reluctant to provide any more information without a valid PO.

Task 7: Demonstrate fueling of heavy-duty trucks with renewable natural gas (RNG) produced by the project. This task was not completed.

In the interim, changes in ownership of the IBE project and financial issues and the lease terms with IEUA lead to a halt of the design and installation of the upgrading system. The priority for the Agency was to use the biogas to generate renewable electricity, rather than produce a low carbon fuel for the use of dedicated truck fleets.

Task 8: Refurbish digester and install new mixing equipment. Completed.

Task 9: Install and operate DAF equipment. Completed.

Task 10: Upgrade receiving area to accommodate new solid food waste feedstocks. Completed.

Task 11: Upgrade effluent treatment and de-watering systems to allow for effluent discharge to Santa Ana River sewer line. Completed.

The dewatering system was successful in removing the solids, providing a dewatered sludge with 20 to 25 percent solids content and a solids capture of 80 to 90 percent. The DAF unit was removing solids expressed as total suspended solids (TSS) from 5,000 mg/L to < 500 mg/L to meet discharge limits.

Task 12: Data collection and analysis. This task was partially completed for the equipment installed.

Summary

In retrospect, some of these issues would have been avoided if the existing AD facility was located in a different location wherein fewer air permit conditions would have applied to evaluate the site. The fact that the IEUA had pending permit applications with the SCAQMD resulted into more complications in what would have been a straight-forward application process. The decision to purchase the major equipment in advance would have been easier if there is enough assurance that the permits will be granted.

CHAPTER 2: Anaerobic Digesters and Feedstock Characterization

The IBE food waste anaerobic digester facility Chino, California has been in operation since 2012. ES Engineering has been continuously monitoring and collecting data from all AD testing activities at the plant in accordance with the requirements of Task 12 of the CEC Grant.

Facility Description

The AD facility shown in Figure 1 consists of two completely mixed digesters operated under mesophilic conditions. The digesters are mixed with a hybrid pump/gas mixing system. Each digester has a diameter of 55 feet, a side water depth of 60 feet and an effective volume of 1.1 million gallons. The two anaerobic digesters are currently processing up to 272 wet metric tons (300 wet tons US) per day, while the plant's permitted capacity is 545 wet metric tons (600 wet tons US) per day. Based on analyses of feedstocks and to maintain digester stability, the two digesters each receives different feedstocks and are typically operated differently as summarized in Table 1. The generated biogas is conditioned and used in power generators with a combined maximum capacity of 3 megawatts (MW)e.

The food waste pre-treatment system at the materials recovery facility (MRF) in Fontana is shown in Figure 2. The contamination, consisting of packaging, cardboard, plastic covers and packaging (PVC, nylon film, PE, etc.), which was removed prior to the processing in the DODA USA hammer mill is shown in Figure 3.

Table 1: Typical Digester Operational Strategy

	Digester 1	Digester 2
Feedstock	High strength liquid waste which comes from industrial food and beverage processing facilities as off-spec products	BioSlurry generated from pre-consumer food waste (e.g. fruit and vegetables) through pre-processing at an offsite MRF
Preprocessing	None	At MRF: Shredding/crushing with hammermill followed by grinding/screening with Bioseparator (10 mm screens and hopper system by DODA, Italy) At IBE: Finer screening with 5 mm DODA screen or 2 mm screening using a Vincent screw press
Hydraulic Retention Time	20-30 days	20-30 days
Temperature	35 °C (95 ° F)	35 °C (95 ° F)
Organic Loading Rate	1.4 COD kg/m^3*day (0.08 lbs / (cu.ft. day))	1.6 kg/m^3*day (0.1 lbs / (cu.ft. day))
Biogas Generation	0.16 m^3/kg COD added (13 cu.ft per lb of COD added)	0.23 m^3/kg COD added (18 cu.ft per lb of COD added)
Digestate processing	Centrifuge dewatering; Centrate solids removal with DAF	Centrifuge dewatering; Centrate solids removal with DAF
Table Note: COD = Chemical Oxygen Demand; DAF = Dissolved Air Flotation; DODA = Italian–American Equipment Supplier.		

Source: ES Engineering, Inc.

Figure 1: Two 1.1 Million-gallon Digesters at the IBE Facility in Chino, California

Photo credit: ES Engineering, Inc.

Figure 2: Mechanical Pretreatment of Food Waste at the Burrtec MRF in Fontana, California

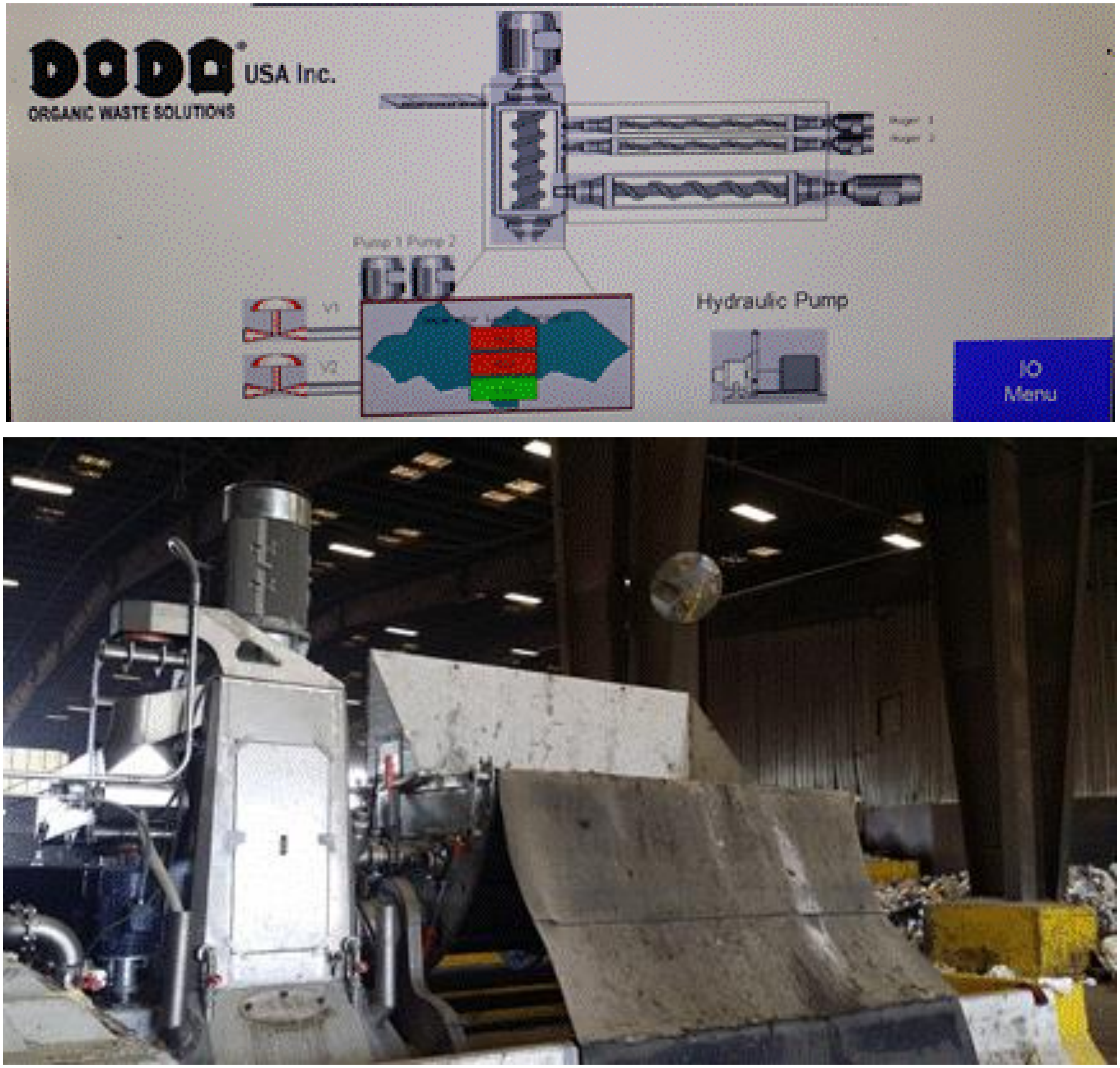

Photo credit: ES Engineering, Inc.

Figure 3: Manually Removed and Presorted Packaging Material Coming From the Fruit and Vegetable

Photo credit: ES Engineering, Inc.

Before the digester facility began accepting various feedstocks, IBE was interested in determining the potential biogas production for each substrate and the amount of final residuals that would require disposal or other management option. This was investigated through an initial assessment of theoretical methane production and biomass yield potentials, and subsequent bench scale tests to determine the biogas yield of various substrates that could be available as digester feedstocks in the local area.

The theoretical methane yield (Y_{CH4}, m^3 standard temperature and pressure [STP]1/kg substrate converted) can be calculated from the elemental composition of a substrate $C_cH_hO_xN_nS_s$ 2,3:

$$Y_{CH4}=22.4*(c/2+h/8+x/4-3n/8-s/4) / (12c+h+16x+14n+16s)$$

Table 2 shows major substrates, a common elemental formula for each substrate, and the associated theoretical methane yield. Fat-containing substrates typically produce higher methane content in the biogas and generate lower amounts of biomass (excess sludge) due to low cell synthesis.4 Carbohydrates provide more energy to these organisms than proteins and fat and subsequently result in biomass yields that are up to 10 times higher than other substrates (e.g. Y_{carb} = 0.35 g cells/g COD consumed vs Y_{fat} = 0.038 g cells/g COD consumed5).

Table 2: Theoretical Methane Yield (m^3 STP/kg substrate converted) for Several Substrates

Substrate	Elemental formula	Theoretical methane yield (m^3 STP/kg)
Carbohydrates	$(CH_2O)_n$	0.37
Proteins	$C_{106}H_{168}O_{34}N_{28}S$	0.51
Fat	$C_8H_{15}O$	1.0
Plant biomass	$C_5H_9O_{2.5}NS_{0.025}$	0.48

Source: ES Engineering, Inc. from Korres, 2013

The experience at IBE, which spans over a period of over 5 years, has found that the actual digester operation and biogas yield is highly dependent on multiple parameters:

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1 STP denotes Standard Temperature and Pressure, where temperature is 0 degrees Celsius and pressure is 1 atmosphere.

2 Korres, N., O'Kiely, B., (2013) *Bioenergy Production by Anaerobic Digestion: Using Agricultural Biomass and Organic Wastes,* Routledge Studies in Bioenergy, Taylor & Francis Ltd.

3 Where C=carbon, H=hydrogen, O=oxygen, N=nitrogen and S=Sulphur.

4 *Ibid.*

5 Speece, R.E., (1995) *Anaerobic Biotechnology for Industrial Wastewaters*, Vanderbilt University, ARCHAE PRESS, Nashville, TN.

- **<u>Substrate Selection</u>**: Not all substrates will contribute equally to biogas yield, which is depended on TSS, volatile suspended solids (VSS) and COD. Additionally, the acidity of substrates needs to be considered because highly acidic substrates can lead to equipment damage through corrosion. Feeds with a high protein content with sulfur-containing molecules will result in higher hydrogen sulfide concentrations in the biogas, which needs to be considered when estimating operational costs or capacities of the gas scrubbers. Also, feeds high in soluble organics and higher concentration of acetates (e.g. vinegars) will decrease the pH and shift the dissolved sulfides to hydrogen sulfide (H_2S).
- **<u>Substrate Particle Size</u>**: Digester operation such as mixing requirements and speed of digestion along with ultimate biogas yield are impacted by the substrate particle size. The feed substrate also impacts the digestate dewaterability and polymer consumption.
- **<u>Effective Screening:</u>** Effective screening is crucial as it protects the downstream equipment from various types of damaging debris (glass, metal, plastics etc.) that is often found in various feedstocks. A screw press for screening was added to remove particles larger than 2 mm.
- **<u>Selecting the Correct Feed Loading Rate</u>**: As reported by Appleton and Rauch-Williams6 conventional digester operating parameters (e.g., volatile solids loading rate ("VSLR")) alone may not be sufficient to characterize high solid waste ("HSW") co-digestion operation. For example a municipal digester, which receives acid whey and cheese waste whey, achieves reliable co-digestion performance at a VSLR of 0.23 lb VS/d-cu ft, which is above the typical recommended limits for conventional AD (up to 0.2 lb VS/d-cu ft (WEF MOP 8, 2010)). Additional considerations for selecting the correct feed loading rate include whether the biogas utilization and flare systems have sufficient capacity to handle the increased biogas production.
- **<u>Maintaining an Optimum Food to Biomass Ratio</u>**: In order to maintain an optimum food to biomass ratio in the digester, a partial return of thickened sludge to the digester should be considered (recuperative thickening, similar to reseeding of fresh substrate in dry batch fermenters). This is especially the case in dedicated industrial digesters (merchant facilities) where a high COD loading, and low VSS loading would cause a wash-out of microorganisms without the partial return of thickened sludge. The total solids (TS) concentration is a simple, but not the most adequate, means to assess if there is sufficient biomass available to digest the organic feed materials. The analysis of the VSS/TS ratio would be better indication as the VSS analysis can also be performed onsite.

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6 Appleton, R., Rauch-Williams, T., (2017) *Co-digestion of organic waste addressing operational side effects*, WERF.

Table 3: Substrate Feed Composition

Substrates	Substrate Added, mL	COD, mg/L	TS, %
Bakery Grain Steeping	200	15,000	<1
Tuna Waste	200	26,000	10
Juice Wastewater	55	91,100	<1
BioSlurry	61	41,000	12
Syrup Wastewater	40	166,200	<1
Creamery DAF sludge 1	23.9	209,000	10
Creamery DAF sludge 2	28.6	174,600	6
Juice bottle waste	200	12,280	<1
Soy Milk	47	105,000	<1
Powdered Starch	53.1	94,060	10
Whey wastewater	137	36,400	<1
Screw Press Reject	NA	1,000,000	16

Source: ES Engingeering, Inc.

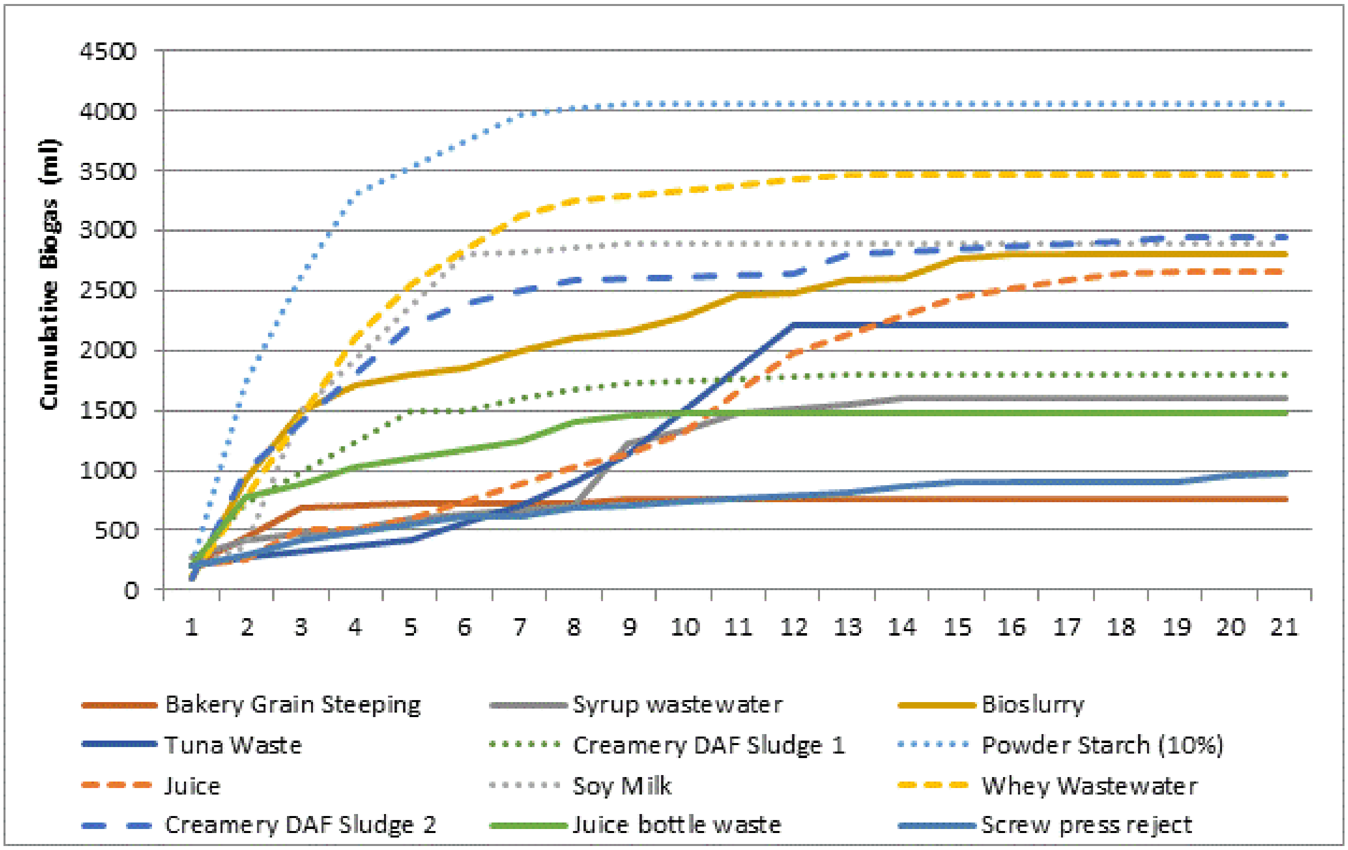
Figure 4 and Table 4 show the bench scale biogas yield test results. Each test was performed over a period of 3 weeks. The Powdered Starch (10 percent) produced the greatest quantity of biogas (4000 mL) and the highest specific biogas production at 0.819 mL biogas/ mg COD applied. Conversely, the bakery waste produced the least amount of gas in 21 days at approximately 750 mL

Figure 4 also shows the biogas production results for the screw press reject (contaminants, fibers, and seeds in the BioSlurry with particle sizes larger than 2 mm removed in the screw press). Although the screw press reject did not have the lowest overall biogas production rate, it did have the lowest specific biogas production at 0.180 mL biogas / mg COD applied. Due to this low biogas production, it was demonstrated that the lignocelluloses in the fruit and vegetable fiber, as well as the seeds, were very difficult to hydrolyze and become amenable for AD. Therefore, this material was removed from the digester feed material and sent to composting off-site.

The time required for digester microorganisms to adapt to the new substrates was also predicted with the bench-scale testing. As shown in Figure 4, based on the immediate gas production little or no acclimation stage was required for the degradation of the starch, whey and BioSlurry. However, an acclimation stage of up to 10 days was required for the other substrates. The acclimation time was used as a basis for the operations plan by implementing a gradual increase of the new substrate digester feed rates over a period of 10 to 15 days.

The bench-scale testing approach is therefore not only helpful in determining the expected biogas yield, but also the time required to develop methane from each substrate. The time to generate methane from various substrates can be only one day for juices, over two days for BioSlurry to over 5 days for organic waste high in organic fibers.

Figure 4: Cumulative Biogas Production From Various Substrates



Source: ES Engineering, Inc.

Table 4: Bench Scale Biogas Production Results

Substrates	Biogas Production After 21 Days (ml)	Biogas Produced (mL/mg COD Applied)
Bakery grain steeping	750	0.250
Tuna waste	2,200	0.423
Juice wastewater	2,660	0.531
BioSlurry	2,800	0.583
Syrup wastewater	1,600	0.241
Creamery DAF sludge 1	1,800	0.360
Creamery DAF sludge 2	2,940	0.589
Soy Milk	2,880	0.584
Juice bottle waste	1,480	0.603
Powdered starch	4,060	0.813
Whey wastewater	3,460	0.694
Screw press reject	980	0.180

Source: ES Engineering, Inc.

After completing the biogas yield tests for various substrates it was confirmed that powdered starch and whey had the highest biogas yields. Glycerin was a substrate tested separately and not shown in Figure 4. Although a glycerin had a high biogas yield, it was found to contain residues of methanol from the biodiesel processing and was therefore not accepted for the full-scale digester due to safety considerations.

From the various substrates tested the following two types of substrates were determined to combine high biogas production potential with low operating costs:

- Syrup or juice waste when delivered in bulk tanker loads were the organic feed stocks with the lowest processing costs because they were free of contaminants.
- BioSlurry had an ideal carbon-to-nitrogen ratio for AD of 20:1 and resulted in a high biogas yield. However, the contaminants (fiber, plastics, metal, and glass) and the solid residuals from digestate dewatering did also lead to higher overall operational costs due to labor, chemical usage, solids disposal and electricity costs.

CHAPTER 3: Processing Equipment and Digester Mixing Systems

Digester Feed

The digester feed pumps and transfer station as shown in Figure 5 consist of Landia chopper pumps. These pumps were retrofitted as part of the grant to accommodate more efficient truck unloading and transfer to the digesters.

Figure 5: Digester Feed Pumping Station After Retrofit

Photo credit: ES Engineering, Inc.

Digester Mixing

The mixing system installed as part of the project grant was efficient in keeping the solid in suspension to produce an ideally mixed digestate that promotes a close contact between substrates and microorganisms in the seed sludge to break down the organics.

The mixing system consisted of two hydraulic mixing pumps MPTK I-150 for each digester operating at 1765 rpm and driven by motors wtih 49 HP (Figure 6).

The hydraulic residence time in the digesters was between 20 and 30 days. The solids from the discharge of the dewatering unit were returned to the digesters as return activated sludge to avoid wash-out of microorganisms.

Figure 6: Landia Gasmix Installed on Both Digesters

Source: ES Engineering, Inc., Landia

Digestate Treatment Equipment

The dewatering equipment consisting of centrifuge and polishing with DAF was essential in meeting the discharge limits for the final effluent disposal to the SARI line (regional Santa Ana River Interceptor discharging to Orange County Sanitation District). The centrifuge used was a Model CS18-4 Dewatering 2PH with automated chemical injection (Figure 7). The costs for the chemicals were determined to be significantly higher than in municipal wastewater plants (based on a dollar per dry ton of biosolids).

Figure 7: Digestate Dewatering Centrifuge From Centrisys

Photo credit: Centrisys, Inc.

Biogas Upgrading Equipment

The planned biogas upgrading station included a containerized Sepuran membrane treatment system by DMT rated at 50 standard cubic feet per minute raw gas and 30 cubic feet per minute biomethane for truck fueling. The upgrading system was engineered, but did not go in manufacturing stage due to the permitting delays and eventual termination of the project.

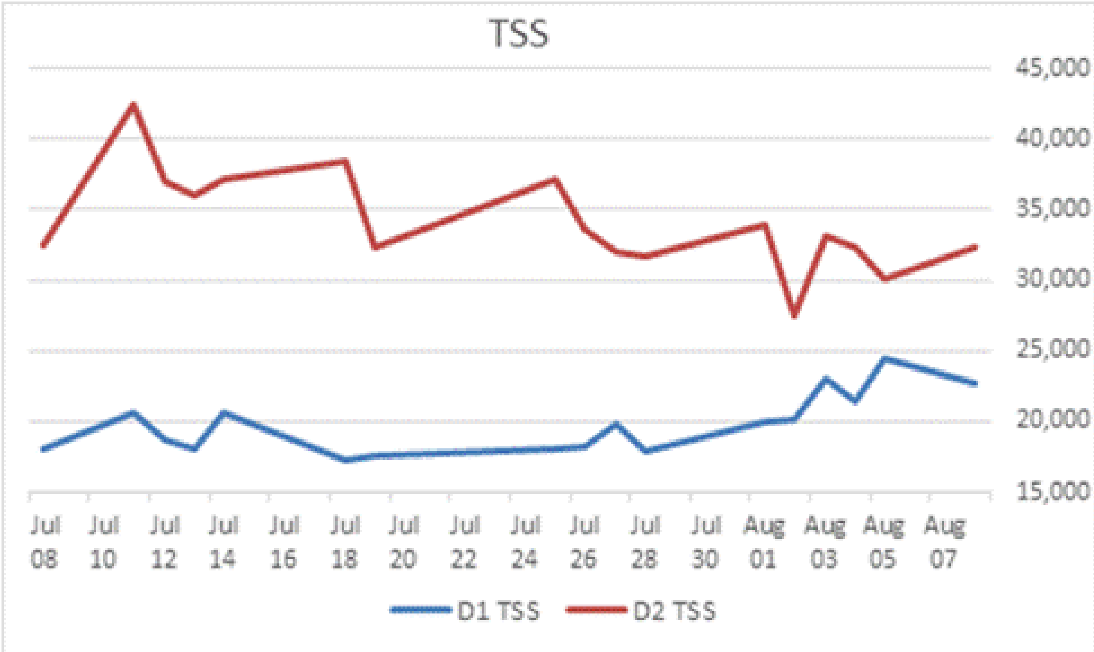
The project team had initial contacts with various suppliers for biogas upgrading systems since this sector offers innovative technology developments based on membrane treatment. For this reason BioCNG (IA) and Innosepra (MA) were evaluated together with DMT based on economics, available and expandable demonstration systems and overall efficiency for methane recovery. DMT with the Sepuran Membrane technology and with a local support team in Portland, Oregon made the final selection.

CHAPTER 4: Biogas Yield Predictions and Full-Scale Operational Data

The operational data for Digester 1 and Digester 2 over a one-month period of full-scale operation are shown in the following graphics (Figures 8 through Figure 10. Digester 1 feedstock is primarily liquid wastes from food processing, so this digester typically operates with low solids concentrations ranging between 1.75 and 2.5-percent TSS. Digester 2 is fed thicker BioSlurry so it operates with a higher solids concentration ranging between 3 and 4-percent TSS. The solids concentrations for each digester are shown in Figure 8.

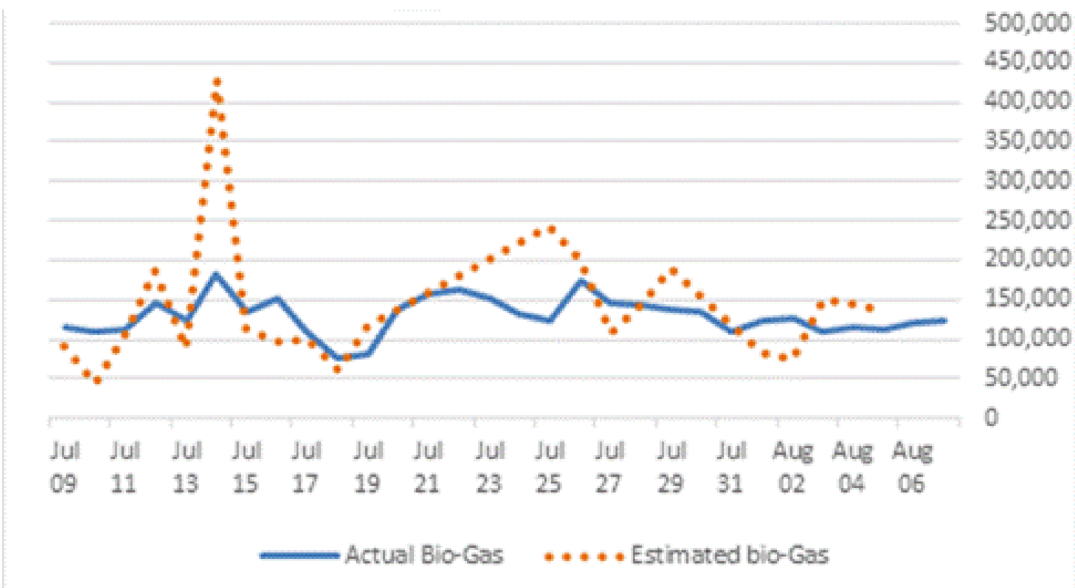
Figures 9 and 10 include expected and actual biogas production values for Digesters 1 and 2, respectively. The expected biogas production values were calculated based on the chemical oxygen demand (COD) in the blended feed stock, the digester feed rate and historical biogas generation per pound of COD added. On an average basis, the expected and actual biogas production values were in relatively close alignment. This alignment supported the use of this method for estimating biogas yields and using the COD concentrations as a method to determine loading rates to the digesters for the blend of different substrates. As shown in Figures 9 and 10, biogas production in Digester 2 is significantly higher than in Digester 1. The BioSlurry produced offsite at the MRF and then fed to Digester 2 is a relatively consistent material in terms of characteristics and biogas yield. The increased biogas production in Digester 2 was related to the consistency of the feedstock, more consistent digester operation and associated biogas yield potential.

Figure 8: TSS Concentrations in Digesters 1 and 2



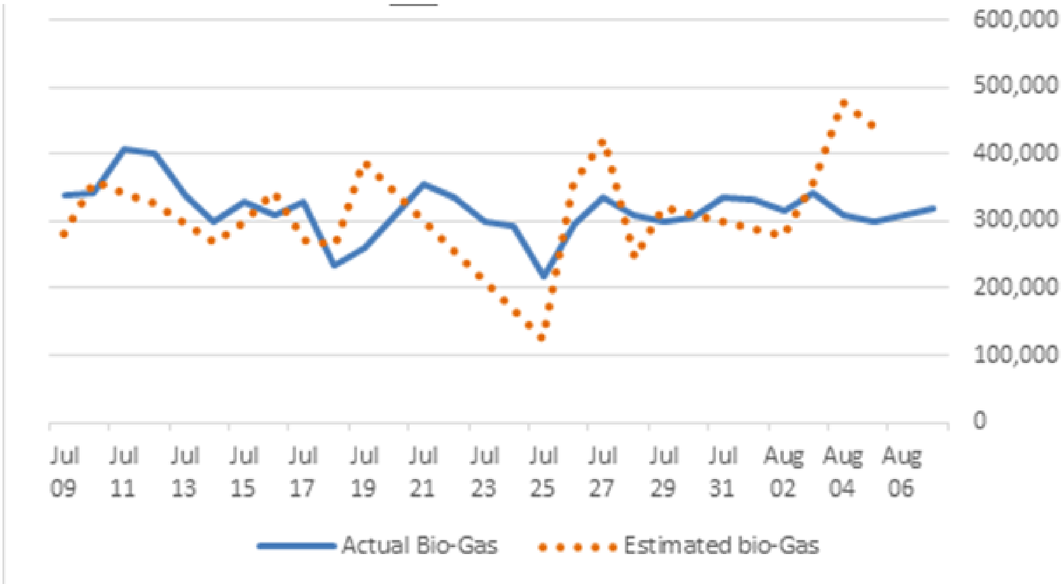
Source: ES Engineering, Inc.

Figure 9: Actual vs. Predicted Biogas Production for Digester 1



Source: ES Engineering, Inc.

Figure 10: Actual vs Predicted Biogas Production for Digester 2



Source: ES Engineering, Inc.

Biogas Quality and Production Rates

Biogas Quality

The biogas quality is expressed as percentage of Methane, which ranged from 55 to 65 percent methane, with the remaining biogas consisting of CO_2 with a content of 35-45 percent. The remaining traces are sulfur-based compounds such as H_2S or Nitrogen.

Biogas Production Rates

Depending on the types of feedstocks and feeding rates, the biogas production ranged from 300,000 to 400,000 cu.ft. per day for the combined feed stocks of Bioslurry and liquid food waste.

The Bioslurry biogas yield was tested separately in a bench-scale test (as shown above) and was resulting in up to 0.583 ml of biogas per mg of COD added. The 25,000 gallons per day of BioSlurry were converted to 100,000 cu.ft per day of biogas. This translates to approximately 504 diesel gallon equivalent (DGE) using an average of 700 Btu/cu ft heat value for biogas.

Biogas Use in Cogeneration System

The main purpose of the lease agreement with IEUA was to provide power to IEUA for the headquarters and wastewater plants.

The existing internal combustion engine which is a 3605 Caterpillar with 1.5 MW of maximum power output was operated with biogas form the IBE facility to achieve an average output of 1 MW (or 24 MWh per day).

The agreement with the CEC was to create an additional beneficial use for the biogas through this RNG demonstration project, which would be the start for a long-term strategy to convert a majority of the biogas from food waste to RNG as the IEUA brings solar, wind and other renewable energy projects online.

Greenhouse Gas Reduction

The highly efficient conversion of organics to biogas with relatively high methane content of over 65 percent resulted in a reduction of methane otherwise emitted from landfills. Methane is a greenhouse gas which is short lived, but more potent than CO_2.

The existing internal combustion engine which is a 3605 Caterpillar with 1.5 MW of maximum power output had an average output of 1 MW (or 24 MWh per day). Also Energy monitored the electrical energy output and reduction of equivalent greenhouse gases.

The initial stage of the proposed project was to process 300 tons of food waste per day. Project calculations showed that amount of food waste would be capable of generating 900,000 cubic feet of biogas per day, the equivalent of 329,950 MMBtu per year. If 10 percent of that gas is converted to RNG for use in transportation, this would be the equivalent of 176,000 gallons of diesel fuel per year. The use of that amount of biofuel generated from the site would eliminate 3,999,896 pounds of CO_2 in vehicle emissions per year.

If the average car emits about six tons of carbon dioxide every year, this would equal 303 cars taken off the street.

The reduction of methane release to the atmosphere from the landfills would be significant. According to GREET 1.8b values, methane has 25 times more global warming potentials for greenhouse gases than CO_2.

The decay of food waste in landfills results in 0.308 $MTCO_2$/MT Waste based on the following equation:

$$M_{FW} = 0.9 \times DOC_f \times MCF_{LF} \times 21 \times (1-OX) \times (16/12) \times F_{CH4}$$

Where,

0.9	= Model correction factor to account for model uncertainties
DOC_f	= The fraction of the degradable organic carbon that decomposesunder anaerobic conditions.
MCF_{LF}	= The Methane Correction Factor of the landfill where the waste would have gone (a fraction between 1 and 0).
21	=The Global Warming Potential (GWP) of methane ($MTCO_2/MTCH_4$)
OX	=Fraction for the oxidation of methane by cover soil bacteria
16/12	=The molar mass ratio of methane to carbon (CH_4/C)
F_{CH4}	=The default fraction of methane gas in landfill gas.

Source: Organic Waste Digestion Project Protocol, Climate Action Reserve, October 7, 2009

For future plant expansion and operation at full capacity emissions from the operation of cogen engines, which generate electricity, biogas compressors, and gas treatment operations, could total approximately 25,550,000 pounds of CO_2 per year, resulting in a net savings of 14,448,996 pounds, or 7,224 tons, of greenhouse gas per year, as shown in the table 5 with CO_2 calculations below.

Cost of Biogas Production

The monthly operating and facility leasing expenses are estimated to be $400,000 per month. The project was able to generate a daily biogas volume of 500,000 cu.ft. per day. After conversion to Diesel Fuel equivalents, this would result in a fuel production cost of $3.84 per gallon (refer to Appendix A for the detailed calculations). An economically viable RNG project would have to be sized to process 400 cfm of raw biogas and to generate 4,000 DGE per day (Note: in this case the project can take advantage of an existing digester facility lease. It is assumed that CEC grant funding is available to cover the capital costs for the biogas to RNG upgrading system).

Table 5: CO_2 Reduction via Biomethane Generated From Food Waste

Factors	Volume	Units
Quantity of waste treated to produce truck fuel	300	tons per day
Biogas generated	900,000	cubic feet per day
Biogas per year	328,500,000	per year
Energy content	700	Btu/cu ft
Energy generated	229,950	MMBtu/year
Petro-diesel energy content	130,500	Btu/gallon
Petrodiesel energy equivalent	1.76	MG gasoline equivalents
	138	MJ/gallon
Energy content	242,767,300	MJ
CO_2 equivalent baseline for petrofuel	**23**	**lbs CO_2/gallon diesel**
CO_2 saved	**40,000,000**	**lbs CO_2 per year**
CO_2 emissions when using grid electricity	*200*	*kWe*
	700	*lbs CO_2 per kWhe*
CO_2 generated	*25,550,000*	*lbs CO_2 per year*
Net CO_2 savings	**14,450,000**	**lbs per year**
	7,225	**tons per year**
CO_2 emission from cars avoided	**1,200**	**Cars per year (at 6 tons per year per car*)**

Source: Climate Action Team Report to the Governor and Legislature

* "Global Warming and Your Car" (https://www.cartalk.com/content/global-warming-and-your-car-0)

CHAPTER 5: Conclusions

In the interest of an economical and streamlined operation of the digesters, it is important to pre-select, to screen and to process the organic substrates to a level, which reduces onsite mechanical processing requirements. The type and the size of the organic solids will determine the mixing requirements and the total biogas yield as well as how fast volatile solids can be digested in the reactor.

During the last years of full-scale digester operations, the management used the bench-scale test results for the selection of the ideal substrates. Optimal substrates that combine the highest biogas production potential with the lowest operating costs were found to be juice or syrup concentrate when delivered in bulk tanker load and BioSlurry. Operators make daily adjustments to the digester feed flow rates to maintain organic loading rates based on the actual COD and VSS concentrations of the various food waste substrates. For periodic quality control the operators sample and test the influent substrates for changes in COD, TSS and VSS.

VSS loading rates might not always be the most adequate measure for digester process control when dealing with food waste containing high fats, oil and greases. The process control was based on using COD and monitoring the food to microorganism ratio.

Monitoring of the substrate and a transparent communication with the operations staff, truck drivers can be helpful in learning the sensitivity of the operations on both ends in conjunction with the support from environmental and plant engineering staff.

The initial goals of converting biogas to RNG for truck fueling were not accomplished at this time. The reason for this was mostly due to SCAQMD permitting delays and an upcoming need to extend the lease agreement and renegotiate terms to make the overall project economically sustainable. The equipment which was funded for this project will continue to be used for the food waste processing, digester mixing and digestate dewatering. With the higher costs for operating internal combustion engines, it is still recommended to plan for biogas upgrading and RNG production systems at this site when the biogas needs for the cogeneration system can be covered and excess biogas might become available with the expansion of the wastewater treatment complex in the next five years.

GLOSSARY

ANAEROBIC DIGESTION (AD) -- A biological process in which biodegradable organic matters are broken down by bacteria into biogas, which consists of methane (CH4), carbon dioxide (CO2), and other trace amount of gases. The biogas can be used to generate heat and electricity.

CHEMICAL OXYGEN DEMAND (COD) – A measure of the oxygen-consuming capacity of organic matter present in wastewater. Chemical oxygen demand is expressed as the amount of oxygen consumed from a chemical oxidant in mg/L during a specific test.[7]

COMPRESSED NATURAL GAS (CNG) - Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

DISSOLVED AIR FLOTATION (DAF) - Has been used for several decades in drinking water treatment as an alternative clarification method to sedimentation. DAF is particularly effective in treating reservoir water supplies; those supplies containing algae, natural color or natural organic matter; and those with low mineral turbidity. It is more efficient than sedimentation in removing turbidity and particles for these type supplies.[8]

DIESEL GALLON EQUIVALENT (DGE) - The amount of alternative fuel it takes to equal the energy content of one liquid gallon of diesel gasoline.

DMT Clear Gas Solutions, LLC (DMT) – A biogas technology provider based in Oregon. DMT is part of a Dutch technology services corporation.

GREENHOUSE GAS (GHG) -- Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

INLAND BIO-ENERGY (IBE) – The name of the anaerobic digestion facility that is the subject of this report. It is based in Chino, California.

INLAND EMPIRE UTILITIES AGENCY (IEUA) – A municipal water agency providing fresh water and wastewater treatment services in Chino, California.

7 California State University, Sacramento, Department of Civil Engineering Water Program, online glossary (http://www.owp.csus.edu/glossary/cod.php)

8 Edzwald, James. "*Dissolved Air Flotation and Me*." Water Research. Vol 44, Issue 7.April 2010

MATERIALS RECOVERY FACILITY (MRF) - A MRF is a facility which sorts and processes materials that are collected elsewhere and brought to the MRF for the purpose of recovery of recyclable materials.[9]

MEGAWATT (MW) - One-thousand kilowatts (1,000 kW) or one million (1,000,000) watts. One megawatt is enough electrical capacity to power 1,000 average California homes.

RENEWABLE NATURAL GAS (RNG) **-** A gaseous mixture of carbon dioxide and methane produced by the anaerobic digestion of organic matter.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (SCAQMD) -- The air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. This area of 10,743 square miles is home to over 16.8 million people– about half the population of the whole state of California. It is the second most populated urban area in the United States and one of the smoggiest. Its mission is to clean the air and protect the health of all residents in the South Coast Air District through practical and innovative strategies.

STANDARD TEMPERATURE AND PRESSURE (STP) – Denotes when temperature is 32˚F (0˚C) and pressure is 1 atmosphere.

TOTAL SUSPENDED SOLIDS (TSS) - The dry weight of suspended particles that are not dissolved in a sample of water that can be trapped by a filter that is analyzed using a filtration apparatus. It is a water quality parameter used to assess the quality of a specimen of any type of water or water body, ocean water for example, or wastewater after treatment in a wastewater treatment plant.

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9 CalRecycle, "Inspection Guidance for Transfer Stations, Materials Recovery Facilities, and Waste-to-Energy Facilities" (https://www.calrecycle.ca.gov/lea/advisories/23/23attb)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) -- A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting and enforcement activities.

VOLATILE SUSPENDED SOLIDS (VSS) - The portion of the sample lost after the sample has been heated to 1,022˚F (550˚C). It is an approximation of the organic material present in water and provides a measure of a water's capacity to consume oxygen.