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NATURAL GAS PROGRAM

FINAL REPORT

Methane Enhancement by Anaerobic Composting of Food Waste and Fat Oil and Grease

EISG AWARDEE

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Abstract

Currently in-vessel high-solid anaerobic digesters are common in Europe for management of organic waste. These plants are usually technically sophisticated making them costly to build and operate. Due to lower waste disposal fees in the US there is a need for a less capital-intensive option. In this project, an Anaerobic Composter Cell (Cell) was developed for anaerobic/aerobic decomposition of food waste, grape pomace, green waste, and fat, oil and grease (FOG) with the recovery of energy and compost. The Cell was operated under anaerobic conditions for 350 days at mesophilic temperature, after which it was aerated for an additional 15 days and the finished compost meet all of the US Composting Council's Seal of Testing Assurance Program. The average methane content during the anaerobic phase was 46% ± 0.5SE, which was slightly below the target value of 48%. Methane generation equated to 38 liters of methane produced per kg of dry solids (1,210 ft^3 methane per dry ton). At the start of the aerobic phase the VOC destruction efficiency ranged between 54.6% (toluene) to 74.2% (total xylenes). Acetone and ethylbenzene had the highest destruction efficiency of all VOCs. During the anaerobic and aerobic phases of operation, biochemical methane potential decreased by 57%. Commercial application of this technology can generate enough electricity to meet the electricity demand of 148,274 households in California or produce 67 million diesel gallon equivalent of compressed natural gas. This will reduce CO_2 emissions by 1.13 $MMTCO_2eq$ annually. When compared with an in-vessel anaerobic digestion, the application of this technology to organic waste in Californnia would reduce the initial capital investment by $3.17 billion and the annual operating cost by $621 million per year.

Key Words: Anaerobic digestion, aerobic composting, organic waste, compost, biogas, biofilter, gas emissions, biofilter, leachate quality

Executive Summary

Introduction

In 2014, Californian's statewide disposal was 31.2 million tons (CalRecycle, 2015). The total amount of organics and paper disposed in landfills were 11.67 million tons (31.6%) and 5.4 million tons (17.4%), respectively (CalRecycle, 2015). Currently, the compostable fraction of these materials, including food, leaves and grass accounts for about 6.9 million tons annually. In addition, agricultural and food processing facilities generate biodegradable waste streams that are also potential sources of energy. This combination of organic waste sources represents a large potential energy source: it has been reported that the source-separated organic fraction of municipal solid waste alone is capable of providing approximately 8% of the energy demands of the state of California (Rapport, Zhang, Jenkins, & Williams, 2008). One promising technology that has been identified by CalRecycle is anaerobic digestion, which has the potential to handle odorous and putrescible wastes such as food waste, meet strict environmental performance standards, and capture new revenue streams through the production of renewable energy and low carbon fuel. While more sophisticated and capital-intensive projects such as in-vessel anaerobic digesters and mass burn waste-to-energy facilities are common in Europe (Rapport et al., 2008; Tsilemou & Panagiotakopoulos, 2006), anaerobic digester plants are usually technically sophisticated making them costly to build and to operate (De Bere, 2000). There is a need for a less capital-intensive method of treating food-waste and other high moisture organic waste that is readily degradable. Additionally, diverting fats, oils, and grease (FOG) to anaerobic digesters can prevent sewer and pump clogging, while FOG can increase methane production in anaerobic digesters when co-digested with green waste / food waste mixture and improve the overall economics and increase renewable energy generation (California Resources Agency (CRA), 2012).

Project Objectives

The project had the following technical objectives to achieve the overall project feasibility:

1. Demonstrate that project design and construction was completed in one month.
2. Demonstrate that filling phase and cover placement were completed in less than two weeks.
3. Demonstrate that the average temperature of cell was at least in the mesophilic range (32 °C - 42°C) during the anaerobic phase.
4. Demonstrate that the methane content during the anaerobic operation phase was greater or equal to 48% (v/v).
5. Demonstrate methane generation was greater than 64 liters of methane per dry kg (2,000 cubic feet per dry ton).
6. Demonstrate that the destruction efficiency for volatile organic compounds (VOCs) was greater than 95%.
7. Demonstrate that biochemical methane potential (BMP) decreased by at least 50%.
8. Demonstrate that the minimum attractive rate of return (MARR) for a full-scale project would be greater than 15%.

Project Outcomes

The following results were achieved for each objective:

1. The design of this project was completed in less than one month as planned.
2. Waste filling and cover placement was completed in two weeks as planned.
3. The average temperature of the cell was within the estimated mesophilic range of (32 °C - 42°C).
4. The average methane content during the anaerobic phase was 46% ± 0.5SE , which was slightly below the target value of 48% as times. This is most likely due to over pulling of the gas collection system. Methane generation equated to 38 liters of methane produced per kg of dry solids (1,210 ft^3 methane per dry ton), which was below the methane generation target value of 64 liters of methane per kg of dry solids (2,000 ft^3 methane per dry ton). This is most likely due to lag time in methane generation and the actual waste characteristics.
5. At the start of aerobic phase the VOC destruction efficiency ranged between 54.6% (toluene) to 74.2% (total xylenes). Acetone and ethylbenzene had the highest destruction efficiency of all VOCs. The target destruction efficiency of greater than 95% was not achieved due to biofilter saturated condition and difficulty with gas sampling. However, it is expected that over time the biofilter destruction efficiency would increase as the microbial community acclimate and biofilter moisture content drops below saturation.
6. During the anaerobic and aerobic phases of operation, BMP decreased by 57% from an average of 93 mL methane per grams of dry solids to 50 mL methane per grams dry solids. This was greater than the project goal of 50% reduction in BMP.
7. For the full-scale project at a waste disposal fee of $49 per ton, the estimated MARR for this project would be greater than 49%. This was greater than the projected value of 15%.

Conclusions

The study successfully demonstrated the construction, monitoring and operation of a batch mesophilic anaerobic digester for mixed FOG, food waste, green waste, and grape pomace. A first-order gas generation model developed for this batch digester predicted a methane generation potential (L_0) of 73 m^3-CH_4/dry Mg (2,339 ft^3/dry ton) and decay rate (k) of 1.27 yr^{-1}, with a half-life of 0.55 years. The laboratory results of BMP from samples collected during the anaerobic phase showed a decrease of 47% in BMP and an additional 10% reduction during the aerobic phase, for a total of 57% reduction in BMP. Due to long retention time during the anaerobic phase where the majority of the VOCs were removed and destroyed by the active biogas collection system the VOC and NH_3 emission emissions from this study were much lower than the current regulatory limits of VOC and NH_3 for composting facilities. Compost produced from the project met all of the composting industry standards. The total parasitic load during the anaerobic and aerobic phases of operation was 4.5% and 18.0%, respectively (total of 23%). Total net energy produced was 49.5 kWh/wet ton or 77.5% of the energy produced. There is no technical limitation to implementation of a full-scale project and project economics are competitive with landfilling fees and can yield MARR > 15%. To reduce the lag time in methane production the ratio of waste to inoculum should be increased. Laboratory tested may be needed to determine the optimum waste to inoculum ratio.

Recommendations

We recommend construction and operation of a commercial size demonstration project (30,000 ton per year) using green waste, food waste, FOG, and other liquid food waste at the Yolo County Central Landfill facility and determine methane yield. The commercial size project can provide critical information on methane yields for various types of waste mixtures and rate of degradation for optimizing the anaerobic phase retention time. Additional emissions data should be collected from the aerobic phase of operation with forced aeration and data be compare with typical windrow composting emissions. In addition, a market study for this technology should be done to assess the potential for implementation of the commercial scale project at other sites.

Public Benefits to California

Application of this technology to waste in California has the potential to generate enough electricity to meet the electricity demand of 148,274 households in California or 1.2% of the total electricity demand of the households in State of California or produce 67 million diesel gallon equivalent (DGE) of compressed natural gas (CNG) to reduce petroleum to a price competitive to natural gas. If biogas produced is converted to CNG and used instead of diesel for transportation the CO_2 emissions are reduced annually by 1.13 $MMTCO_2eq$. Other benefits include: a) production of 4.6 million tons of compost for use in agriculture which can reduce the reliance on chemical fertilizer and, reduce water evaporation from soil and increase crop yield; b) reduction of high-solid organic waste treatment cost for Californians when compared with an in-vessel anaerobic digester. When this technology is applied to current organic waste disposed in Californians landfills, the initial capital cost would be reduced by $3.17 billion and the annual operating cost would be reduced by $621 million per year.

Introduction

California leads the nation in energy efficiency and has already implemented many regulatory programs to manage energy use and reduce the carbon footprint of the energy sector. California is also working to ensure that 33 percent of the state's electricity is generated from renewable resources. To keep up with growing energy demands and ensure economic growth, it is vital for Californians to continue to increase the generation of renewable energy.

In 2014, Californian's statewide disposal was 31.2 million tons (CalRecycle, 2015). Currently, the compostable fraction of these materials, including food, leaves and grass accounts for about 6.9 million tons annually (CalRecycle, 2015). In addition, agricultural and food processing facilities generate biodegradable waste streams that are also good sources of energy. This combination of organic waste sources represents a large potential energy source; it has been reported that the source-separated organic fraction of municipal solid waste alone is capable of providing approximately 8% of the energy demands of the state of California (Rapport et al., 2008).

Composting infrastructure expansion has remained stagnant over the past 10 years because of increased costs to comply with air quality and water quality requirements, and feedstock competition due to low landfill tipping fees. These regulatory barriers increase composting costs and inhibit the development of organics diversion infrastructure. In addition, the regulatory barriers encourage the landfilling of organic wastes. CalRecycle estimates that traditional composting would need to expand by nearly 70% to handle just the compostable materials currently disposed in landfills. Traditional organics processing will not be able to accommodate this and, therefore, other means must be developed to handle organic material (CalRecycle, 2008).

One promising technology that has been identified by CalRecycle is anaerobic digestion, which has the potential to handle odorous and putrescible wastes such as food waste, meet strict environmental performance standards, and capture new revenue streams through the production of renewable energy and low carbon fuel. However, anaerobic digester plants are usually technically sophisticated making them costly to build and to operate (De Bere, 2000). More sophisticated and capital-intensive projects such as in-vessel anaerobic digesters and mass burn waste-to-energy facilities are common in Europe (Rapport et al., 2008; Tsilemou & Panagiotakopoulos, 2006). These plants work well on a steady supply of relatively homogeneous feedstocks, similar to what is available at a wastewater treatment facility. Here, the feedstock contains minimal amounts of foreign matter or contamination and may require pretreatment. On the other hand, solid organic waste composition varies considerably (day-to-day or even hour-to-hour). Accommodating this variability adds process complexity and cost. This is why the use of anaerobic digester plants in the U.S. is quite limited relative to landfills. Currently there are five anaerobic digestion facilities in California handling organic materials from the waste stream with 0.14 million tons per year of processing capacity (CalRecycle, 2013). These facilities use in-vessel processing that are capital intensive and are expensive to operate. There is significant interest in identifying feasible technologies to increase the diversion of food waste from landfills while producing biogas. Thus, there is a need for a less capital-intensive method of treating food-waste and other high moisture

organic waste that is readily degradable. Additionally, diverting fats, oils, and grease (FOG) to anaerobic digesters can prevent sewer and pump clogging, increase methane production in anaerobic digesters when co-digested with green waste/food waste mixtures, improve the overall economics and increase renewable energy generation (California Resources Agency (CRA), 2012).

In 2007, Yolo County constructed a digester cell where green waste and manure were used as feedstocks. Materials were first degraded under anaerobic conditions followed by aerobic conditions (Yazdani, 2010; Yazdani, Barlaz, Augenstein, Kayhanian, & Tchobanoglous, 2012). This two-stage batch digester process proved to be simple to operate and was an effective strategy for the management of yard waste. This type of in-situ digester can also be applied for the treatment of other organic wastes such as food waste/green waste mixture, waste water sludge as seed, and FOG which could increase the overall methane production and provide an economically viable diversion technology for food waste.

Project Objectives

The objective of this research was to design, construct, operate and monitor a two-stage Anaerobic Composter (anaerobic/aerobic) batch digester cell for treatment of a source-separated food waste/green waste mixture amended with FOG with the concomitant recovery of energy and compost. The performance of the Anaerobic Composter with respect to waste decomposition, biogas production, compost quality, leachate quality, air emissions, and life cycle cost and feasibility analysis was investigated. The project had the following objectives with quantifiable performance and cost targets:

1. Demonstrate that project design and construction was completed in one month.
2. Demonstrate that filling phase and cover placement were completed in less than two weeks.
3. Demonstrate that the average temperature of cell was at least in the mesophilic range (32 °C - 42°C) during the anaerobic phase.
4. Demonstrate that the methane content during the anaerobic operation phase was greater or equal to 48% (v/v).
5. Demonstrate methane generation was greater 64 liters of methane per dry kg (2,000 cubic feet per dry ton).
6. Demonstrate that biochemical methane potential (BMP) decreased by at least 50%.
7. Demonstrate that the destruction efficiency for volatile organic compounds (VOCs) was greater than 95%.
8. Demonstrate that the minimum attractive rate of return (MARR) for a full-scale project would be greater than 15%.

Evaluation of the design, filling, field monitoring, and laboratory monitoring of this Anaerobic Composter Cell will provide valuable data for feasibility analyses of a large-scale Anaerobic Composter.

Project Approach

The following tasks were developed to accomplish the project objectives:

Task 1 Approach: Design, Construct, and Fill Anaerobic Composter Cell (Cell)

An existing site at the Yolo County Central Landfill was designated for this project. This existing Cell on top of a lined landfill was used for this demonstration project. Plans for filling and the design of instrumentation, biogas collection system, water injection system, leachate injection and recirculation system, and air injection began in August, 2015 and were completed by the end of the month.

Waste Placement- The base of the existing Cell was about 27.4 m (90 feet) by 33.5 m (110 feet) and a fill average depth of 1.5 m (5 feet). The entire Cell bottom was covered with 0.3 m (1 foot) of wood chips as part of the drainage system. After placement of 0.9 m (three lifts of 0.3 m each) of waste, 0.3 m (1 foot) of wood chips and 0.3 m (1 foot) of finished compost were used to cover the waste and the entire cell was sealed using a synthetic liner. The wood chip layer above the waste was designed to insulate the Cell from ambient air. The top biofilter layer was used for treatment VOC gases during the aerobic phase of operation (see

Figure 1).

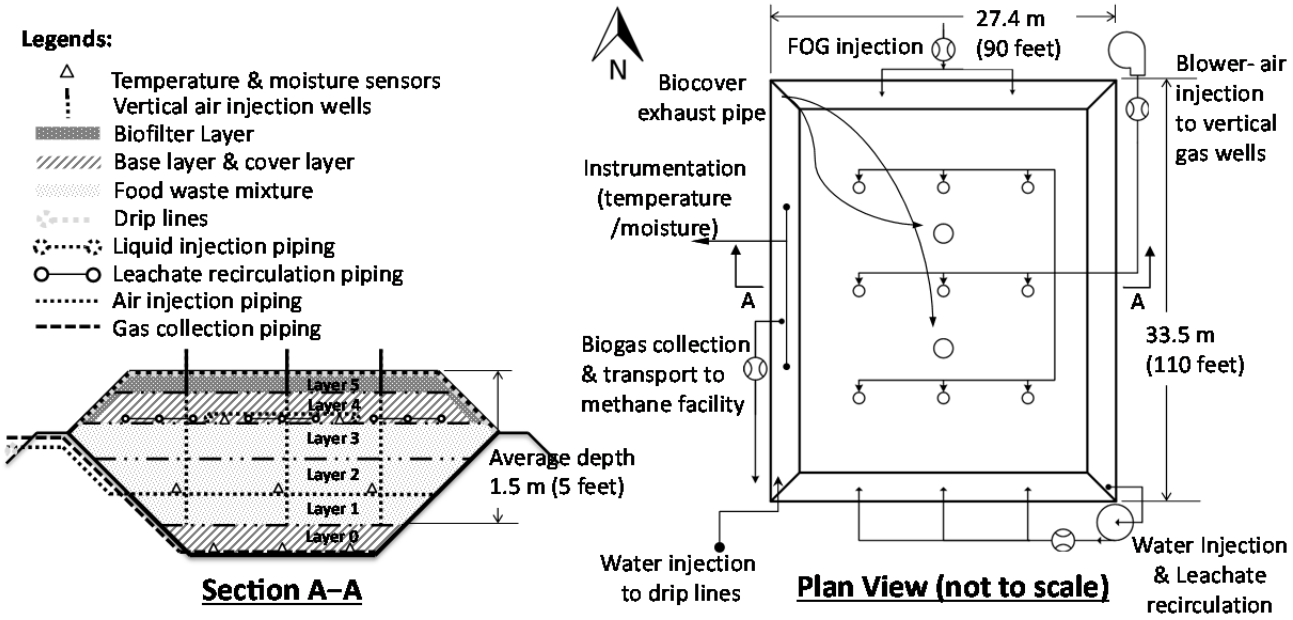

Figure 1. Anaerobic Composter Cell plan view and cross-section.

Waste Mixture- Mixed source separated organic waste was prepared and delivered to Yolo County Central Landfill. The source separated organic waste was the main waste feedstock for the Anaerobic Composter Cell (Cell). The ground food waste, green waste, and grape pomace, was

mixed with wood chips and delivered to the Cell (see Figure 2). The mixed waste was directly pushed into the cell (see Figure 3). The filling of waste in the Cell started in September 15, 2014. The construction of the base layer (layer 0) of Cell started on September 14, 2015.

Figure 2. Food waste before grinding and food waste and green waste mixture before delivery.

Figure 3. Food waste mixture placement in Cell.

Cell Instrumentation- The Cell was instrumented with temperature sensors for continuous monitoring of waste temperature (see Figure 4). Seven temperature sensors were installed at the bottom of the base layer (layer 0), three on bottom of layer 2 and six on the bottom of layer 4. Horizontal sensor spacing ranged from 5 to 10 m (17 to 33 feet) for each layer of waste. Each location received a temperature sensor with a temperature range of 0°C to 100°C (QT06005, Quality

Thermistor, Inc., Boise, ID), a 6.4 mm ID (0.25 inch) linear low-density polyethylene (LLDPE) tubing for pressure and internal gas composition measurement, and an on layer 0 electrical resistance moisture sensor to monitor the degree of waste wetness. A total of 15 thermistor, 21 LLDPE tubes and 7 electrical resistance moisture sensors were installed. In order to protect the sensors from damage, each sensor was encased in a 32 mm ID (1 ¼ inch) high-density polyethylene (HDPE) pipe. The LLDPE tubing was used to monitor fluid pressure (total gas and liquid pressure) at the end of each tube. Prior to placement of waste, a 30.5 cm (12 inch) thick layer of wood chips was placed over the entire base layer to protect it from further damage during waste filling.

Cell Cover Liner - The surface liner, which completely covered the digester cell, was 0.51 mm (20 mil) high-strength reinforced polyethylene (Dura Skrim R20DDK, Raven Industries, Sioux Falls, SD) on top of 288 gram per square meter (8.5 ounce per square yard) non-woven geotextile (Type C100NW, Contech Construction Products, Inc., West Chester, OH). The outer edges of the liner were connected and sealed to the previously installed liner in the outer anchor trench. A system of tires and ropes set on strips of textured 1 mm (40 mil) double-textured LLDPE liner (GSE Lining Technology, Houston, TX) was constructed on top of the surface liner. Tires were used to weigh down the liner during high wind conditions. The ropes were anchored in the outer anchor trench by attaching them to rope in the trench. The ropes across the top surface of the liner, attached to the tires, held the tires and textured liner in place.

Figure 4. Temperature and pressure tubing installed for Cell monitoring and leachate injection/recirculation and gas collection piping were installed.

Liquid Injection and Recirculation System- Horizontal leachate injection piping was installed on top of layers 3 and 5 for water and leachate addition and/or recirculation (see

Figure 1 & Figure 4). Each injection line consisted of a 50.8 mm ID (2 inch) high-density polyethylene (HDPE) pipe which extended completely through the waste. The injection lines were placed at approximately 3 m (10 feet) spacing. Each injection line was perforated by drilling a 2.4 mm (3/32-inch) hole every 3 m (10 feet). In addition, a low flow drip tape system was installed on

top of layer 5 for the addition of water to the biofilter under the surface liner system. The total volume of leachate injection to the digester was measured using a magnetically driven flow meter (1"PMM, Sensus Meters, Uniontown, PA). The total amount of water added to the digester using the drip tape system was measured by a flow meter (2" SR, Sensus Meters, Uniontown, PA). Two horizontal 10 cm ID (4 inch) HDPE pipes were installed on layer 3 for injection of FOG. Each pipe was perforated by drilling a 6.4 mm (1/4 inch) hole every 0.6 m (2 feet). The total volume of FOG injected was measured using a magnetically driven flow meter (4" W-1000 DRS, Sensus Metering Systems, Uniontown, PA).

The bottom of the digester cell was sloped to the east and south at a slope of 5 percent and 1 percent, respectively. At the lowest point of the base liner, a constructed sump allowed the collection and pumping of the leachate drained from the waste. A pneumatic double diaphragm pump with a maximum flow rate of 140 liters per minute (37 gpm) (P2R Wilden, Grand Terrace, CA) was used to pump the leachate that collected in the sump back into the leachate injection lines in the cell. The discharge line of the pneumatic pump was connected to a 5 cm ID (2 inch) HDPE pipe which could be routed to any or all of the leachate injection lines (see

Figure 1). The pump was turned on and off automatically by a bubbler monitor system (Model 12259 Digital Control Corporation, Clearwater, FL) which controlled the depth of water in the sump to below 10 cm (4 inches).

Gas Collection and Aeration System - The gas collection system was designed to collect gas from the bottom of the waste during the anaerobic phase of operation. The horizontal gas collection lines at the bottom of the cell (layer 0) consisted of a 15.2 cm ID (6 inch) schedule 40 PVC pipe with four lateral lines. The total gas flow rate from the cell was measured using a positive displacement meter (Roots Meters Series B3, Model 5M175 Roots, Houston, TX). Gas composition was monitored daily for concentrations of methane, carbon dioxide and oxygen using a GEM™ 2000 landfill gas analyzer (CES Landtec Inc., Colton, CA).

The waste aeration system was designed for horizontal (layer 1) and vertical air injection. Three horizontal aeration lines were installed on top of layers 1. They consisted of 10 cm ID (4 inch) HDPE solid pipes that were perforated by drilling a 6.4 mm (1/4 inch) hole every 0.6 m (2 feet). For the vertical aeration lines, nine 5 cm (2 inch) slotted pipes were installed to increase aeration in the Cell (see

Figure 1).

Task 2 Approach: Operate and Monitor Anaerobic Composter (Cell)

Waste Temperature- Following initial waste filling temperature sensors installed in the Cell were continuously read using the on-site Supervisory Control and Data Acquisition (SCADA) system.

Gas Volume, Composition and Methane Generation Rate-

Anaerobic Phase—During the anaerobic phase of operation, the Cell gas collection header pipe was connected to the main landfill gas collection system which, in turn, was connected to a single blower under suction. The total gas volume from the Cell was continuously monitored using the positive displacement meter. At least weekly, the main header line and the individual gas well flow rate, composition, and well suction were monitored and recorded by the GEM™ 2000 landfill gas analyzer. The GEM™ 2000 was field-calibrated daily against gas standards (5 percent O_2 and 95 percent N_2; and 50 percent CH_4, 35 percent CO_2 and 15 percent N_2).

Data Analysis—During the anaerobic phase of operation the gas collection data was analyzed to determine the methane generation rate relative to conventional landfills. Methane recovery in landfills is typically modeled using the U.S. EPA's LandGem model (Alexander, Burklin, & Singleton, 2005):

$$Q_n = kL_0 \sum_{i=0}^{n} \sum_{j=0.0}^{0.9} \frac{M_i}{10} e^{-k \cdot t_{i,j}} \qquad \textbf{(A)}$$

where, Q_n= CH_4 collection rate (m^3/yr) in year n, M_i = mass of waste accepted (Mg) in year i, L_0= ultimate methane yield (m^3 CH_4/yr), k = decay rate (yr^{-1}), j = the decimal year time increment, t = time (yr). AP-42 default values for k and L_0 for conventional landfills are 0.04 /yr and 100 m^3/yr.

The Cell was filled and covered quickly such that most of the gas produced was collected and there were no additional solids added once the gas collection began, which allowed for a thorough decay rate analysis. The cumulative collectable methane can be calculated from Eq. (B) which is the integral form of Eq. (A),

$$V = L_0 M(1 - e^{-kt}) \qquad \textbf{(B)}$$

where, V is cumulative CH_4 collected from beginning of life to time t (m^3), M is the initial mass of solids in digester (Mg)

The decay rate was calculated by linear regression at site-specific L_0 and the measured V. The site-specific L_0 was based on the weighted average of the laboratory measurement of biochemical methane potential (BMP) of four samples of food waste mixture and three samples of aged manure collected during the filling phase sampling event. The decay rate value was optimized by minimizing the sum of squared errors (SSE) of Eq. (C).

$$\text{SSE} = \left\{ ln\left(\frac{L_0 - \frac{V}{M}}{L_0} \right) - (-kt) \right\}^2 \qquad \textbf{(C)}$$

Task 3 Approach: Field and Laboratory Testing of Gas, Solids, and Liquids

Gas Emissions Testing and Analysis-

Anaerobic Phase— During the anaerobic phase of operation, the gas from the Cell was sampled from the main header gas line on 2/18/15 and 7/1/15. These gas sampling events corresponded to the start-up of gas collection and moisture addition and 156 days and 288 days after the project start up, respectively. Gas samples were taken from the main gas collection header line as well as a combination of three 6-mm ID HDPE tubes (¼-inch ID) that were installed within the waste. Results of the anaerobic phase gas sampling events are shown in Appendix A.

Aerobic Phase— During the aerobic phase of operation a blower was used to aerate the Cell. The total volume of air injection into the Cell was continuously monitored using a thermal gas flow meter (Model 8840MP, Eldridge Products, Inc. Monterey, CA). Each air injection well was monitored daily for flow rate using an orifice plate. The exhaust gases filtered through the biofilter cover and the gas composition (O_2, N_2, CH_4, and CO_2) were measured every half hour using a micro gas chromatograph (GC) (MTI P200, MTI Analytical Instruments, CA). The micro GC was equipped with dual thermal conductivity detectors (TCD), a 10m MS-5A capillary column (channel A) and an 8m Poraplot U capillary column (channel B). Column temperature was independently controlled to allow simultaneous use of both channels. Three point standard curves for target gas components were used to calibrate the instrument.

The original planned number of days for aerobic phase operation was 30 to 60 days. However, this was reduced to 15 days to minimize the required aeration and electricity use as well as allow adequate time for solids testing and reporting of laboratory results for the final report. During the aerobic phase of operation gas was collected from the Cell both from the main header gas line and the gas exhaust pipes over the biofilter cover. Gas sampling was performed on August, 19, 2015 (two days after aerobic phase started), August 26, 2015 (nine days after aerobic phase started), and September 1, 2015 (fifteen days after aerobic phase started). Gas samples were collected using 6 liter evacuated sample canisters equipped with a particulate matter filter and mass flow controller adjusted to give a constant flow for a sampling period of 24 hours. The gas parameters and test methods used are listed in Table B1 and B2 and results of aerobic phase gas sampling events are shown in Table B3, Appendix B. Similarly, gas samples were collected for VOCs and fixed gases. In addition, gas samples were also collected using a 60 mL plastic syringe inserted into a stopcock installed at the main header pipe and the biofilter gas exhaust pipe. The syringe was flushed with gas sample by withdrawing gas and injecting it back into the gas pipe, after which a 60 mL sample was collected and injected into evacuated 20 mL serum bottles, sealed with butyl rubber stoppers and aluminum crimps. Samples collected from each location were within approximately 5 to 10 minutes of each other and were wrapped in aluminum foil to keep out of sunlight. Samples were shipped to North Carolina State University for analysis. Nitrous oxide (N_2O) concentrations were measured on a Shimadzu GC2014 Greenhouse Gas analyzer. The system was specially equipped with a five column system for the analysis of greenhouse gases. N_2O separation was accomplished using a Hayesep D column (packed column, 80/100 mesh, 2 m length, 1/8 in OD, 2.1 mm ID, stainless steel) and an electron capture detector (ECD). The temperature of the inlet was maintained at 100°C, column oven temperature was maintained at 75°C (Isotemp for 8.10 minutes), and detector temperature was maintained at 325°C. Nitrogen was used as a carrier gas operated in constant pressure mode with a maintained pressure of 293.5 kPa (total column flow was 25.9 mL/min).

Gas samples from the main header and the biofilter's exhaust pipes were monitored daily for CO, NH_3, and H_2S with indicator tubes (Carbon monoxide, ammonia and hydrogen sulfide detector tubes (SKC West Inc., Fullerton, CA). A hand-help pump (DRAGER Model No. 6400000, SKC West Inc., Fullerton, CA) with a carbon filter was used to extract the gas sample from the pipe. Simultaneously, H_2S was measured using a multi gas detector (Altair 4X, Mine Safety Appliances Company, Cranberry TWP, PA) with a sampling pump (Universal Pump Probe, Mine Safety Appliances Company, Cranberry TWP, PA). The instrument was calibrated daily using automated test system (Galaxy GX2, Mine Safety Appliances Company, Cranberry TWP, PA).

Data Analysis— Eq. (D) was used to calculate the emission mass flow rate for each of the detected compounds shown in Tables B1 and B2 from the main gas header line and the exhaust gas from the biofilters.

$$R = \left(\frac{C \times MW}{V_{ideal}}\right) \times Q \qquad \textbf{(D)}$$

where, R = emission flow rate (mg/hr),
C = pollutant concentration ($ppmv$),
MW = molecular weight of pollutant, (g/mol)
Q = gas flow rate (m^3/hr)
V_{ideal} = volume of pollutant per mole in ideal condition (L)

Eq. (E) was used to calculate the combined destruction efficiency (DE) in percent for both biofilters.

$$DE\ [\%] = \frac{R_{in} - R_{out}}{R_{in}} \times 100 \qquad \textbf{(E)}$$

where, R_{in} = mass flow rate into the biofilter (mg/hr)
R_{out} = mass flow rate out of biofilter (mg/hr)

Eq. (F) was used to calculate the total emission yield per dry kg of waste for NH_3, N_2O, and CO during the aerobic operation of the digester cell.

$$Y = \frac{24\left[\frac{hr}{day}\right]}{dry\ kg} \times \sum_{d=1}^{24} R \qquad \textbf{(F)}$$

where, Y = total emission yield ($\frac{mg}{dry\ kg}$)

Solids Sampling and Testing- Waste samples were collected for solids testing during the filling phase prior to liquid addition, and at the end of anaerobic and aerobic phases of operation. These samples were mailed on ice to North Carolina State University where they were analyzed for

moisture, cellulose, lignin, hemicellulose, organic solids, and biochemical methane potential (BMP). The laboratory BMP test is a standard measure of the amount of decomposition that is possible for a particular waste sample under ideal anaerobic conditions. Full test protocols are presented in Appendices C and D. Samples from the windrow curing phase were also measured for stability, maturity, pathogens, inerts, size distribution, chemical composition, nutrient content, and metals. A full list of parameters measured and methods used is presented in Table E1 in Appendix E.

Leachate Testing- Leachate quality was monitored on a weekly basis for the following field parameters: pH, electrical conductivity (EC), oxidation-reduction potential (ORP), total dissolved solids (TDS), and temperature. Field parameters were measured with an Ultrameter II instrument (Model 6P, Myron L Company, Carlsbad, CA) by sampling fresh leachate from the digester using the leachate recirculation pump. Prior to sampling, the Ultrameter was calibrated with three standard pH solutions as well as one conductivity standard solution. A leachate sample was obtained by running the recirculation pump for several minutes to get a fresh leachate sample in the line at the sampling location, then discharging into a sampling beaker for Ultrameter measurements. Leachate samples were taken during each sampling event and frozen in 125 ml plastic bottles for volatile fatty acids (VFAs) testing. Frozen leachate samples were placed in a cooler and maintained at 4 °C (39 °F) using crushed ice and were shipped on ice overnight to North Carolina State University for VFAs laboratory analysis. The following volatile fatty acids were tested: acetic, propionic, isobutyric, butyric, isovaleric, valeric, isocaproic, and hexanoic. The total VFAs concentrations were calculated as acetic acid using eq. (G):

$$[T_{VFAs}] = [Acetic] + 60.05\left(\frac{[propionic]}{74.08} + \frac{[isobutyric + butyric]}{88.11} + \frac{[isovaleric + valeric]}{102.13} + \frac{[isocaproic + hexanoic]}{116.16}\right) \quad \text{(G)}$$

where, total VFAs ($[T_{VFAs}]$) are expressed in mg/L as acetic acid, brackets indicates the concentration in mg/L, and numerals are the molecular weight of each compound in grams per mole.

Additional leachate parameters were analyzed by an independent laboratory for the parameters listed in Table F1, Appendix F.

During the aerobic operation phase of the digester cell, on three occasions, an additional testing was carried out to determine VOC concentrations in the leachate.

Task 4 Approach: Perform Life Cycle Cost and Feasibility

An economics model was developed to evaluate the net present value and the internal rate of return for a full-scale Anaerobic Composter Cell. The following assumptions were made for this model.

Project construction assumptions:

1) Project size- six 0.2 hectare (0.5-acre) cells were assumed to be constructed with waste capacity of 5,500 tons per cell.
2) Methane to electricity facility-the existing methane gas to electricity facility will be utilized with no additional capital cost for expansion.
3) Project funding- the project capital cost will be funded through operating cash.

Project operation cost assumptions:

1) Monitoring and management labor cost- the cost of labor for monitoring and management include one full-time technical staff and one part time management staff.
2) Annual labor cost increase- labor cost increases at a rate of 4% per year were assumed.
3) Annual cost increase for contracted work – the annual cost of waste processing, waste placement, waste removal and compost screening and marketing were assumed to increase 2% per year.
4) Annual materials and supplies rate increase – a rate increase of 2% per year was assumed.
5) Annual electricity price increase – a rate increase of 3% per year was assumed.

Other assumptions for the life cycle cost and feasibility of the full-scale project:

Project Design & Permitting— The cost of design, permitting, and initial survey for the design of the project is included in the project design & permitting cost.

Monitoring and Management— The costs of labor for monitoring and project management for operation contracts are included.

Subgrade Preparation and Cell Construction— This cost associated with the following work was included: clearing existing vegetation at subgrade; grading and compacting the underlying soil layer; grading the bottom of the Cell to drain to a low spot; installing the base liner and protective layer; installing a leachate sump; constructing levees to contain the leachate drained at the bottom of the Cell; and install and backfill an anchor trench for the base liner.

Waste Processing and Compost Screening— This cost includes the cost of equipment, fuel, maintenance, labor, and all other related activities for picking litter mixed in the waste, grinding the material to less than 3 inches, delivery of the material to each Cell, screening of the material at the end of the aerobic phase, and transporting of the excavated compost for final curing and transport to off-site market.

Waste Placement/Removal and Compost Cover Placement— The cost for waste placement/removal and compost cover placement and removal includes the following: labor, equipment, fuel, maintenance, and all other related activities for pushing of wood chips at the bottom of the Cell as part of the drainage system and to protect the liner below; pushing and compacting the delivered food waste mixture and manure; compacting food mixture and grading waste before it is sealed; after the anaerobic phase the interim cover removal; placement of compost biofilter placement over

the cell before aeration; removal of the finished compost; and preparing the Cell for reloading with fresh waste.

Liquid Injection and Recirculation System and Instrumentation and Control— This includes the cost of the leachate piping, valves, flow meters, pumps, surface leachate injection system, and all other items related to installation of the water and leachate addition and recirculation system. The instrumentation cost includes the cost of materials and installation for the temperature and moisture sensors installed and all other associated instrumentation for collection of data and operation of the pumps. An existing SCADA system will be utilized to collect and operate the system, which was not included as an additional cost here. Some SCADA programming is needed for the operation and data collection.

Biogas Collection and Aeration System— This includes the cost of materials and installation for the gas collection system and air injection for the anaerobic and aerobic phase, respectively. This includes biogas collection wells, flow meters, gas condensate sumps, and other related fittings, pipes, and valves. The existing gas removal system at the landfill will be used to collect the gas and divert the gas to the current methane to electricity generation facility. The cost also includes materials, labor for installation waste aeration system. Other costs that included are: piping, pumps, valves, fitting, flow meters, and electricity for operation of the blowers and pumps.

Daily and Interim Cover— The cost of equipment, labor, and material for application of daily cover and interim cover.

Electricity Cost for Operation— The cost of electricity to operate pumps, blowers, and other electrical equipment not including waste processing and screening is included in this cost.

Energy Balance - The energy input and the energy output for the operation of the digester cell during the aerobic and anaerobic phase was either directly measured or calculated based on field measurement.

Energy Input for Liquid Pumping— The energy used to pump water, leachate and gas condensate was calculated based on the total volume of liquid pumped using eq. (H) below.

$$E = \frac{Q \times H \times T \times 100}{5380 \times \eta} \qquad \text{(H)}$$

where, Q = flow rate (gpm), H = hydraulic head (ft), T = time of pump operation (hrs), η = efficiency in percent (%) (assumed 90% for pumps)

Energy Input for Gas Collection & Air Injection— Energy used for gas collection and air injection was monitored estimated based on previous study where a digital energy monitor (Model No. ELF 3234-3 Class 1.0, Karnataka, India) was installed on each blower.

Energy Output— Energy output during the anaerobic phase of operation was based on the total volume of methane produced. An assumed heating value of 1,012 Btu per standard cubic feet of methane and 11,250 Btu per kWhr was used in the energy calculation.

Project Outcomes

The following discussion of project outcomes is related to the quantifiable objectives and targets of the project.

Objective 1 Outcomes: Demonstrate that project design and construction is completed in one month.

The project team designed and prepared an existing Anaerobic Composter Cell at Yolo County Central Landfill (YCCL) for organic waste filling in less than one month. The detail design was described earlier in the project approach section.

Objective 2 Outcomes: Demonstrate that filling phase and cover placement is completed in less than two weeks.

Source separated organic waste used as the feedstock was processed and delivered to the project site. Waste processing facility was given a design for a food mixture recipe (by weight) of: food waste, yard waste, grape pomace, and compost overs wood chips. The food mixture was ground and delivered to the YCCL and pushed into the Cell. The filling phase of the project was completed in eleven days. Final cover placement was completed in two days. Waste filling and final cover placement were completed in two weeks as planned. Table 1 shows the different layers and the tonnage of each type of material buried in the Cell.

Table 1. Food waste mixture used to construction the Cell.

Cell Layer (Construction Date)	Food Mixture, Mg (tons)	Horse Manure, Mg (tons)
Layer 0	-	28.5 (31.4)
Layer 1 (9/15/2014)	190.6 (210.1)	18.7 (20.6)
Layer 2 (9/16-9/17/14)	324.6 (357.8)	20.6 (22.7)
Layer 3 (9/18/2014)	106.8 (117.7)	21.4 (23.6)
Layer 4 (9/23, 9/24/14)	-	-
Layer 5 (9/25/2014)	-	-
Total	**622.0 (685.6)**	**89.3 (98.4)**

Table 2. Average composition and waste characteristics.

Description	Moisture (%)	pH	Cellulose	Hemi cellulose	Lignin	Volatile Solids	BMP (mL CH_4/g of VS)
			(% dry basis)				
Average Food waste mixture*	44.81	4.6	17.01	7.30	23.18	75.67	124.08
Horse manure	19.79	7.8	26.69	12.61	21.81	73.84	68.10
Food waste	71.90	7.5	23.85	4.68	7.23	88.52	337.89
Green waste	31.78	5.4	17.90	8.86	23.26	74.37	87.14
Grape pomas	57.25	3.9	7.12	4.98	31.29	89.31	102.40

*Mixture of 40.5% Food waste, 21.2% Grape pomas, 10.1% green waste, and 28.3% compost wood chip overs by weight

Objective 3 Outcomes: Demonstrate that the average temperature of cell was at least in the mesophilic range (90-108 deg. Fahrenheit) during the anaerobic phase.

Anaerobic Phase Waste Temperature -The average monthly temperature for each layer in the Cell is shown in Figure 5. The average monthly temperature during the anaerobic phase, ranged from 28-49°C (82-120°F), and was well above the ambient air outside of the Cell. During the filling phase, the waste temperature reached a maximum of 36°C (97°F), which indicates some aerobic activity was initially dominant. The temperature increase was due to exothermic (heat-generating) biochemical reactions that took place as waste decomposition proceeded.

Shortly after waste filling, during the anaerobic phase of operation, between September 29, 2014 and August 16, 2014, the temperature within the waste decreased. The temperature in layers 0 continued to increase in the first 123 days after filling while waste temperature decreased in layers 2 and 4. The drop in the temperature in layer 2 and 4 was likely due to a combination of factors including heat loss to the atmosphere and the addition of cooler liquids to the Cell.

Towards the end of the anaerobic phase of operation (300 days), the temperature of all layers in the Cell reached an average temperature of 35°C (95°F). This indicates that Cell temperature had reached a steady state condition and the wood chip (layer 4) and the finished compost biofilter layers (layer 5) provided a certain degree of insulation from the ambient air. On average, the temperatures of waste layers were within the estimated mesophilic range of (32 °C - 42°C).

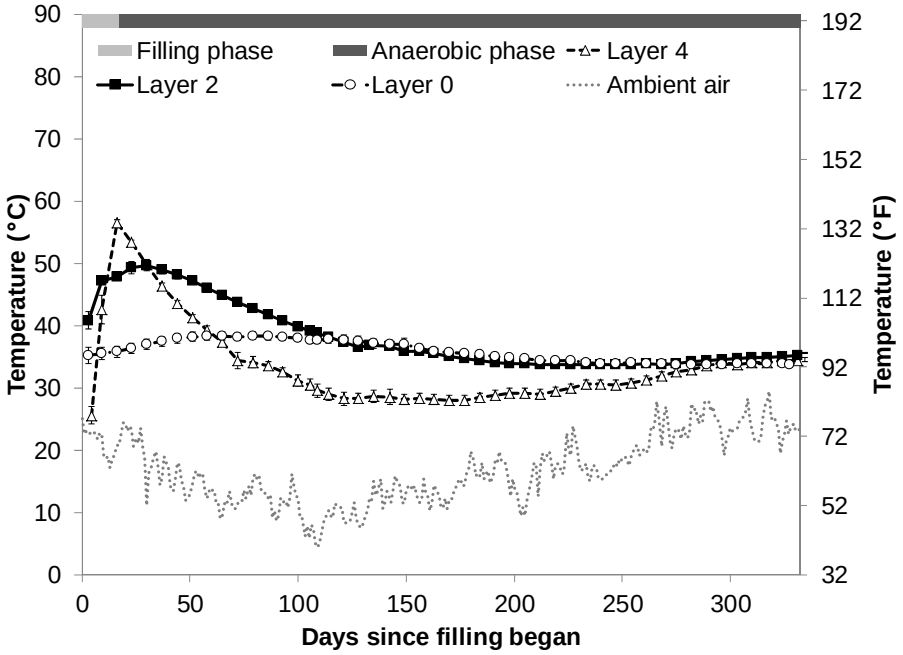

Figure 5. Anaerobic Composter Cell weekly average waste temperature for different layers during anaerobic phase of operation.

Aerobic Phase Waste Temperature - Nine vertical gas wells were installed before aeration began. During the first week of cell aeration the rates of temperature increase in layers 2 and 4 were 4.6 °C per day and 2.6°C per day, respectively. For layer 0, the rate of temperature increase was only 0.4 °C per day. Waste samples and moisture sensors from layer 0 showed high level of moisture which inhibited full aeration of this layer and therefore increase in temperature. After seven days of aeration, a second biofilter exhaust pipe was installed on the cover liner to increase air circulation in the Cell and reduce the internal waste temperature. As shown in **Figure 6**, after installation of the second exhaust pipe, the internal waste temperature in layer 4 decreased while the temperature in layer 2 reached a steady state. The daily average temperatures for both layer 2 and layer 4 at the end of the aerobic phase were between 50 °C to 60 °C.

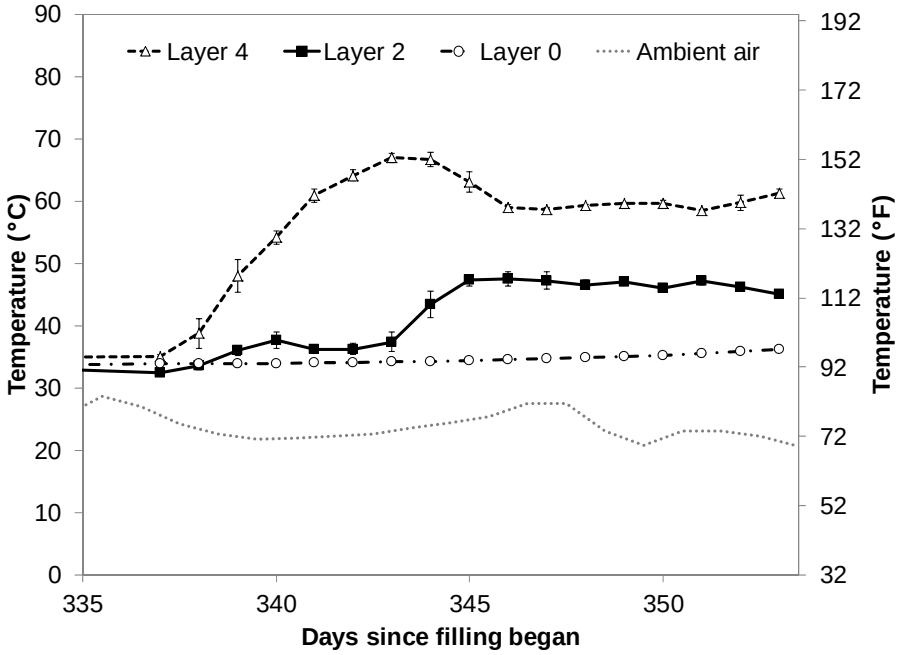

Figure 6. Aerobic Composter Cell daily average waste temperature for different layers during aerobic phase of operation.

Cell Aeration and Safety- During aeration of waste explosive gas may be formed if gas mixture is within a specific range (CH_4 content is approximately between 6% to 14% and oxygen content is 14% to 19%, Figure7). As part of the aerobic operation the gas composition must be monitored and the gas composition be kept outside of this range by reducing or increasing the air injection rate. At the start of the aerobic phase the methane content in the gas is normally too high to be in the explosive range but after aeration has been established and the cell is fully aerobic there is not enough methane in the gas mixture. Only during waste excavation or long period of blower shout down is when gas mixture could have enough methane to form a flammable mixture or be in the explosive range. A continuous monitoring system for methane and oxygen as well as gas temperature would allow for safe operation of the project.

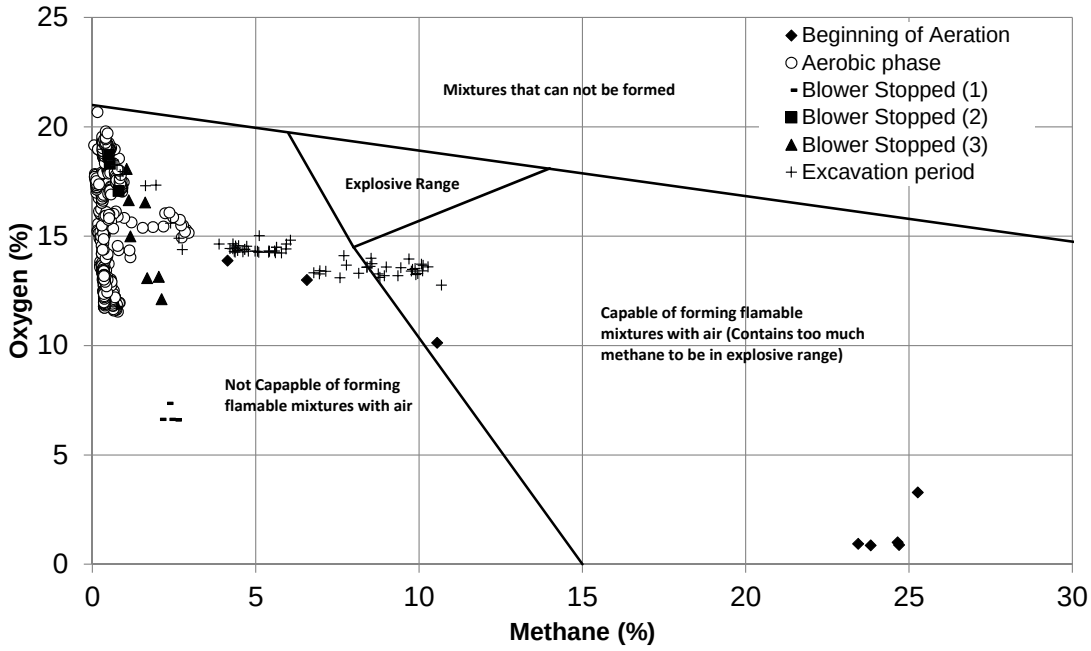

Figure 7. Anaerobic Composter Cell exit gas composition during the aerobic phase of operation.

Objective 4 Outcomes: Demonstrate that the methane content during the anaerobic phase is greater or equal to 48%.

Methane Content During Anaerobic Phase- In order to increase moisture content, increase methane generation, and seed the waste with anaerobic bacteria, liquid waste was injected into the cell. During the period methane generation was slow and it took about 120 days before significant gas was produced. After this period methane production and methane content increased. The average methane content after the initial 120 days was 46% ± 0.5% SE. This was slightly below the target value of 48% (Figure 8).

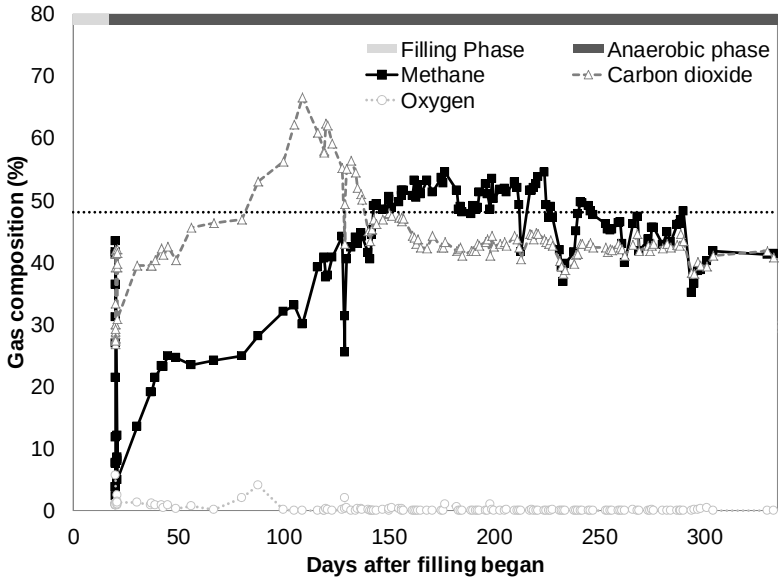

Figure 8. Anaerobic Composter Cell gas composition over time during the anaerobic phase of operation.

Objective 5 Outcomes: Demonstrate that the methane generation was greater than 2,000 cubic feet per dry ton.

Anaerobic Phase Gas Volume- During the anaerobic phase, the total volume of biogas generated was 3.4 x 10^4 cubic meter (1.2 x 10^6 cubic feet) and the total volume of methane produced was 1.6 x 10^4 cubic meter (5.6 x10^5 cubic feet). This equates to 38 liters of methane produced per kg of dry solids (1,210 ft^3 CH_4/ dry ton) from the Cell during the anaerobic phase of operation (Figure 9), which was below the methane generation target value of 64 liters of methane per kg of dry solids (2,000 ft3 methane per dry ton). This is most likely due to lag time in methane generation and the actual waste characteristics. The sudden drop in the methane content between day 250 to 300 was due to drilling and waste sampling. Holes were drilled for waste sampling, which introduced air into the cell and reduced the methane content.

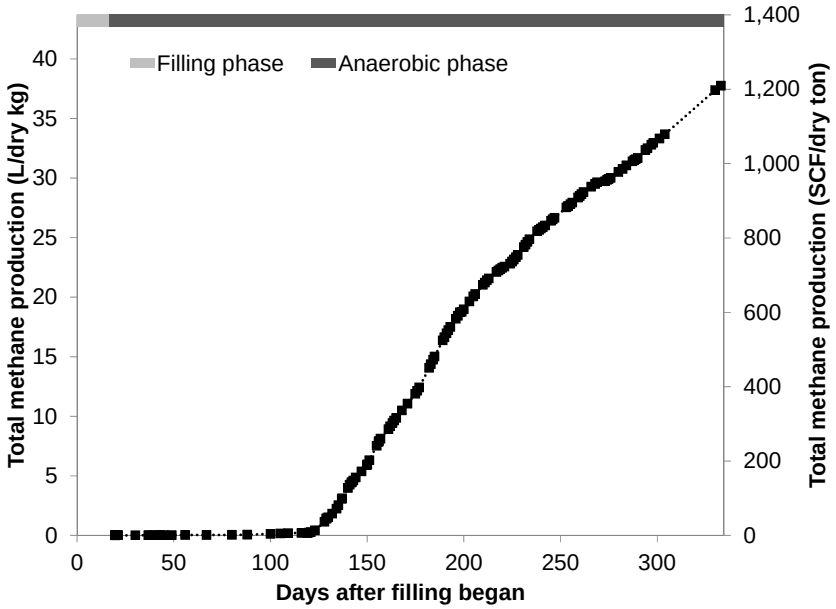

Figure 9. Total methane production per dry mass of solids.

Methane Generation Model – Equation shown in Figure 9 was used to calculate the cumulative collected methane (V in m^3) from beginning if life to time t, M is the initial mass of solids in cell (metric tons) (Barlaz, et al., 2010). The decay rate was calculated by linear regression at a site-specific L_0 and the measured V. The site-specific L_0 was based on the weighted average biochemical methane potential (BMP) of waste mixtures. The decay rate value was calculated by minimizing the sum of squared errors (SSE) using Goal Seek function in Microsoft Excel. The estimated decay rate (k) at methane generation potential (L_0) of 73 m^3-CH_4/dry Mg (2,339 ft^3/dry ton) was calculated to be 1.27 yr^{-1} with a half-life of 0.55 years.

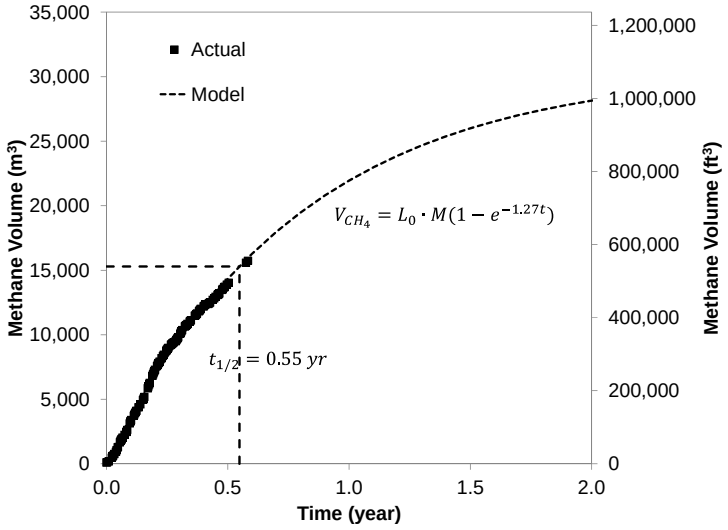

Figure 10. Methane generation model compared to actual field data over time.

Objective 6 Outcomes: Demonstrate that the destruction efficiency for VOCs was > 96%.

Results of gas testing and destruction efficiency of VOCs and other gases during the aerobic phase of operation are discussed below.

CH_4, and N_2O Gas Emissions – Summary of emission rate and destruction efficiencies for CH_4, and N_2O are presented in Table 3. The average methane content in the exhaust gas during the first ten days was 0.5%±0.03SE and it dropped to 0.4%±0.02SE during the last five days of aerobic operation. The calculated methane destruction efficiency of the biofilter during the first ten days of aerobic operation and the last five days of operation was -29%, and 44%, respectively. Prior to aerobic operation 98,420 liters (26,000 gallon) of water was added to the biofilter through the drip system on top in order to increase moisture content of the biofilter. This increase in moisture content likely reduced the effectiveness of aeration of the biofilter. Once the biofilter moisture content was reduced it became more active during the last five days of aerobic operation and methane destruction efficiency increased to 44%. During the one day of emissions testing (8/19/2015) the calculated destruction efficiency of methane was as high as 98.5% (see Table 5).

The average N_2O concentrations in and out of the biofilter were 1.72 ppm and 2.47 ppm, respectively. The overall destruction efficiency of N_2O was -30.1% which indicates that the biofilter was producing more N_2O than destroying it. At times, the concentration of N_2O was higher in the biofilter than in the inlet. N_2O is produced during the oxidation of organic matter under aerobic or anaerobic conditions. Under aerobic conditions, NH_4^+ is converted to NO_2^- (nitrification). Anaerobic ammonia oxidation (anammox) under anoxic conditions can also occur to produce N_2O where NH_4^+ is converted to NO_2^- and NO_3^- (denitrification). One potential explanation of N_2O production in the biofilter is that ammonia is very soluble in water, and because portions of the biofilter was oversaturated and in an anoxic condition, it is likely the denitrification of ammonia resulted in production of N_2O. Calculating the global warming potential of the N_2O (298 times than of CO_2) and CH_4 (25 times than of CO_2) released during the aerobic phase, the total amount of 0.16 tonnes of CO_2eq. is calculated, which is not a significant amount.

Table 3. Emission rates and destruction efficiencies for N_2O, andCH_4.

Location Description	N_2O mg/dry kg (lbs/dry ton)	CH_4 – first 10 days mg/dry kg (lbs/dry ton)	CH_4 – last 5 days mg/dry kg (lbs/dry ton)
Input to Biofilter	0.55 (0.00109)	4.45 (0.0089)	1.70 (0.0034)
Output from Biofilter	0.71 (0.00142)	5.75 (0.0115)	0.95 (0.0019)
Destruction Efficiency	-30.1%	-29.2%	43.8%

Ammonia, Carbon Monoxide, and Hydrogen Sulfide Gas Emissions—Table 4 below summarizes the results of other gas emission rates and destruction efficiencies for ammonia, CO_2 and H_2S. Please note that these data should not be generalized or assumed to be representative for a longer aeration activity. Ammonia gas was not detected in the gas stream during the start of aeration. Ammonia was detected after three days of aeration when the biofilter temperature increased from 35 °C to 57 °C.

The concentration of ammonia from the outlet of the biofilter was higher than the inlet. As discussed earlier, this indicates that the biofilter was producing ammonia which could have been due to saturated conditions of the biofilter after water addition. The overall destruction efficiency of ammonia was -52.3%.

Carbon monoxide gas was detected during the first four days of aeration at a concentration between 110 to 10 ppm and quickly declined to levels less than 10 ppm. The overall destruction efficiency for carbon monoxide was 25.4%.

No hydrogen sulfide was detected until eight days after aeration and it was between 3 to 7 ppm at the inlet to the biofilter. The biofilter destruction efficiency for hydrogen sulfide was over 90% and no odor was detected during the anaerobic or aerobic phases of operation.

Table 4. Emission rates and destruction efficiencies for NH_3, CO, and H_2S.

Location Description	NH_3 mg/dry kg (lbs/dry ton)	CO mg/dry kg (lbs/dry ton)	H_2S mg/dry kg (lbs/dry ton)
Input to Biofilter	2.20 (0.0044)	6.70 (0.0134)	0.26 (5.13×10^{-4})
Output from Biofilter	3.35 (0.0067)	4.95 (0.0099)	0.02 (4.98×10^{-5})
Destruction Efficiency	-52.3%	25.4%	90.3%

VOCs Destruction Efficiency— As discussed earlier, gas samples were collected using 6-liter evacuated sample canisters. Gas sampling was performed on August 19, 2015 (two days after the aerobic phase started), August 26, 2015 (nine days after the aerobic phase started), and September 1, 2015 (fifteen days after the aerobic phase started). After the evacuated canisters arrived at the laboratory for testing it was discovered that samples collected from the outlet of the biofilter on August 26 and September 1, 2015 were empty. However, all other samples from the biofilter exhaust pipe were sampled properly. As a result only one complete set of data was available for calculation of destruction efficiency for VOC and non-methane organic compounds (NMOCs) by the biofilter. The gas destruction efficiencies of the biofilter would improve over time as the microbial communities in the biofilter acclimate to aerobic conditions, as demonstrated in the previous study (Yazdani, 2010).

Table 5 presents the limited results of the biofilter destruction efficiency during the aerobic phase start up (August 19, 2015) for VOCs and other compounds. The destruction efficiency for the aromatic compounds ranged between 54.6% (toluene) to 74.2% (total xylenes) but total xylenes was not detected during the later tests. Acetone and ethylbenzene had the highest destruction efficiency of all VOCs (74%). However, acetone continued to be present in the gas stream during the rest of the tests with increasing concentration from 130 ppbv to 800 ppbv. Additionally, ethanol not initially detected, was found at biofilter out at concentration of 2,800 ppbv on the last day of gas sampling (see Appendix B, Table B3).

The chlorinated compound (dichlorodifluoromethane) had the lowest destruction efficiency (36.4%) because it is more stable and less degradable aerobically but it was not detected in the outlet during the later tests. The total mass of VOCs in the gas stream accounted for about 11 percent of the total NMOC present. The destruction efficiency of the NMOCs was 33.3%. The calculated emission rates for NMOC and VOCs are presented in Table 5.

In summary, the target destruction efficiency of greater than 95% for VOC was not measured due to difficulty in gas sampling and biofilter saturated condition. However, it is expected that over time the biofilter destruction efficiency would improve as biofilter moisture content drops below saturation and the microbial community acclimate.

Table 5. Concentration and destruction efficiencies for VOCs, methane, and others by the biofilter.

Compound Name	Concentration In-Biofilter (8/19/2015)	Concentration Out-Biofilter (8/19/2015)	Compound Destruction Efficiency (8/19/2015)
Aromatics			
Ethylbenzene	500 ppbv	130 ppbv	74.0%
Total Xylenes	< 97* ppbv	25 ppbv	74.2%
Toluene	110 ppbv	50 ppbv	54.6%
Ketones			
Acetone	500 ppbv	130 ppbv	74.0%
Chlorinated Compounds			
Dichlorodifluoromethane	22 ppbv	< 14* ppbv	36.4%
Other			
NMOC	18 ppbv	12 ppbv	33.3%
Methane	18 %v/v	0.27 %v/v	98.5%
Carbon Monoxide	7.3 % v/v	0.32 % v/v	95.6%

* The parameter was not detected above the method detection limit, so the method detection limit was used in calculations as a conservative estimate.

Table 6. Total emission of NMOCs and VOCs during the aerobic phase.

Date of emission sampling	8/19/2015	8/26/2015	9/1/2015
Days after filling began	338	345	351
Emission concentration (ppmv)	12.0	8.1	2.4
Emission Rate for NMOC	7.70 mg/dry kg (0.0154 lbs/dry ton)		
Emission Rate for VOCs (11% of NMOC)	0.85 mg/dry kg (0.001694 lbs/dry ton)		

In **Error! Reference source not found.** Table 7 below, the results for VOCs and NH_3 emissions were compared with the regulatory emission factors. The emissions factors for windrow composting of green waste in California developed by the South Coast Air Quality Management District (SCAQMD) and San Joaquin Valley Air Pollution Control District (SJVAPC) were used for comparison. The results of VOC and NH_3 emission factors from our study are much lower than the regulatory limits. This is due to a much longer retention time during the anaerobic phase where the majority of the VOCs were removed and destroyed by the active biogas collection system. The longer retention time not only maximizes methane gas captured, but it also reduces emissions during the aerobic phase and generates higher net energy.

Table 7. Regulatory emission factor compared with project emissions factors.

Waste Type	Process	NMOCs	VOCs	NH_3	CH_4	N_2O	CO	H_2S
		(pounds per wet tons)						
Yolo Project-Green Waste, Food Waste, Grape Pomace, and Manure mixed	Controlled	0.0090	0.0010	0.0039	0.0548	0.0008	0.0058	0.00003
Waste Type (SCAQMD Rule 1133)								
Green Waste			4.67	0.66				
Green Waste	Controlled		2.8	0.53				
Co-Composting	Uncontrolled		1.78	2.93				
Process Type (SJVAPCD Rule 4566)								
Stockpile			1.06					
Active Phase Windrow Composting			5.14					
Curing Phase Windrow Composting			0.57					

Note: The total mass of VOCs in the gas stream accounted for 11 percent of the total NMOCs.

Objective 7 Outcomes: Demonstrate that BMP decreased by at least 50%.

The primary parameters used to assess the extent of decomposition were BMP, cellulose, hemicellulose, lignin, and organic solids content. Generally, a decrease in these parameters indicates an increase in the degree of waste decomposition.

Biochemical Methane Potential (BMP)— BMP measures the amount of decomposition that is possible for a particular waste sample under optimal anaerobic conditions. Figure 11 below shows the BMP results over the course of the project for the anaerobic and aerobic phases of operation. During the course of anaerobic and aerobic phases, BMP decreased by 57% from an average of 93 mL±3.5SE CH4/g dry solids to 50 mL±2.2SE CH4/g dry solids. This is greater than the project goal of 50% reduction in BMP. The BMP reduction of 10% was observed between the end of the anaerobic phase to the end of the aerobic phase (Figure 10).

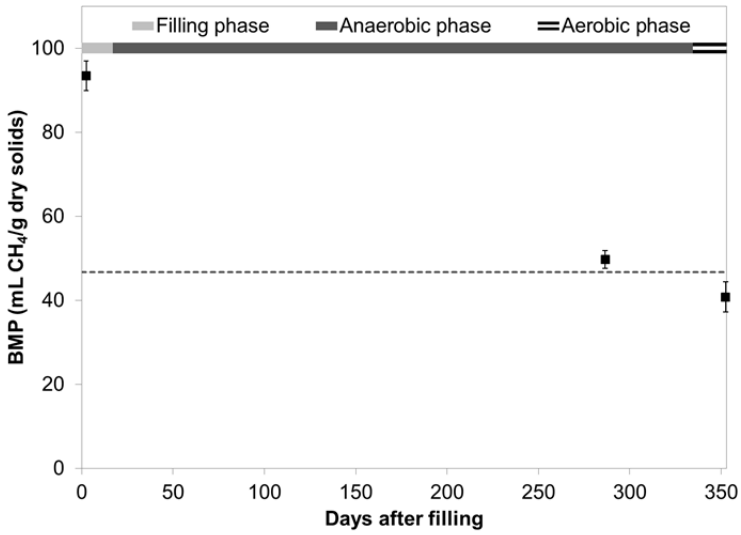

Figure 11. Biochemical Methane Potential (BMP) over time.

Ratio of Cellulose and Hemicellulose to Lignin— Another indicator of degradation is the ratio of cellulose (C) plus hemicellulose (H) to lignin (L). Cellulose and hemicellulose represent the major degradable component of refuse where lignin is essentially recalcitrant under methanogenic conditions and its concentration will increase as cellulose and hemicellulose decompose. As shown in Figure 12, this average ratio of samples collected was 1.20 ± 0.15SE during the filling phase and decreased to an average of 1.08 ± 0.03SE by the end of the anaerobic phase, indicating that cellulose and hemicellulose degraded at a much faster rate than did lignin. The average ratio reduced further to 0.85± 0.04SE at the end of the aerobic phase, indicating that lignin still degraded more slowly than cellulose and hemicellulose under aerobic conditions.

Compost Biological, Chemical, and Physical Testing— Appendix E, Table E2 and E3 shows the results of compost tests using the US Compost Council's Seal of Testing Approval Standards after excavation of digester material at the conclusion of aerobic operation. In Table E2 test results from this project by Soil Control Laboratory was compared to average values from more than 3,000 compost samples from North American compost facilities (data obtained from Soil Control Laboratory). Overall, the compost produced met the typical industry standard for all parameters tested. Further interpretations of the results are provided in Table E3.

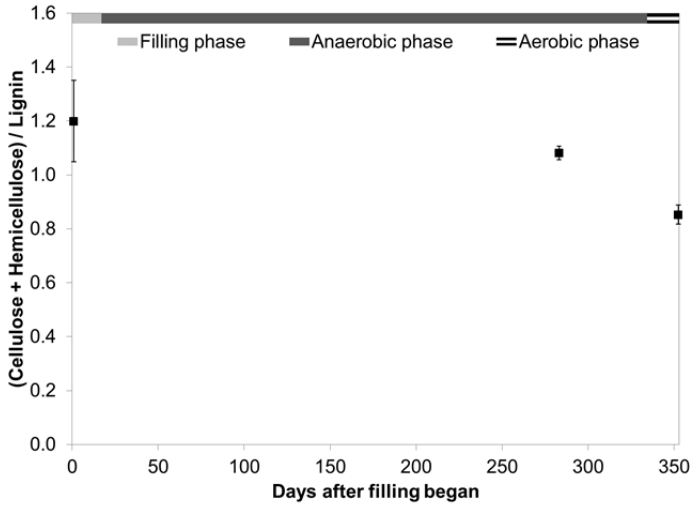

Figure 12. Ratio of (Cellulose + Hemicellulose) to Lignin over time.

Liquids Testing Results- In this section leachate quantity/quality and interpretation of data collected are presented. A complete list of leachate data is presented in Appendix F, Table F2.

pH & Total VFAs— Shortly after liquid addition and recirculation, during the early stages of the anaerobic decomposition phase, volatile fatty acids (VFAs) were accumulated (Figure **13**). This is consistent with the slight decrease in the pH to 6.7 (Figure 14). The concentration of total VFAs as acetic acid is expected to decrease over time in a well-operated anaerobic digester because acids are consumed by methanogens and methane is produced. As more of the acids are consumed and the population of the methanogens is increased, the leachate pH is expected to increase. This expected pattern is seen in Figure 13, where the majority of the acid is consumed and the concentration of total VFAs is reduced from more than 30,500 mg/L to an average value of 170 mg/L and the pH of leachate increased from 6.7 to an average of 7.7 (Figure 14).

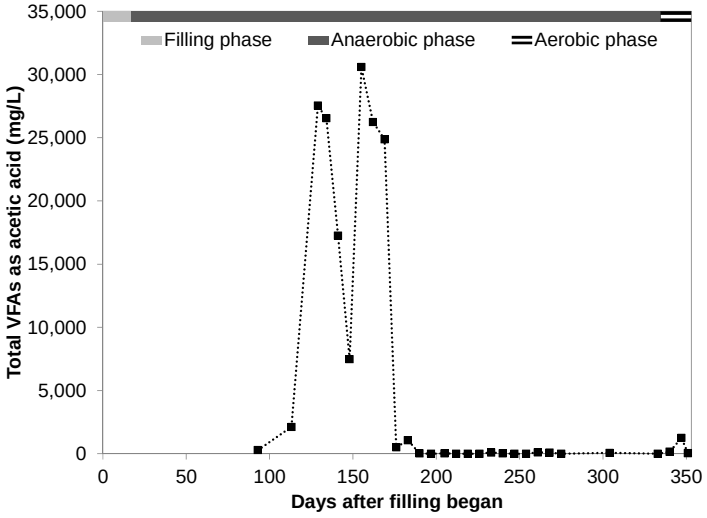

Figure 13**. Cell leachate total VFAs as acetic acid over time.**

Total Alkalinity as $CaCO_3$—The maximum total alkalinity of leachate reached 18,182 mg/L during the anaerobic phase and decreased to 170 mg/L at the end of the anaerobic phase. During the aerobic phase of operation the alkalinity increased to 7,800 mg/L (Figure 14).

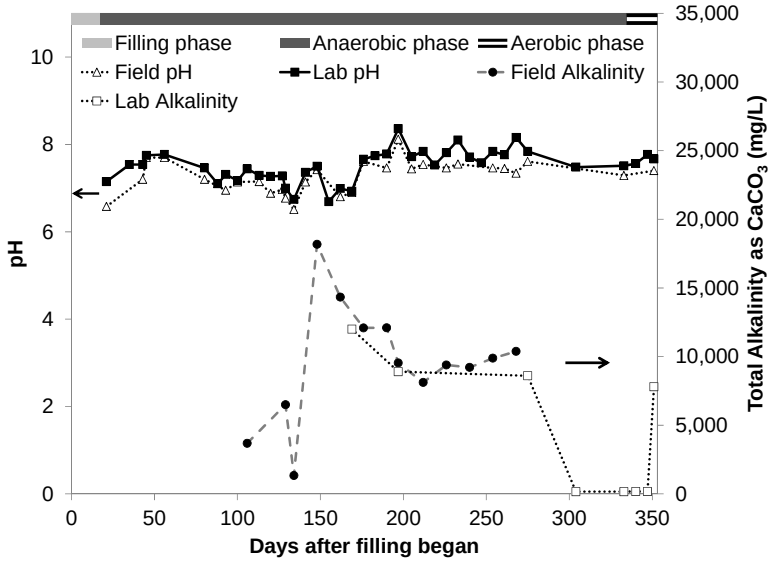

Figure 14. Cell leachate pH and total alkalinity as $CaCO_3$ over time.

Metals and other inorganics—Table F2 in Appendix F presents the minimum, maximum, and average values for metals and inorganics for leachate tested from the Cell. Generally, no elevated levels of heavy metals were found in the leachate that could inhibit biological activity.

Ammonia as Nitrogen—Ammonia levels reached as high as 443 mg/L and gradually dropped to an average of 92 mg/L towards the end of the anaerobic phase. Ammonia gas measurements during the aerobic phase of operation were discussed in earlier section.

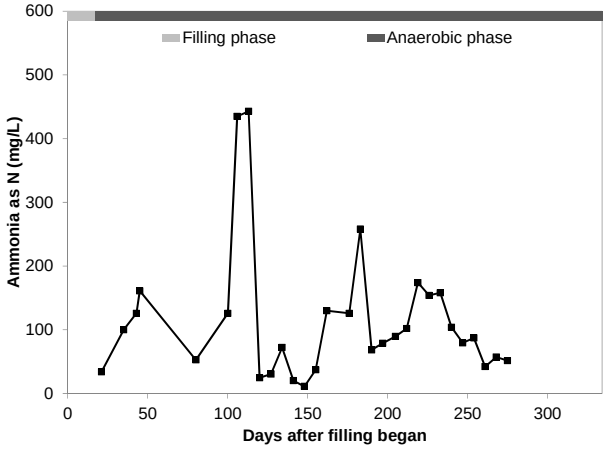

Figure 15. Ammonia concentration as nitrogen in leachate over time.

BOD_5 /COD ratio— The ratio of BOD_5/COD is used as a measure of wastewater biodegradability (Tchobanoglous, Theisen, & Vigil, 1993). A ratio above 0.1 as gas production accelerated as expected for well decomposing waste (Figure 15). Also, biogas production suggests that waste decomposition proceeded in a satisfactory manner as indicated by leachate pH (Figure 16).

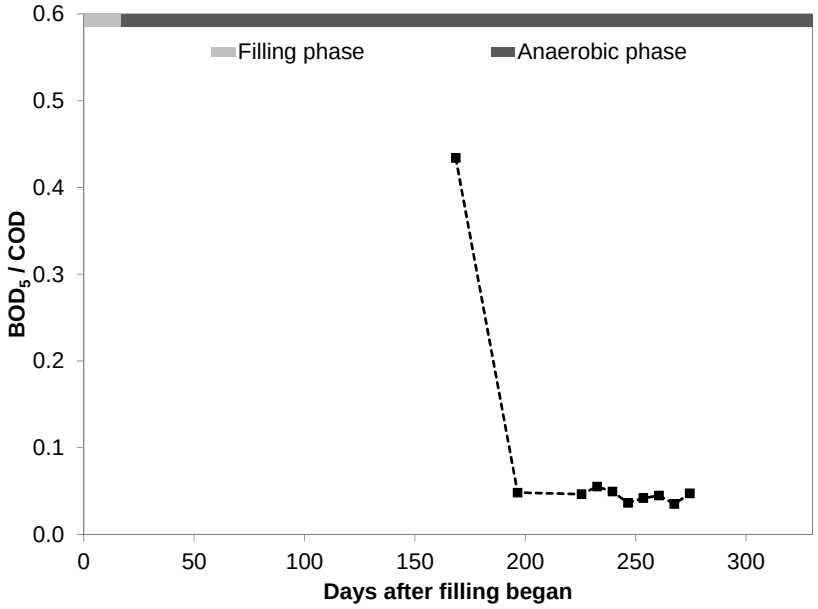

Figure 16. BOD_5/COD ratio of Cell leachate over time

Objective 8 Outcomes: Demonstrate that the minimum attractive rate of return (MARR) for a full-scale project would be > 15%.

An economics model was developed to evaluate the net present value and the internal rate of return for a full-scale project. Project was assumed to be constructed on top of an existing landfill and therefore no cost for land was included. It was also assumed that the no revenue would be seen from selling the compost. This is a conservation assumption which would increase the value of the investments if compost is sold actually sold at $15 per ton (current local price). It is also assumed that the current methane facility has adequate capacity to not require additional engine installed. All costs and revenues associated with the full-scale project were considered in a 10-year project life. Cost data were estimated based on various assumptions that were listed earlier. Summary of the initial capital cost for a full-scale project is shown in **Error! Reference source not found.**

Table 8. Summary of initial capital cost for a full-scale project.

Work Description	Initial Capital Cost
Project Design and Permitting	$80,000
Subgrade Preparation and Cell Construction	$148,500

Work Description	Initial Capital Cost
Liquid Injection, Recirculation System, and Instrumentation and Control	$132,000
Biogas Collection and Aeration System	$165,000
Equipment for Application of Daily and Intermediate Cover	$95,000
Total Capital Cost	**$ 620,500**

Error! Reference source not found. show summary of the 2nd year of operations and maintenance cost for the full-scale project. The values below are provided for informational items only and should not be used on other similar projects. For each unique full-scale project that cost of operation and maintenance should be estimated according to field conditions.

Table 9. Summary of annual (2nd year of 10 year project) operations, maintenance cost of full-scale project.

Work Description	Annual Operations & Maintenance Cost (2nd year)
Monitoring and Management	$141,440
Supplies for Application of Daily and Intermediate Cover	$15,300
Waste Placement/Removal and Compost Cover Placement	$404,352
Waste Processing, Compost Screening, and Marketing	$873,630
Electricity Use for Operation	$16,035
Total 2nd year operation & maintenance cost	**$ 1,450,757**

The main revenues assumed were the waste disposal fees and electricity generated from the project (**Error! Reference source not found.**). The revenue from the waste disposal was assumed to increase 3% per year. Other revenues from selling compost and carbon credits were not included here in the model.

Table 10. Summary of annual (2nd year) revenue from the full-scale Anaerobic Composter.

Work Description	Annual Revenue (2nd year)
Waste Disposal Fee	$1,514,100
Electricity Generation	$174,054
Total 2nd year annual revenue	**$ 1,688,154**

Figure 17 shows the annual cash flow and cumulative cash flow for the full-scale project.

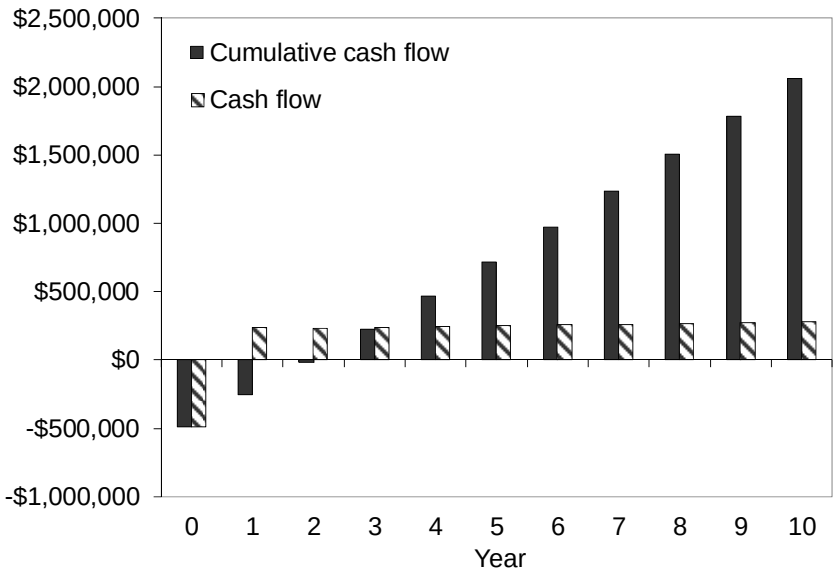

Figure 17. Annual and cumulative cash flow for a full-scale project.

In order to determine what waste disposal fee should be charged to meet the minimum attractive rate of return (MARR) for this investment, the net present value for the various disposal fees were calculated and was set to zero. Figure 18 shows the project NPV versus discount rate for the various waste disposal fees. In Table 11. , the MARR for the different waste disposal fees are presented. The current disposal fee at the Yolo County Central Landfill for green waste and green waste mixed with food waste is $49 and $53 per ton, respectively. Based on the current disposal fee in the region the MARR for the project is 48.6%, which is clearly higher than 15%.

Table 11. Internal rate or return for various waste disposal fee options.

Waste Disposal Fee Per Ton	Minimum Attractive Rate of Return
$45	13.0%
$46	21.6%
$47	30.2%
$48	39.1%
$49	48.6%
$50	59.0%

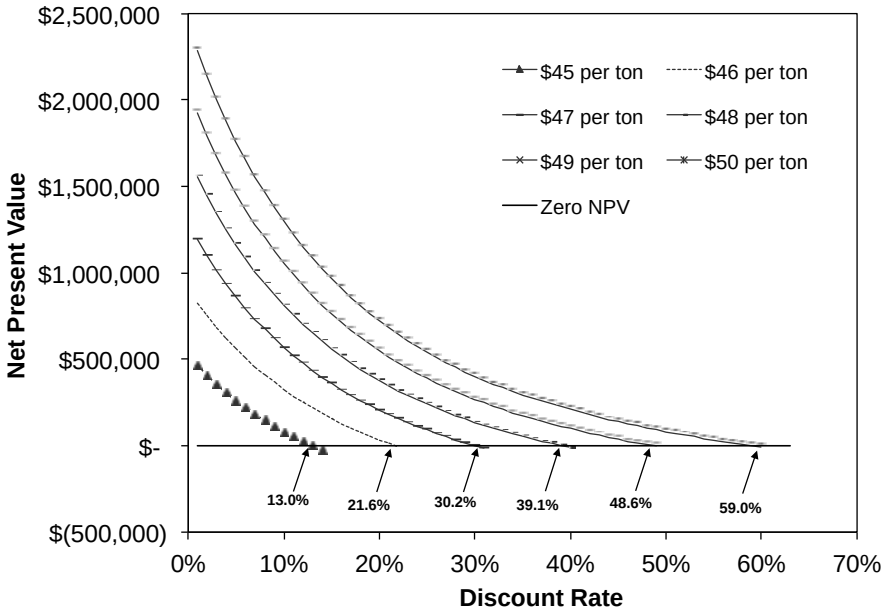

Figure 18. Full-scale Anaerobic Composter net present value for various discount rates.

Energy Balance- The total energy used during the anaerobic and aerobic phase of operation for the various type of operation are shown in Table 12. The total parasitic load during the anaerobic and aerobic phases of operation was 4.5% and 18.0%, respectively. The total parasitic load for this project was 23%. Typical tank digesters equipped with a heating coil, and pump for feeding and recirculation and tank mixture can have parasitic load as high as 50% to 70% (Bohn, Björnsson, & Mattiasson, 2007). In this project, the total net energy produced was 49.5 kWh/wet ton or 77.5% of the energy produced.

Table 12. Energy balance for anaerobic and aerobic phase of digester cell.

Type of Operation	**Anaerobic Phase (kWh/ wet ton)**		**Aerobic Phase (kWh/ wet ton)**	
Liquid Management	**Input**	**Output**	**Input**	**Output**
Liquid addition pumping	2.20	*NA*	5.31	*NA*
Leachate recirculation pumping	0.24	*NA*	0.03	*NA*
Leachate removal pumping	*NA*	*NA*	0.01	*NA*
Condensate pumping	0.01	*NA*	*NA*	*NA*
Biogas & Aeration System	**Input**	**Output**	**Input**	**Output**
Gas collection & removal	0.39	63.73	*NA*	*NA*
Air injection	*NA*	*NA*	6.06	*NA*
Total	2.84	63.73	11.41	0
Parasitic Load (%)	4.5%		18.0%	
Net energy (Percent Available)	49.48 kWh/wet ton (77.5%)			

Conclusions

The study successfully demonstrated the construction, monitoring, operation and energy and compost recovery from a high solids in-situ batch anaerobic digester for mixed waste (food waste, green waste, and grape pomace) and FOG. The Anaerobic Composter Cell at Yolo County Central Landfill (YCCL) was designed in less than one month. Waste filling and final cover placement were completed in two weeks as planned.

The temperature of this batch digester during the anaerobic phase was in the mesophilic range (32 °C - 42°C) and during the aerobic phase was between 50 °C to 60 °C. The average methane content during the anaerobic phase was 46% ± 0.5SE. The methane content was 2% lower than the target value of 48% because of air dilution. The recommended full-scale project would have about five times the volume of this demonstration project and a higher biogas generated rate, which would not be effected by air dilution as seen in this small demonstration project.

During the anaerobic phase of operation the 38 liters of CH_4 per kg of dry solids (1,210 ft^3 CH_4/ dry ton) was produced from the Cell, which was below the methane generation target value of 64 liters of CH_4 per kg of dry solids (2,000 ft^3 CH_4/ dry ton). This was most likely due to lag time in methane generation and the actual waste characteristics. The first-order gas generation model developed for this batch digester resulted in maximum methane generation potential of 73 m^3-CH_4/dry Mg (2,339 ft^3/dry ton) and an estimated decay rate of 1.27 yr^{-1}, with a half-life of 0.55 years.

Shortly before the start of the aerobic phase and during, about 98,420 liters (26,000 gallons) of leachate and gas condensate were removed from the Cell, while 166,558 liters (44,000 gallons) of water was added to the biofilter to improve VOC removal and maintain waste moisture. The calculated moisture content at the end of the anaerobic and aerobic phase was 55% and 59%, respectively. Samples collected from the digester at the end of the aerobic phase had moisture content ranging between 49 percent and 68 percent and were close to the calculated values.
Gas emissions monitoring during the aerobic phase of operation did not reach the target destruction efficiency of greater than 95% for VOC due to difficulty in gas sampling and biofilter saturated condition. However, it is expected that over time the biofilter destruction efficiency would improve as the microbial community acclimate and biofilter moisture content drops below saturation.

The laboratory results of BMP from samples collected during the anaerobic phase showed a decrease of 47% in BMP and an additional 10% reduction during the aerobic phase, for a total of 57% reduction in BMP. Another indicator of degradation of waste was ratio of cellulose plus hemicellulose to lignin, which reduced from an average ratio of 1.20 ± 0.15SE to 1.08 ± 0.03SE during the anaerobic phase and 0.85± 0.04SE at the end of the aerobic phase. This indicates that lignin degraded slower than cellulose and hemicellulose under both anaerobic and aerobic conditions.

During the aeration phase the exhaust gases out of biofilter were used to calculate the emission factor for VOCs, NMOCs, ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S) nitrous, oxide

(N_2O), and carbon dioxide (CO). The results for VOCs and NH_3 emissions were compared with the regulatory emission factors. The emission factors for windrow composting of green waste in California developed by the South Coast Air Quality Management District (SCAQMD) and San Joaquin Valley Air Pollution Control District (SJVAPC) were used for comparison. The results of VOC and NH_3 emission factors from this study were much lower than the regulatory limits. This was the result of long anaerobic retention time where the majority of the VOCs were removed and destroyed by the active biogas collection system. The long retention time during the anaerobic phase not only maximizes methane gas capture but it also reduced emissions during the aerobic phase and increased the net energy yield to over 77%.

The economic feasibility of implementing this technology at an existing landfill can be profitable and reduce the overall energy use and air emissions. Implementation of the commercial scale project can utilize organic waste that's received for disposal at the landfill. Additionally, co-digesting of FOG with organic waste can increase biogas production while preventing sewer and pump clogging and improve the overall economics of project. Implementation of this technology will be competitive with the current landfill disposal fee and can yield MARR values of 48.6% which is greater than the 15% target value.

Recommendations

This project demonstrated that there is potential for widespread implementation of an Anaerobic Composter system for conversion of organic waste to biogas and compost. The recommended next step is a commercial size demonstration project (29,937 Mg per year or 33,000 ton per year) using green waste, food waste, FOG, and other food liquid waste at the Yolo County Central Landfill. The data generated from such a demonstration project will benefit the waste management industry and other interested parties.

Although, in this small demonstration project the methane yield was slightly lower than estimated, likely due to seasonal variations in the waste stream and the lag time in methane production. The expected methane yield for a commercial size demonstration project would be higher due to waste received throughout the year and early liquid injection and gas collection to prevent lag time. In order to eliminate the lag time that was experience in this demonstration project and increase methane yield, fresh waste should be mixed with digestate (or manure) at a higher ratio. This will increase the inoculum to waste ratio and shorten the lag time for methane production. We recommend laboratory tests to determine the right percentage of substrate to inoculum ratio. Further BMP study should be conducted to determine the actual methane yield from a commercial scale project.

The long retention time during the anaerobic phase was not only beneficial in terms of methane gas yield but it also reduced emissions and energy requirements during the aerobic phase. Compost produced from the project met all of the composting industry standards. Further research on various types of waste and rate of degradation can help the industry in optimizing the retention time for various types of waste and when the aeration phase should be initiated to minimize energy use for forced aeration and water requirements.

Currently there are limited publications on air emissions from composting of food waste/green waste, and other liquid waste (FOG, other food liquid waste) and no emissions data for the proposed batch system in this study. There is also limited data on air emissions from forced aeration composting operations. It is recommended to further study and quantify the total aerobic phase composting air emissions of green waste, food waste, and liquid waste mixture. The reduction in air emission benefits from the Anaerobic Composter system could be compared with air emissions from a typical windrow composting as well as energy utilized for operation.

An additional recommendation is to further develop the market analysis for this technology. In particular, which landfills in California are ideal for construction of such a facility and what type of waste they could accept. Determination of the infrastructure and capabilities unique to each site should be performed.

Public Benefits to California

Based on the California's 2014 waste disposal study (CalRecycle, 2014, 2015) the total statewide disposal of food waste (5.6 million tons), green waste (2.1 million tons), manure (0.17 million), and green waste that is currently used as alternative daily cover (1.3 million tons) used at landfills is over 9.2 million tons annually. Additionally, 11.5 million gallons of fats, oils, and grease (FOG) generated in California is disposed that can also be used to increase methane generation (California Wastewater Training and Research Center, 2002) and reduce water use in California.

In California, application of the Anaerobic Composter technology for treatment of organic waste would yield about 11.4 billion standard cubic feet of methane annually or 11.5 million MMBtu per year. The potential electricity generated annually (assumed 11,250 Btu per kWh) would be over 1,023 GWh. Assuming an annual electricity use per household of 6,896 kWh (U.S. EIA, 2009), this would meet the electricity demand of 148,274 households in California. This is also about 1.2% of the total electricity demand of the households in State of California (U.S. EIA, 2009).

Another potential use of the biogas would be conversion of methane to transportation fuel such as compressed natural gas (CNG). Assuming 127,500 Btu per diesel gallon equivalent (DGE) and 70% conversion efficiency then over 67 million DGE per year can be produced to reduce petroleum use at a competitive price to natural gas. Using California Air Resources Control Board (ARB, 2015) avoided carbon intensity of 124.94 g per MJ and 134.52 MJ per gallon when using bioCNG instead of diesel, annually this would yield a reduction in CO_2 emissions by 1.13 $MMTCO_2eq$. Assuming carbon market value of \$25 per $MTCO_2eq$. the total value of this carbon sold on the market would be over \$25 million annually.

In addition to generation of renewable energy, compost is also produced. Assuming 50% reduction in the initial mass of organic waste, over 4.6 million tons of compost would be produced. This would be used by farmers and reduce reliance on chemical fertilizer. The use of compost would also reduce water evaporation from soil and increase crop yield.

The technology demonstrated in this research project for treatment of high solid organic waste is lower in both capital cost and operation cost when compared to other in-vessel European technologies (Rapport, et. al. 2008). As discussed earlier in the economics section, the capital cost and operating cost of 33,000 ton per year facility would be \$620,500 and \$45 to \$50 per ton, respectively. The capital cost and operating cost of a similar size European technology, only for the anaerobic treatment and not including the cost for aerobic treatment of the digestate was reported to be \$12 million and \$110 to \$120 per ton, respectively (Rapport, et. al. 2008). Assuming that 92 facilities at a capacity of 100,000 tons per year would have to be constructed throughout California, and the total capital cost for these Anaerobic Composter facilities would be \$173 million versus \$3.34 billion for the in-vessel European technology. The Anaerobic Composter technology would reduce the capital cost by \$3.17 billion.

Considering the operating cost, the Anaerobic Composter at an average operating cost of $47.50 per ton would cost a total of $437 million dollars per year but using the European technology at an average operating cost of $115 per ton would cost $1.058 billion per year. The Anaerobic Composter technology would reduce the operating cost by $621 million by year.

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Glossary

BMP: biochemical methane potential
bioCNG: compressed natural gas produced from biologically produced CNG
CNG: compressed natural gas
DGE: diesel gallon equivalent
EC: electrical conductivity
ECD: electron capture detector
FOG: fats, oils, and grease
GC: Gas Chromatograph
HDPE: high-density polyethylene
LLDPE: low-density polyethylene
MARR: minimum attractive rate of return
NMOCs: Non Methane Organic Carbons
NPV: net present value
Mj: megajoules
ORP: oxidation-reduction potential
SCADA: Supervisory Control and Data Acquisition
SCAQMD: South Coast Air Quality Management District
SJVAPC: San Joaquin Valley Air Pollution Control District
TCD: thermal conductivity detectors
TDS: total dissolved solids
VFAs: volatile fatty acids
VOCs: volatile organic compounds
YCCL: Yolo County Central Landfill

Appendix A: Anaerobic phase VOCs and other gas emissions

Compound	Unit	02/18/15	07/01/15
1,1,1-Trichloroethane	*ppbv*	< 50 *	< 98 *
1,1,2,2-Tetrachloroethane	*Ppbv*	< 50 *	< 98 *
1,1,2-Trichloro-1,2,2-trifluoroethane	*ppbv*	< 50 *	< 98 *
1,1,2-Trichloroethane	*ppbv*	< 50 *	< 98 *
1,1-Dichloroethane	*ppbv*	< 50 *	< 98 *
1,1-Dichloroethene	*ppbv*	< 50 *	< 98 *
1,2,4-Trichlorobenzene	*ppbv*	< 100 *	< 200 *
1,2,4-Trimethylbenzene	*ppbv*	< 50 *	< 98 *
1,2-Dibromoethane	*ppbv*	< 50 *	< 98 *
1,2-Dichloro-1,1,2,2-tetrafluoroethane	*ppbv*	< 50 *	< 98 *
1,2-Dichlorobenzene	*ppbv*	< 50 *	< 98 *
1,2-Dichloroethane	*ppbv*	< 50 *	< 98 *
1,2-Dichloropropane	*ppbv*	< 50 *	< 98 *
1,3,5-Trimethylbenzene	*ppbv*	< 50 *	< 98 *
1,3-Butadiene	*ppbv*	< 50 *	< 98 *
1,3-Dichlorobenzene	*ppbv*	< 50 *	< 98 *
1,4-Dichlorobenzene	*ppbv*	< 50 *	< 98 *
1,4-Dioxane	*ppbv*	< 50 *	< 98 *
2-butanone	*ppbv*	8000	570
2-Hexanone	*ppbv*	< 50 *	< 98 *
4-Ethyltoluene	*ppbv*	< 50 *	< 98 *
4-methyl-2-pentanone	*ppbv*	44	< 98 *
Acetone	*ppbv*	1500	2900
Acrylonitrile	*ppbv*	< 100 *	< 200 *
Allyl chloride	*ppbv*	< 50 *	< 98 *
Benzene	*ppbv*	25	50
Benzyl chloride	*ppbv*	< 100 *	< 200 *
Bromodichloromethane	*ppbv*	< 50 *	< 98 *
Bromoform	*ppbv*	< 50 *	< 98 *
Bromomethane	*ppbv*	< 50 *	< 98 *
Carbon disulfide	*ppbv*	75	180
Carbon tetrachloride	*ppbv*	< 50 *	< 98 *
Chlorobenzene	*ppbv*	< 50 *	< 98 *
Chloroethane	*ppbv*	< 50 *	< 98 *
Chloroform	*ppbv*	< 50 *	< 98 *
Chloromethane	*ppbv*	< 50 *	< 98 *
cis-1,2-Dichloroethene	*ppbv*	< 50 *	< 98 *
cis-1,3-Dichloropropene	*ppbv*	< 50 *	< 98 *
Cyclohexane	*ppbv*	< 50 *	< 98 *
Dibromochloromethane	*ppbv*	< 50 *	< 98 *

Compound	Unit	02/18/15	07/01/15
Dichlorodifluoromethane	*ppbv*	< 50 *	< 98 *
Ethanol	*ppbv*	1800	2200
Ethyl acetate	*ppbv*	< 50 *	< 98 *
Ethylbenzene	*ppbv*	< 50 *	84
Hexachlorobutadiene	*ppbv*	< 50 *	< 98 *
Hexane	*ppbv*	< 100 *	< 200 *
Isopropyl alcohol	*ppbv*	270	< 98 *
Methyl tert-butyl ether	*ppbv*	< 50 *	< 98 *
Methylene chloride	*ppbv*	160	< 98 *
n-Heptane	*ppbv*	< 50 *	< 98 *
Styrene	*ppbv*	< 50 *	< 98 *
Propylene	*ppbv*	< 50 *	790
Tetrachloroethene	*ppbv*	61	< 98 *
Tetrahydrofuran	*ppbv*	< 50 *	< 98 *
Toluene	*ppbv*	160	620
Total Xylenes	*ppbv*	86	200
o-Xylene	*ppbv*	22	54
m, p-Xylene	*ppbv*	63	150
trans-1,2-Dichloroethene	*ppbv*	< 50 *	< 98 *
trans-1,3-Dichloropropene	*ppbv*	< 50 *	< 98 *
Trichloroethene	*ppbv*	< 50 *	< 98 *
Trichlorofluoromethane	*ppbv*	< 50 *	< 98 *
Vinyl acetate	*ppbv*	< 50 *	< 98 *
Vinyl chloride	*ppbv*	< 50 *	< 98 *
Carbon disulfide	*ppbv*	< 40 *	< 390 *
Carbonyl sulfide	*ppbv*	< 40 *	< 390 *
Dimethyl disulfide	*ppbv*	< 40 *	< 390 *
Dimethyl sulfide	*ppbv*	< 64 *	< 390 *
Ethyl Mercaptan	*ppbv*	< 64 *	< 390 *
Hydrogen Sulfide	*ppbv*	1200	< 390 *
Methyl Mercaptan	*ppbv*	88	< 390 *
Carbon dioxide	*% by Vol*	43	32
Carbon monoxide	*% by Vol*	< 0.05 *	21
Methane	*% by Vol*	52	40
Nitrogen	*% by Vol*	4.2	7.2
Oxygen	*% by Vol*	0.66	0.29
NMOC	*ppmv*	45	73

* The parameter was not detected above the method detection limit, so the MDL was used in calculations as a conservative estimate.

Appendix B: Aerobic phase list of parameters and test methods (Table B1), and VOCs and other gas emissions (Table B2)

Table B1- List of parameters and test methods

Parameter	Test Method
Volatile Organic Compounds (VOCs)	U.S. EPA TO-15
Fixed Gases (CO_2, CO, CH_4, N_2, O_2)	U.S. EPA 25/3C
Total Non-Methane Organic Compounds	U.S. EPA 25/25C
Sulfur Compounds	SCAQMD Method 307-91

Table B2- List of VOC parameters tested

Name of Compounds		
1,1,1-Trichloroethane	1,1,2,2-Tetrachloroethane	1,1,2-Trichloroethane
1,1,2-Trichloro-1,2,2-trifluoro ethane	1,2-Dichloro-1,1,2,2-tetrafluoro ethane	1,1-Dichloroethane
1,1-Dichloroethene	1,2,4-Trichlorobenzene	1,2,4-Trimethylbenzene
1,2-Dibromoethane	1,2-Dichlorobenzene	1,2-Dichloroethane
1,2-Dichloropropane	1,3,5-Trimethylbenzene	1,3-Butadiene
1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,4-Dioxane
2-butanone	2-Hexanone	4-Ethyltoluene
4-methyl-2-pentanone	Acetone	Acrylonitrile
Allyl chloride	Benzene	Benzyl chloride
Bromodichloromethane	Bromoform	Bromomethane
Carbon disulfide	Carbon tetrachloride	Chloroethane
Chlorobenzene	Chloroform	Chloromethane
cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	Cyclohexane
Dibromochloromethane	Dichlorodifluoromethane	Ethanol
Ethyl acetate	Ethylbenzene	Hexachlorobutadiene
Hexane	Isopropyl alcohol	Methyl tert-butyl ether
Methylene chloride	n-Heptane	Styrene
Propylene	Tetrachloroethene	Tetrahydrofuran
Total Xylenes	m, p-Xylene	o-Xylene
trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	Trichloroethene
Trichlorofluoromethane	Vinyl acetate	Vinyl chloride
Toluene		

Table B3- Aerobic phase VOCs and other gas emissions

Compound	Unit	8/19/2015		8/26/2015	9/1/2015
		BF-IN	BF-OUT	BF-OUT	BF-OUT
1,1,1-Trichloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,1,2,2-Tetrachloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,1,2-Trichloro-1,2,2-trifluoroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,1,2-Trichloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,1-Dichloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,1-Dichloroethene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2,4-Trichlorobenzene	*ppbv*	< 97 *	< 28 *	< 48 *	< 34 *
1,2,4-Trimethylbenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2-Dibromoethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2-Dichloro-1,1,2,2-tetrafluoroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2-Dichlorobenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2-Dichloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,2-Dichloropropane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,3,5-Trimethylbenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,3-Butadiene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,3-Dichlorobenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,4-Dichlorobenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
1,4-Dioxane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
2-butanone	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
2-Hexanone	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
4-Ethyltoluene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
4-methyl-2-pentanone	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Acetone	*ppbv*	500	130	400	800
Acrylonitrile	*ppbv*	< 97 *	< 28 *	< 48 *	< 34 *
Allyl chloride	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Benzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Benzyl chloride	*ppbv*	< 97 *	< 28 *	< 48 *	< 34 *
Bromodichloromethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Bromoform	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Bromomethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Carbon disulfide	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Carbon tetrachloride	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Chlorobenzene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Chloroethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Chloroform	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Chloromethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
cis-1,2-Dichloroethene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
cis-1,3-Dichloropropene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Cyclohexane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Dibromochloromethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *

Compound	Unit	8/19/2015		8/26/2015	9/1/2015
		BF-IN	BF-OUT	BF-OUT	BF-OUT
Dichlorodifluoromethane	*ppbv*	22	< 14 *	< 24 *	< 17 *
Ethanol	*ppbv*	< 97 *	< 28 *	< 48 *	2800
Ethyl acetate	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Ethylbenzene	*ppbv*	< 48 *	7.9	< 24 *	< 17 *
Hexachlorobutadiene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Hexane	*ppbv*	< 97 *	< 28 *	< 48 *	< 34 *
Isopropyl alcohol	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Methyl tert-butyl ether	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Methylene chloride	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
n-Heptane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Styrene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Propylene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Tetrachloroethene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Tetrahydrofuran	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Toluene	*ppbv*	110	50	30	< 17 *
Total Xylenes	*ppbv*	< 97 *	25	< 48 *	< 34 *
o-Xylene	*ppbv*	< 48 *	8	< 24 *	< 17 *
m, p-Xylene	*ppbv*	< 48 *	17	< 24 *	< 17 *
trans-1,2-Dichloroethene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
trans-1,3-Dichloropropene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Trichloroethene	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Trichlorofluoromethane	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Vinyl acetate	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Vinyl chloride	*ppbv*	< 48 *	< 14 *	< 24 *	< 17 *
Carbon disulfide	*ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Carbonyl sulfide	*ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Dimethyl disulfide	*ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Dimethyl sulfide	*ppbv*	< 190 *	< 55 *	110	< 67 *
Ethyl Mercaptan	*ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Hydrogen Sulfide	*ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Methyl Mercaptan	*Ppbv*	< 190 *	< 55 *	< 97 *	< 67 *
Carbon dioxide	*% by Vol.*	19	4.7	3.7	5.4
Carbon monoxide	*% by Vol.*	7.3	0.32	0.7	1.3
Methane	*% by Vol.*	18	0.27	0.42	1.9
Nitrogen	*% by Vol.*	48	77	77	73
Oxygen	*% by Vol.*	8.4	18	19	18
NMOC	*ppmv*	18	12	8.1	2.4

* The parameter was not detected above the method detection limit, so the MDL was used in calculations as a conservative estimate.

Appendix C: Biochemical Methane Potential Testing Protocol

Introduction

There are three distinct steps to the biochemical methane potential (BMP) procedure. The first step consists of maintaining a culture that will be used to inoculate BMP assays. Culture maintenance requires preparing media and transferring the culture into this media regularly. The second step involves initiating the BMP assay. Initiating BMPs includes weighing refuse into serum bottles, preparing BMP media, transferring the media into serum bottles, and inoculating the serum bottles. The final step of the BMP procedure is to measure methane production from the serum bottles. This includes measuring both gas volume and gas composition, using a gas chromatograph.

Preparation of black butyl stoppers for bottles

1. Soak in ethanol overnight.
2. Rinse in DI water.
3. Autoclave for 30 min in 0.1N NaOH.
4. Rinse in DI.
5. Autoclave for 30 min 0.1N HCl.
6. Rinse in DI.

Inoculum Maintenance

A mixed culture or consortium that is acclimated to growth on dried ground refuse is maintained in the laboratory to serve as an inoculum for BMP tests. This culture must be transferred every 2 weeks to maintain the culture in an active state. In addition, the culture should be transferred two weeks prior to use as an inoculum for a BMP test. This is to minimize background methane production associated with the inoculum. The medium used for culture maintenance is described below.

Sulfide Reduced Consortia Maintenance Medium Preparation

1. Add the following components to a 2L round bottom flask with a stir bar in the order listed.
2. Adjust pH of media to 7.2.
3. Boil solution under 80 percent/20 percent mixture of N_2/CO_2. Watch the solution closely while boiling as the solution will foam and boil over quickly because it contains yeast extract.
4. After boiling, allow the solution to cool for about 5 minutes and then add 3.5 g $NaHCO_3$.
5. Allow solution to cool to room temperature while stirring and under 80 percent/20 percent mixture of N_2/CO_2.
6. Place approximately 0.40 g of ground fresh refuse in a 125 mL serum bottle. This refuse provides a substrate for consortium growth. (Weighing refuse into multiple serum bottles can be done in advance.).
7. Using a 25mL pipette, dispense 84 mL of cooled medium into the serum bottles containing refuse under 80 percent/20 percent mixture of N_2/CO_2.

Table C1. Medium for Refuse Consortium Maintenance

Component	per liter
PO_4 solution	100 mL
M_3 solution	100 mL
Trace Mineral solution	10 mL
Vitamin solution	10 mL
Yeast extract	0.25 g
Trypticase peptones	0.25 g
Hemin (0.01%)	10 mL
Resazurin (0.1%)	2 mL
Distilled water	758 mL

8. Stopper and crimp the serum bottles. One liter makes 11 serum bottles.
9. Autoclave the bottles using a sterilization temperature of 250°C and a sterilization time of 15 minutes. Take caution when removing from the autoclave as the serum bottles are hot.
10. As described below, 1 mL of sodium sulfide solution is added per bottle to reduce the medium. The sulfide reducing agent should be added to the serum bottle less than one day prior to use. One serum bottle per batch of medium should be reduced, and then sacrificed to verify that the pH is 7-7.3.
11. Some of the media in the bottles may have turned pink after being autoclaved. The media should turn back to a faint yellow by the next day. In any case, this medium is reduced just prior to use as described below. Media that is not a faint yellow after sulfide addition is not sufficiently anaerobic and should not be used.

Preparation of Sodium Sulfide Solution for Medium Reduction

1. Add boiling chips and 50 mL of water to a flask. Place a stir bar in the flask.
2. Mark the water level in the flask.
3. Add an additional 10 mL of water.
4. Boil the water until it evaporates to the 50 mL mark under O_2-free N_2.
5. Allow water to cool under N_2.
6. Weigh out 2.405 g of $Na_2S{\cdot}9H_2O$, choosing large, clear (white) crystals. Small, wet, or off color crystals may be cleaned by immersing them in distilled water for a short time, followed by drying with tissue or a paper towel. (Sodium sulfide is stored at 4°C.)
7. Add the sulfide to the O_2-free water and swirl to dissolve.
8. Close the flask with a rubber stopper, move into the anaerobic hood and dispense into a serum bottle. Seal and autoclave using a sterilization temperature of 250°C and sterilization time of 15 minutes.
9. This solution is then used to reduce serum bottles at the rate of 1 mL per serum bottles (see step 10 above).
   NEVER BOIL SULFIDE SOLUTION! Always write the date on the labels, and discard the solution within 4 weeks.

Inoculum Preparation

1. Cultures for transfer should be at least two weeks old.
2. With the use of a 23 gauge, 1" syringe needle, remove the overpressure from the culture by venting the gas under a fume hood. The absence of overpressure would suggest that the culture did not grow and is not a suitable inoculum.
3. Transfer all supplies into the anaerobic hood. This should include:
    a. 1-500 mL wide mouth flask (to pour all of the old culture into)
    b. 1 stir bar
    c. Serum bottle containing sodium sulfide solution
    d. 1-10mL plastic syringe
    e. 2-IM1 needles (23 gauge, 1")
    f. 3 serum bottles containing culture that are two weeks old
    g. 3 serum bottles of sulfide-reduced consortia maintenance medium. Make sure they are labeled and dated. Additional serum bottles containing the media will be needed when making inoculum for the BMPs
    h. 1 wide-bore pipette and bulb
    i. 1 de-crimping tool to remove aluminum crimp tops
4. Once all supplies have been transferred into the hood, uncrimp all bottles containing fresh medium and the microbial culture. Remove the stoppers from the fresh sulfide-reduced consortia maintenance medium and dispense 1 mL of the sodium sulfide solution into each bottle using the 10 mL plastic syringe and needle. To facilitate removal of sodium sulfide solution from the serum bottle, the bottle can be pressurized with O_2-free N_2 prior to moving the bottle into the anaerobic chamber.
5. Swirl each bottle of maintenance medium to mix in the sulfide. Wait a few minutes for the media to turn clear, which indicates that it is reduced.
6. Unstopper all the serum bottles containing the two-week-old culture and pour the contents of all bottles into the 500 mL flask. Put the flask on a stirring plate and make sure the culture is continuously mixed.
7. Add 15 mL of old culture to each bottle of reduced fresh medium using a wide bore pipette.
8. Stopper the serum bottle containing the new inoculum and shake each bottle until well mixed. Transfer any remaining old inoculum into the original bottles, making sure not to fill any bottle more than half full of old culture, and stopper. The culture will still produce gas so there needs to be ample headspace in each bottle.
9. Remove all items from anaerobic hood. Crimp all bottles, label and place in a 37°C incubator.

    If culture is needed for use as an inoculum for BMP tests, then calculate the amount needed to inoculate all samples (15 mL inoculum is dispensed into each serum bottle, each refuse sample is tested in triplicate serum bottles, and each set of BMPs contains five blanks). Follow the procedure described above to prepare sufficient inoculum. Allow sufficient inoculum to do a transfer in addition to the amount needed for BMP assays.

Biochemical Methane Potential Test

Overview

Tests are conducted in 125 mL serum bottles sealed with black butyl rubber stoppers and aluminum crimps. A set of triplicate serum bottles containing anaerobic medium (Table C2) and a ground refuse sample is inoculated with a culture enriched on ground refuse. Five blanks containing anaerobic medium only are also inoculated. After incubation for 60 days, the volume of gas and its methane concentration are measured.

Preparation of Medium for BMP Test

1. Pre-weigh refuse into 125 mL serum bottles, remembering to make 5 blanks (no refuse). Record the weights to two decimal points. Each day, the scale should be calibrated using the 100 gm internal calibration procedure for the scale. The amount of refuse to be added is discussed below.
2. Prepare medium by adding the following components (Table C2) in the order listed to a 2L round bottom flask, while stirring constantly.
3. Adjust the pH to 7.1-7.4.
4. While stirring, boil solution under N_2/CO_2 (80/20).
5. Allow to cool about 5 minutes and add 3.5 g $NaHCO_3$ under N_2/CO_2.
6. Let cool to room temperature, while stirring and under N_2/CO_2, then add 10 mL of 5% cysteine hydrochloride solution. The solution should turn pink.
7. Dispense 80 mL of the solution into each serum bottle containing a refuse sample under N_2/CO_2. Also dispense 80 mL into 5 serum bottles without refuse for use as blanks.
8. Stopper bottles and place in 37°C incubator until solution turns clear (~3 hrs). At this point bottles are ready to inoculate.
9. Note that bottles have not been autoclaved. If they are not to be inoculated the same day, then they should be stored in the refrigerator for no more than 24 hrs prior to use.

Table C2. BMP Medium Composition

Component	per liter
PO_4 solution	100 mL
M_3 solution	100 mL
Trace Mineral solution	10 mL
Vitamin solution	10 mL
Resazurin (0.1%)	2 mL
Distilled water	768 mL

Preparation of cysteine hydrochloride

1. Add 100 mL of water to a 250 mL flask. Place a stir bar in the flask.
2. Mark the water level in the flask.
3. Add an additional 10 mL of water.
4. Boil the water until it evaporates to the 100 mL mark under O_2-free N_2.
5. Add 5 g of cysteine to the flask and transfer the solution to a serum bottle.

6. Cap the bottle with a rubber butyl stopper and an aluminum crimp. Cysteine is located in the cabinet area with other BMP materials.
7. Autoclave the serum bottle at a sterilization temperature of 250°C for 15 minutes. Allow the solution to cool before use. (Note – the cysteine solution does not have to be autoclaved if it is to be used immediately and not stored.)

Inoculation

1. Vent inoculum before unstoppering.
2. Working at the gassing station, pour all inoculum to be used into a round bottom flask under N_2/CO_2 and stir. The inoculum should be two weeks old.
3. Unstopper bottles containing BMP medium/refuse samples under a stream of N_2/CO_2.
4. Dispense 15 mL of innoculum into each bottle containing the BMP medium using a wide bore pipette.
5. Stopper and crimp the bottles and incubate at 37°C.

Quantity of Refuse to Add

It is important to add sufficient refuse so that the volume of methane produced is significantly greater than the volume of methane that is attributable to the blank. However, more is not better to an infinite extent as the serum bottles should not be pressurized above 2 atm total. This means that if the headspace in the bottle is 60 mL, then no more than 60 mL of gas production is desirable. The calculated methane potential of cellulose ($C_6H_{10}O_5$) and hemicellulose ($C_5H_8O_4$) is 414.8 and 424.2 mL CH_4 at STP per dry gm, respectively. These figures should be doubled (~850 mL/gm) to allow for equal volumes of methane and carbon dioxide.

Fresh refuse can be assumed to be 50-60 percent cellulose plus hemicellulose. Thus, 1 gm of fresh refuse will have 510 ml of gas potential (0.6*850). Of course, all of this gas potential will not be realized. Assuming that 50 percent of the gas potential is realized, a samples size of 0.1 – 0.2 gm is appropriate. As refuse decomposes, the cellulose and hemicellulose concentrations decrease, thus larger sample sizes are appropriate. Historically, 0.5 gm for refuse samples that are 2-5 years old and 1 gm for samples known to be well decomposed were used.

Gas Volume and Composition Measurement

1. Withdraw a 1 mL sample of the headspace using the 2.5 mL gas tight syringe and vent. 2.5 mL should then be removed for injection into the GC. The technique for measurement of gas composition is described in a separate protocol. The volume should be removed and recorded in the same notebook as weights of refuse were recorded and added to the overpressure measurement described in the following step.
2. Overpressure in each bottle should be measured and recorded after the gas composition analysis is complete. A 50 mL wetted ground glass syringe with 3-way valve should be used to remove and measure the overpressure gas volume in the serum bottle. Put a needle on the valve and then onto the syringe with the syringe at the 0 mLs position. Close the valve to the needle and insert the needle into the serum bottle. Slowly open the valve to the bottle and the plunger will start to fill. If there is over 50 mLs overpressure close the valve at 50 mLs and record the volume. Leaving the needle in the bottle, open the valve so the gas in the syringe is expelled through the open valve port. Shut off this port and the syringe will start to fill again. Repeat as necessary until all overpressure is removed being sure to record all volumes and then total.

CAUTION: The use of the 3-way valve is tricky and gas from the bottle can be expelled accidently. Practice with the valve before using and have a full understanding of how it works.

Cleaning up after the BMPs are completed

All BMP tests and old inoculum serum bottles should be taken out of the incubator. Each bottle should have the headspace vented using a 23 g disposable needle in the hood. The bottles can then be autoclaved at a sterilization temperature of 250°C for 15 minutes using the liquid cycle. Once the bottles have cooled, they can be uncrimped and the butyl rubber stoppers taken off in the hood. Let the bottles sit for a few hours to avoid the generation of odors in the lab, after which the bottles can then be rinsed and soaked in soapy water.

Table C3 Phosphate Solution Composition

Component	per liter
KH_2PO_4	16.1 g
$Na_2HPO_4 \bullet 7H_2O$	31.89 g

Prepare in carbonate-free water and store under N_2 at 4°C. Carbonate-free water is prepared by boiling under nitrogen.

Table C4 M3 Solution Composition

Component	per liter
NH_4Cl	10 g
NaCl	9 g
$MgCl_2 \bullet 6H_2O$	2 g
$CaCl_2 \bullet 2H_2O$	1 g

Store solution at 4°C.

Table C5 Trace Mineral Solution Composition

Component	Amount to add per liter of Solution (g)
Nitrilotriacetic Acid	1.5
$FeSO_4 \bullet 7H_2O$	0.1
$MnCl_2 \bullet 4H_2O$	0.1
$CoCl_2 \bullet 6H_2O$	0.17
$CaCl_2 \bullet 2H_2O$	0.1
$ZnCl_2$	0.1
$CuCl_2 \bullet 2H_2O$	0.02
H_3BO_3	0.01
Na $MoO_4 \bullet 2H_2O$	0.01
NaCl	1.0
Na_2SeO_3	0.017
$NiSO_4 \bullet 6H_2O$	0.026
$Na_2WO_4 \bullet 2H_2O$	0.033

Dissolve the nitrilotriacetic acid in 200 mL of hot distilled H_2O and then adjust the pH to 6.5 with KOH. Add this solution to about 600 mL of distilled water and dissolve the components in the order listed. Dilute to one liter. Store in the refrigerator under nitrogen.

Note: Procedure is as described by Kenealy and Zeikus (1981) except for the addition of 0.033 g of $Na_2WO_4 \bullet 2H_2O$.

Reference:
Kenealy, W. and Zeikus, J. G., "Influence of Corrinoid Antagonists on Methanogen Metabolism." *J. Bacteriol*., 146(1):133, 1981.

Table C6 Vitamin Solution Composition

Component	Amount to add per liter of Solution (g)
Biotin	0.002
Folic Acid	0.002
B_6 (pyridoxine) HCl	0.01
B_1 (thiamine) HCl	0.005
B_2 (riboflavin)	0.005
Nicotinic Acid (niacin)	0.005
Pantothenic Acid	0.005
B_{12} (cyanocobalamin) crystalline	0.0001
PABA (P-aminobenzoic acid)	0.005
Lipoic Acid (thioctic)	0.005

Add ingredients in the order given and let dissolve. Store in a dark container in the refrigerator under nitrogen.

Reference:
Wolin, M. E., et al., "Formation of Methane by Bacterial Extracts." *Biol. Chem*., 238(8):2882, 1963.

Hemin Solution: Prepare a 0.1 percent Hemin solution (by weight) and store at 4°C.

Reference:
Wang, Y.-S., Byrd, C.S., and Barlaz, M.A., "Anaerobic Biodegradability of Cellulose and Hemicellulose in Excavated Refuse Samples Using a Biochemical Methane Potential Assay." *Journal of Industrial Microbiology*, 13:147-153, 1994.

Resazurin Solution: Prepare a 0.1 percent Resazurin solution (by weight) and store at 4°C.

Appendix D: Extractives, Cellulose, Hemicellulose and Lignin Content-Testing Protocol and Determination of Volatile Fatty Acids by Gas Chromatography Flame Ionization Detection

Cellulose Hydrolysis Methodology:
The complete analysis of cellulose and hemicellulose involves four distinct steps: removal of lipophilic extractives, hydrolysis, sample cleanup, and HPLC analysis. Conceptually, solvent extracted refuse samples that have been ground to pass a 1 mm screen are subjected to an acid hydrolysis. During hydrolysis, cellulose and hemicellulose are converted to their monomeric sugars. The refuse that remains includes lignin, other organics that do not dissolve in 72 percent sulfuric acid, and inorganics. The lignin content is calculated as the weight loss after combustion of the solids that remain after refuse hydrolysis. The acid hydrolyzate, which contains the monomeric sugars, is cleaned prior to injection into an HPLC equipped with a pulsed electrochemical detector.

Removal of Lipophilic Extractives:
Lipophilic extractives are removed from the sample by refluxing in a solvent toluene/ethanol (2:1 v/v). It is important to remove lipophilic extractives because these materials can interfere with the determination of lignin. The method described below was developed at the Environmental Engineering laboratory at NC State University, using a SOXTEC 255 extractor. The method is equivalent to 4 hr traditional Soxhlet extraction which is typically applied for the removal of extractives in plant tissues.

1. Use thimble support to weigh 1 g of dry sample in a thimble (note: the thimble needs to be dried and weighed accurately if extractives will be measured indirectly).
2. Transfer thimbles to thimble stand. Add defatted cotton plug.
3. Empty the solvent collection vessel.
4. Adjust the cooling water flow rate of at least 2 L/min
5. Move condenser to the load position by lifting the right handle to the top position (“Cup load”).
6. Move the left handle to the lowest position (“boil” position) then insert the thimbles manually or using the thimble holder. Make sure that the thimbles are centered.
7. Move both handles to the top position. Use cup holder to insert 6 extraction cups (pre-weighed and tared with glass pellets 5-6 mm dia). Move the right handle to middle position (“Solvent load position”) to mate the cups withe condensers.
8. Move left handle to the middle position to open the valves for solvent loading and load the cups with 80 mL toluene/ethanol (2:1 v/v) solvent using connectors on top of the extraction unit and a solvent addition kit connected to a dispenser.
9. Lower the right handle to clamp condensers and cups to the hot plate. Make sure that the cups are held tightly in place by twisting them for best contact with the hot plate and seals.
10. Use the extraction program with the following settings:
    a. Over-temperature OT: 330 °C
    b. Boil Time: 20 min.
    c. Rinse Time: 90 min.
    d. Recovery: 5 min

e. Dry: 3 min

11. Start the program on the control unit by pressing run button. The buzzer signal starts when the set temperature minus 5 °C is reached. Move the left handle to lowest position ("boil"). Press" TIMER" to start the countdown for "boil" step.
12. When countdown for boiling has reached zero, the control unit starts the buzzer signal. Move the thimbles to "rinse" position (middle, left handle) then press "TIMER then the countdown for rinsing starts.
13. When rinsing countdown is reached the control unit will start buzzer signal, Move thimbles to "recovery" position ("top", left handle) then press "TIMER".
14. The air pump automatically run when there is 3 min left in the analysis, the last traces of solvent is collected in the condenser and transferred to the collection vessel.
15. Press "FAN" button to further dry the sample at a time specified.
16. Control unit starts buzzer signal when the countdown is finished.
17. Lift the condensers to the "load" position (top, right handle). Take the cups out with the cup holder. Record the dry weight of the cups after drying 75 °C overnight.
18. Take out the thimbles using thimble holder or tongs. Bend the thimbles to release from magnetic attachment. Let the thimbles air out under the fume hood overnight then dry at 75 °C overnight.
19. Shutdown
    a. Turn off the main switch.
    b. Turn of cold water tap.
    c. Empty solvent collection vessel.
    d. Unplug the equipment

Refuse Hydrolysis Procedure:

The methodology for cellulose/hemicellulose hydrolysis given below is a modification of a procedure developed by Petterson and Schwandt (USDA's Forest Products Laboratory, Madison, Wisc.).

1. Weigh ~0.3 gram of dry extracted refuse samples into a pressure tube. Record the weight of refuse removed to 4 decimal places.
2. Add 3 ml of 72 % (w/w) sulfuric acid. Using a long glass PTFE stirring rod, carefully mix the refuse and acid. Immerse the tube in a water bath at 30°C and 100 rpm for 1 hour.
3. Use 20 mL of water to wash the stirring rod and then remove the stirring rod from the tube. Add 63 mL deionized water into the pressure tube to dilute the concentration of the acid.
4. Using a calibrated automatic pipettor add 1.0 ml of the 40 g/L fucose solution into the tube.
5. Place the test tube in an autoclavable tray and autoclave for 60 minutes at 121°C and 15 psi for the second stage acid digestion. After the autoclave cycle is complete, take the tube out of the autoclave and allow the tubes to cool to room temperature.
6. Vacuum filter the sample through a pre-fired glass fiber filter (Whatman 934AH) in a Gooch crucible. Collect and set aside about 30 mL filtrate for sugars analysis by HPLC. Filter the remaining digestion mixture and wash the rest of the solids deionized water.
7. Dry the residue in the crucible at 105°C overnight and then cool to room temperature and record the dry weight.

8. Fire the Gooch crucible in a furnace at 550 °C for 2 h. Allow to cool to 105 °C then transfer to a desiccator and allow to cool to room temperature. After cooling, record the weight of the crucible. The weight loss on ignition represents lignin.

Hydrolyzate Clean-Up Procedure:

1. Weigh out 1.98 g of barium hydroxide octahydrate ($Ba(OH)_2*8H_2O$) into a 50 ml plastic centrifuge tube. Using a graduated cylinder for measuring, pour 16 ml of hydrolyzate into the centrifuge tube. Cap the tube tightly and vortex at high speed (setting ~6) until the crystals of barium hydroxide dissolve. The solution will become milky white due to the formation of insoluble barium sulfate, which can make the undissolved crystals harder to see. When you can no longer see barium hydroxide crystals on the bottom of the tube, this step is complete.
2. Centrifuge for 10 minutes at 3,500 rpm. When centrifugation is complete, handle the tube(s) carefully to avoid disturbing the white precipitate of barium sulfate
3. Remove the plunger from a 20 ml plastic disposable syringe. Attach a 0.2 micron syringe filter (Acrodisc PF, Fisher P/N 09-730-242) to the outlet of the cartridge.
4. Carefully, so as to avoid disturbing the precipitate, pour the sample into the syringe barrel). Insert the plunger and force the sample through the filter into a 20ml plastic scintillation vial. Samples should be kept frozen until ready for analysis.
5. Prepare a 1/20 dilution of the purified hydrolyzate by pipetting 1 ml into a 10 ml volumetric and diluting to volume with deionized water. Note: Different dilutions may be necessary based upon the concentrations of your samples and the range of your standard curve. The samples may first be analyzed full strength, and the appropriate dilutions determined empirically.
6. Fill 5 ml "Poly Vial" autosampler vials (Dionex P/N 20933*) with pure hydrolyzate and the diluted hydrolyzete with one vial per solution. * Can be ordered together as Dionex P/N 38141.
7. Cap the vials with "Poly Vial" filter caps (Dionex P/N 20934*) by inserting them until the top of the slotted cap rim is flush with the mouth of the vial (i.e., room is left for expansion). Insert filled vials into an autosampler cassette and store in the freezer until use.
8. Store leftover, undiluted hydrolyzate in the freezer. Dump unused, diluted hydrolyzate into the waste bottle.
9. The hydrolyzate is then analyzed by a Dionex HPLC equipped with a pulsed electrochemical detector using a CarboPAc PA1 column and a solution of sodium hydroxide and sodium acetate.

Determination of Volatile Fatty Acids by Gas Chromatography Flame Ionization Detection:

The preparation of samples for the determination of Volatile Fatty Acids (VFAs) by Gas Chromatography Flame Ionization Detection (GC FID) followed the procedure that can be found in Standard Methods for the Examination of Water and Wastewater (Method 5560D). Briefly, the samples were acidified to a pH of less than 2 using phosphoric acid (85%). The acidified samples were then transferred to a centrifuge tube and centrifuged until the centrate was separated from the supernatant. The supernatant was then transferred to a disposable syringe and filtered through a

0.8/0.2 μm syringe filter. GC analyses were performed on a GC2014 (Shimadzu Instruments, Columbia, MD) gas chromatograph equipped with a flame ionization detector. Separation was accomplished using a DB-FFAP capillary column (30 m, 0.45 mm I.D., 0.85 μm film thickness, Agilent Technologies, Santa Clara, CA). The injector and detector temperatures were 150°C and 250°C, respectively. The carrier gas used was helium. The analyses were performed using the following temperature program: 0.5 min at 50°C, ramp to 156°C at 8°C/min, hold for 0 minutes, ramp to 240°C at 60°C/min, hold for 5 minutes. A 0.5 μL injection volume was used.

Appendix E: Compost testing parameters test method (Table E1), comparisons with other compost in North America (Table E2), and Soil Control Lab compost test results (Table E3).

Table E1- Compost testing parameters and test method.

Parameters	Test Method
pH	TMECC 04.11-A Elastometric pH 1:5 Slurry Method pH Units
Soluble Salts	TMECC 04.10-A Electrical Conductivity 1:5 Slurry Method dS/m (mmhos/cm)
Moisture Content	TMECC 03.09-A Total Solids & Moisture at 70+/- 5 deg C % Wet Weight Basis
Organic Matter Content	TMECC 05.07-A Loss-On-Ignition Organic Matter Method (LOI) % Dry Weight Basis
Maturity	TMECC 05.05-A Germination and Vigor Seed Emergence Seedling Vigor % Relative to Positive Control
Stability	TMECC 05.08-B Carbon Dioxide Evolution Rate mg CO_2-C/g OM per day
Particle Size	TMECC 02.02-B Sample Sieving for Aggregate Size Classification % Dry Weight Basis
Pathogen	TMECC 07.01-B Fecal Coliform Bacteria < 1000 MPN/gram dry wt.
Pathogen	TMECC 07.02-B Salmonella < 3 MPN/4 grams dry wt.

Parameters	Test Method
Physical Contaminants	TMECC 02.02-C Man Made Inert Removal and Classification: Plastic, Glass and Metal % > 4mm fraction
Physical Contaminants	TMECC 02.02-C Man Made Inert Removal and Classification: Sharps (Sewing needles, straight pins and hypodermic needles) % > 4mm fraction
Soluble Available Nutrients & Salts: Total Nitrogen Ammonia (NH4-N) Nitrate (NO3-N) Org. Nitrogen (Org.-N) Phosphorus (P) Potassium (as K2O) Potassium (K) Calcium (Ca) Magnesium (Mg) Sulfate (SO4-S) Boron (Total B) Sodium (Na) Chloride (Cl)	 TMECC 4.02-D TMECC 4.02-C TMECC 4.02-B TMECC 4.02-A TMECC 4.05-P TMECC 4.04-A TMECC 4.04-B TMECC 4.05-Ca TMECC 4.05-Mg TMECC 4.05-B TMECC 4.05-Na TMECC 4.05-Cl mg/kg
Bulk Density	TMECC 3.01-A lb/cu ft
Lime Content: Carbonates (CaCo3)	TMECC 4.05-Ca lb/ton
Organic Carbon	TMECC 4.01-A % Dry Weight Basis
Ash	TMECC 3.02-A % Dry Weight Basis
C/N ratio	ratio
Ag Index	TMECC 5.02-E ratio
Carbonates	TMECC 04.05-Ca lb/ton

Table E2- Comparison of Yolo County Anaerobic Composter Cell Results with other compost in North America.

Parameter	Units	Yolo County Anaerobic Composter Cell Project (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
Total Nitrogen	(%)	1.0 - 1.1	1.6 ± 0.0
Ammonia (NH4-N)	(mg/kg)	230 - 280	902.1 ± 25.5
Nitrate (NO3-N)	(mg/kg)	All < 1.0	311.7 ± 12.8
Org. Nitrogen (Org-N)	(%)	0.97 – 1.1	N/A ± N/A
Phosphorus (P2O5)	(%)	0.39 - 0.42	1.3 ± 0.0
Phosphorus (P)	(mg/kg)	1700 - 1800	5930.8 ± 100.0
Potassium (K2O)	(%)	0.98 - 1.0	1.1 ± 0.0
Potassium (K)	(mg/kg)	8200 - 8400	0.9 ± 0.0
Calcium (Ca)	(%)	1.1 – 1.2	3.6 ± 0.0
Magnesium (Mg)	(%)	0.74 - 0.99	0.6 ± 0.0
Sulfate (SO4-S)	(mg/kg)	38 - 50	3999.3 ± 95.5
Boron (total B)	(mg/kg)	25 - 43	48.7 ± 1.4
Moisture (as received)	(%)	37.4 – 4.7	38.1 ± 0.2
Sodium (Na)	(%)	All 0.16	0.2 ± 0.0
Chloride (Cl)	(%)	0.23 - 0.25	2446.2 ± 46.6
pH value	(unit)	7.03 – 7.11	7.6 ± 0.0
Bulk Density (Dry wt)	(lb/cu ft)	21 - 22	26.0 ± 0.2
Carbonates (CaCO3)	(lb/ton)	3.6 – 4.1	54.1 ± 1.9
Conductivity (EC5)	(mmhos/cm)	2.9 - 3.4	6.4 ± 0.1
Organic matter	(%)	48.8 – 51.9	46.3 ± 0.3
Organic Carbon	(%)	23.0 – 26.0	24.3 ± 0.2
Ash	(%)	48.1 – 51.2	53.7 ± 0.3
C/N Ratio	(ratio)	21 - 25	16.5 ± 0.1
Ag Index	(ratio)	All 6	N/A ± N/A
Aluminum (Al)	(mg/kg)	11000 - 14000	8121.6 ± 115.2
Arsenic (As)	(mg/kg)	5.7 – 5.3	7.3 ± 1.5
Cadmium (Cd)	(mg/kg)	1.1- <1.0	2.4 ± 0.1
Chromium (Cr)	(mg/kg)	41 - 64	29.8 ± 6.8
Cobalt (Co)	(mg/kg)	7.5 – 9.2	4.7 ± 0.1
Copper (Cu)	(mg/kg)	36 - 38	123.8 ± 3.8

Parameter	Units	Yolo County Anaerobic Composter Cell Project (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
Iron (Fe)	(mg/kg)	16000 - 19000	13888.9 ± 227.0
Lead (Pb)	(mg/kg)	16 - 17	35.7 ± 1.2
Manganese (Mn)	(mg/kg)	340 - 370	412.1 ± 9.6
Mercury (Hg)	(mg/kg)	all < 1.0	±
Molybdenum (Mo)	(mg/kg)	1.1 - < 1.0	4.3 ± 0.1
Nickel (Ni)	(mg/kg)	54 - 79	17.2 ± 0.5
Selenium (Se)	(mg/kg)	all < 1.0	2.1 ± 0.1
Zinc (Zn)	(mg/kg)	91 - 95	262.4 ± 4.8
Total Respirometry -- Organic Matter basis	(mg CO2-C/g OM/day)	3.2 – 3.4	3.2 ± 0.1
Total Respirometry -- Total Solids basis	(mg CO2-C/g TS/day)	1.6 – 1.7	NA
Respirometry: (based on Biologically available Carbon) -- Organic Matter basis	(mg CO2-C/g OM/day)	3.4 – 3.5	14.1 ± 0.9
Respirometry: (based on Biologically available Carbon) -- Total Solids basis	(mg CO2-C/g TS/day)	1.7 – 1.8	NA
Stability rating		all Stable	±
Emergence	(%)	all 100	83.3 ± 0.6
Seedling vigor	(%)	109 -110	83.9 ± 0.7
Description of plants		all Healthy	0.0 ± 0.0
Fecal Coliform	(MPN/g)	48 - <7.5	314.6 ± 16.2
Rating		all pass	
Salmonella	(MPN/4g)	all < 3	< 3 ± 0.0
Rating		all Pass	±
Plastic	(% by weight)	< 0.21 - < 0.5	0.2 ± 0.1
Glass	(% by weight)	all < 0.5	0.1 ± 0.0
Metal	(% by weight)	< 0.27 - < 0.5	0.0 ± 0.0

Parameter	Units	Yolo County Anaerobic Composter Cell Project (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
Sharps	(% by weight)	all Non Detected	0.0 ± 0.0
Size Distribution (by weight)			
<2.0 mm	(% by weight)	40.1 – 40.4	59.8 ± 0.3
2.0-4.0 mm	(% by weight)	19.2 -20.2	18.6 ± 0.1
4.0-6.3 mm	(% by weight)	9.5 - 11.7	10.1 ± 0.1
6.3-9.5 mm	(% by weight)	10.1 - 11.6	7.3 ± 0.1
9.5-16 mm	(% by weight)	11.4 - 13.8	3.2 ± 0.1
16 to 25 mm	(% by weight)	4.9 – 5.0	0.7 ± 0.1
25-50 mm	(% by weight)	1.3 - 0.9	0.1 ± 0.0
>50 mm	(% by weight)	All 0	0.0 ± 0.0

a. These represent the range of values for all windrow compost samples. All parameters are reported on a dry weight basis, with the exception of moisture content and pH, and are results from the Soil Control Lab, unless noted otherwise.

b. Compost Data from over 3,661 North American Compost samples supplied by the Soil Testing Lab. They represent a mix of different compost facilities and mixtures and are used as is (no editing or deletions).

Table E3- Soil Control Lab compost test results

ANALYTICAL CHEMISTS
and
BACTERIOLOGISTS
Approved by State of California

SOIL CONTROL LAB

42 HANGAR WAY
WATSONVILLE
CALIFORNIA
95076
USA

TEL: 831-724-5422
FAX: 831-724-3188
www.compostlab.com

Account #: 5100583-1/2-5971
Group: Oct.15 C #23
Reporting Date: October 28, 2015

Yolo County Central Landfill
44090 County Road 28H
Woodland, CA 95776-9101
Attn: Ramin Yazdani

Date Received: 16 Oct. 15
Sample Identification: Compost Windrow North #1- #3
Sample ID #: 5100583 - 1/2

Nutrients	Dry wt.	As Rcvd.	units
Total Nitrogen:	1.0	0.62	%
Ammonia (NH_4-N):	280	170	mg/kg
Nitrate (NO_3-N):	< 1.0	< 0.6	mg/kg
Org. Nitrogen (Org.-N):	0.97	0.58	%
Phosphorus (as P_2O_5):	0.42	0.25	%
Phosphorus (P):	1800	1100	mg/kg
Potassium (as K_2O):	1.0	0.60	%
Potassium (K):	8400	5000	mg/kg
Calcium (Ca):	1.2	0.70	%
Magnesium (Mg):	0.74	0.44	%
Sulfate (SO_4-S):	50	30	mg/kg
Boron (Total B):	31	19	mg/kg
Moisture:	0	40.7	%
Sodium (Na):	0.16	0.097	%
Chloride (Cl):	0.23	0.13	%
pH Value:	NA	7.03	unit
Bulk Density :	21	35	lb/cu ft
Carbonates ($CaCO_3$):	4.1	2.5	lb/ton
Conductivity (EC5):	3.4	NA	mmhos/cm
Organic Matter:	51.9	30.8	%
Organic Carbon:	26.0	15.0	%
Ash:	48.1	28.6	%
C/N Ratio	25	25	ratio
AgIndex	6	6	ratio

Stability Indicator:		Biologically
CO2 Evolution	Respirometery	Available C
mg CO_2-C/g OM/day	3.4	3.4
mg CO_2-C/g TS/day	1.7	1.8
Stability Rating	*stable*	*stable*

Maturity Indicator: Cucumber Bioassay	
Compost:Vermiculite(v:v)	1:2
Emergence (%)	100
Seedling Vigor (%)	109
Description of Plants	*healthy*

Pathogens	Results	Units	Rating
Fecal Coliform	< 7.5	MPN/g	*pass*
Salmonella	< 3	MPN/4g	*pass*

Date Tested: 16 Oct. 15

Inerts	% by weight
Plastic	< 0.5
Glass	< 0.5
Metal	0.27
Sharps	ND

Metals	Dry wt.	EPA Limit	units
Aluminum (Al):	11000	-	mg/kg
Arsenic (As):	5.7	41	mg/kg
Cadmium (Cd):	< 1.0	39	mg/kg
Chromium (Cr):	41	1200	mg/kg
Cobalt (Co)	7.5	-	mg/kg
Copper (Cu):	38	1500	mg/kg
Iron (Fe):	16000	-	mg/kg
Lead (Pb):	17	300	mg/kg
Manganese (Mn):	340	-	mg/kg
Mercury (Hg):	< 1.0	17	mg/kg
Molybdenum (Mo):	1.1	75	mg/kg
Nickel (Ni):	54	420	mg/kg
Selenium (Se):	< 1.0	36	mg/kg
Zinc (Zn):	95	2800	mg/kg

Size Distribution	
MM	% by weight
> 50	0.0
25 to 50	0.9
16 to 25	4.9
9.5 to 16	13.8
6.3 to 9.5	11.6
4.0 to 6.3	9.5
2.0 to 4.0	19.2
< 2.0	40.1

Analyst: Assaf Sadeh

*Sample was received and handled in accordance with TMECC procedures.

Account No.: 5100583 - 1/2 - 5971
Group: Oct.15 C No. 23

Date Received 16 Oct. 15
Sample i.d. Compost Windrow North #1- #3
Sample I.d. No. 1/2 5100583

INTERPRETATION:

Is Your Compost Stable?

Respiration Rate
3.4 mg CO2-C/ g OM/day

Biodegradation Rate of Your Pile

++++++++++++++
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Biologically Available Carbon (BAC)
3.4 mg CO2-C/ g OM/day

Optimum Degradation Rate

++++++++++++++
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Is Your Compost Mature?

AmmoniaN/NitrateN ratio
2500 Ratio

++
VeryMature>|< Mature >|< Immature

Ammonia N ppm
280 mg/kg dry wt.

++++++++++++++++++++++++++++++++
VeryMature>|< Mature >|< Immature

Nitrate N ppm
< 1.0 mg/kg dry wt.

+
< Immature >|< Mature

pH value
7.03 units

++
< Immature >|< Mature >|< Immature

Cucumber Emergence
100.0 percent

++
< Immature >|< Mature

Is Your Compost Safe Regarding Health?

Fecal Coliform
< 1000 MPN/g dry wt.

+++++++
< Safe >|< High Fecal Coliform

Salmonella
Less than 3 /4g dry wt.

+++++++
<Safe (none detected) >|< High Salmonella Count(> 3 per 4 grams)

Metals US EPA 503
Pass dry wt.

+++++++++
<All Metals Pass >|< One or more Metals Fail

Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)
2.4 Percent dry wt.

++++++++++++++++++
<Low >|< Average >|< High Nutrient Content

AgIndex (Nutrients / Sodium and Chloride Salts) ((N+P2O5+K2O) / (Na + Cl))
6 Ratio

++++++++++++++++++++++++++++++++
Na & Cl >|< Nutrient and Sodium and Chloride Provider >|< Nutrient Provider

Plant Available Nitrogen (PAN) Estimated release for first season
3 lbs/ton wet wt.

++++++++++
Low Nitrogen Provider>|< Average Nitrogen Provider >|<High Nitrogen Provider

C/N Ratio
25 Ratio

++
< Nitrogen Release >|< N-Neutral >|< N-Demand>|< High Nitrogen Demand

Soluble Available Nutrients & Salts (EC5 w/w dw)
3.4 mmhos/cm dry wt.

++++++++++++++++++
SloRelease>|< Average Nutrient Release Rate >|<High Available Nutrients

Lime Content (CaCO3)
4.1 Lbs/ton dry wt.

++++++
< Low >|< Average >|< High Lime Content (as CaCO3)

What are the physical properties of your compost?

Percent Ash
48.1 Percent dry wt.

++
< High Organic Matter >|< Average >|< High Ash Content

Sieve Size % > 6.3 MM (0.25")
31.2 Percent dry wt.

++
All Uses >|< Size May Restrict Uses for Potting mix and Golf Courses

Account No.:		Date Received	16 Oct. 15
5100583 - 1/2 - 5971		Sample i.d.	Compost Windrow North #1- #3
Group:	Oct.15 C No. 23	Sample I.d. No.	1/2 5100583

INTERPRETATION:

Is Your Compost Stable?

Respiration Rate

3.4 Low: Good for all uses mg CO2-C/g OM/day

The respiration rate is a measurement of the biodegradation rate of the organic matter in the sample (as received). The respiration rate is determined by measuring the rate at which CO2 is released under optimized moisture and temperature conditions.

Biologically Available Carbon

3.4 Low: Good for all uses mg CO2-C/g OM/day

Biologically Available Carbon (BAC) is a measurement of the rate at which CO2 is released under optimized moisture, temperature, porosity, nutrients, pH and microbial conditions. If both the RR and the BAC test values are close to the same value, the pile is optimized for composting. If both values are high the compost pile just needs more time. If both values are low the compost has stabilized and should be moved to curing. BAC test values that are higher than RR indicate that the compost pile has stalled. This could be due to anaerobic conditions, lack of available nitrogen due to excessive air converting ammonia to the unavailable nitrate form, lack of nitrogen or other nutrients due to poor choice of feedstock, pH value out of range, or microbes rendered non-active.

Is Your Compost Mature?

AmmoniaN:NitrateN ratio

2500 immature

Ammonia N ppm

280 mature

Nitrate N ppm

< 1.0 immature

pH value

7.03 mature

Composting to stabilize carbon can occur at such a rapid rate that sometimes phytotoxins remain in the compost and must be neutralized before using in high concentrations or in high-end uses. This step is called curing. Typically ammonia is in excess with the break-down of organic materials resulting in an increase in pH. This combination results in a loss of volatile ammonia (it smells). Once this toxic ammonia has been reduced and the pH drops, the microbes convert the ammonia to nitrates. A low ammonia + high nitrate score is indicative of a mature compost, however there are many exceptions. For example, a compost with a low pH (<7) will retain ammonia, while a compost with high lime content can lose ammonia before the organic fraction becomes stable. Composts must first be stable before curing indicators apply.

Cucumber Bioassay

100.0 Percent Cucumbers are chosen for this test because they are salt tolerant and very sensitive to ammonia and organic acid toxicity. Therefore, we can germinate seeds in high concentrations of compost to measure phytotoxic effects without soluble salts being the limiting factor. Values above 80% for both percent emergence and vigor are indicative of a well-cured compost. Exceptions include very high salts that affect the cucumbers, excessive concentrations of nitrates and other nutrients that will be in range when formulated to make a growing media. In addition to testing a 1:1 compost: vermiculite blend, we also test a diluted 1:3 blend to indicate a more sensitive toxicity level.

Is Your Compost Safe Regarding Health?

Fecal Coliform

< 1000 / g dry wt. Fecal coliforms can survive in both aerobic and anaerobic conditions and is common in all initial compost piles. Most human pathogens occur from fecal matter and all fecal matter is loaded in fecal coliforms. Therefore fecal coliforms are used as an indicator to determine if the chosen method for pathogen reduction (heat for compost) has met the requirements of sufficient temperature, time and mixing. If the fecal coliforms are reduced to below 1000 per gram dry wt. it is assumed all others pathogens are eliminated. Potential problems are that fecal coliform can regrow during the curing phase or during shipping. This is because the conditions are now more favorable for growth than during the composting process.

Salmonella Bacteria

Less than 3 3 / 4g dry wt. Salmonella is not only another indicator organism but also a toxic microbe. It has been used in the case of biosolids industry to determine adequate pathogen reduction.

Metals

Pass The ten heavy metals listed in the EPA 503 regulations are chosen to determine if compost can be applied to ag land and handled without toxic effects. Most high concentrations of heavy metals are derived from woodwaste feedstock such as chrome-arsenic treated or lead painted demolition wood. Biosolids are rarely a problem.

Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)

2.4 Average nutrient content

This value is the sum of the primary nutrients Nitrogen, Phosphorus and Potassium. Reported units are consistent with those found on fertilizer formulations. A sum greater than 5 is indicative of a compost with high nutrient content, and best used to supply nutrients to a receiving soil. A sum below 2 indicates low nutrient content, and is best-used to improve soil structure via the addition of organic matter. Most compost falls between 2 and 5.

Account No.:		Date Received	16 Oct. 15
5100583 - 1/2 - 5971		Sample i.d.	Compost Windrow North #1- #3
Group:	Oct.15 C No. 23	Sample I.d. No.	1/2 5100583

INTERPRETATION: Page three of three

AgIndex (Nutrients/Na+Cl)

6 Average nutrient ratio Composts with low AgIndex values have high concentrations of sodium and/or chloride compared to nutrients. Repeated use of a compost with a low AgIndex (< 2) may result in sodium and/or chloride acting as the limiting factor compared to nutrients, governing application rates. These composts may be used on well-draining soils and/or with salt-tolerant plants. Additional nutrients form another source may be needed if the application rate is limited by sodium or chloride. If the AgIndex is above 10, nutrients optimal for plant growth will be available without concern of sodium and/or chloride toxicity. Composts with an AgIndex of above 10 are good for increasing nutrient levels for all soils. Most composts score between 2 and 10. Concentrations of nutrients, sodium, and chloride in the receiving soil should be considered when determining compost application rates. The AgIndex is a product of feedstock quality. Feedstock from dairy manure, marine waste, industrial wastes, and halophytic plants are likely to produce a finished compost with a low AgIndex.

Plant Available Nitrogen (lbs/ton)

3 Low N Provider Plant Available Nitrogen (PAN) is calculated by estimating the release rate of Nitrogen from the organic fraction of the compost. This estimate is based on information gathered from the BAC test and measured ammonia and nitrate values. Despite the PAN value of the compost, additional sources of Nitrogen may be needed during he growing season to off-set the Nitrogen demand of the microbes present in the compost. With ample nutrients these microbes can further breakdown organic matter in the compost and release bound Nitrogen. Nitrogen demand based on a high C/N ratio is not considered in the PAN calculation because additional Nitrogen should always be supplemented to the receiving soil when composts with a high C/N ratio are applied.

C/N Ratio

25 Indicates immaturity As a guiding principal, a C/N ratio below 14 indicates maturity and above 14 indicates immaturity, however, there are many exceptions. Large woodchips (>6.3mm), bark, and redwood are slow to breakdown and therefore can result in a relatively stable product while the C/N ratio value is high. Additionally, some composts with chicken manure and/or green grass feedstocks can start with a C/N ratio below 15 and are very unstable. A C/N ratio below 10 supplies Nitrogen, while a ratio above 20 can deplete Nitrogen from the soil. The rate at which Nitrogen will be released or used by the microbes is indicated by the respiration rate (BAC). If the respiration rate is too high the transfer of Nitrogen will not be controlable.

Soluble Nutrients & Salts (EC5 w/w dw - mmhos/cm)

3.4 Average salts This value refers to all soluble ions including nutrients, sodium, chloride and some soluble organic compounds. The concentration of salts will change due to the release of salts from the organic matter as it degrades, volatilization of ammonia, decomposition of soluble organics, and conversion of molecular structure. High salts + high AgIndex is indicative of a compost high in readily available nutrients. The application rate of these composts should be limited by the optimum nutrient value based on soil analysis of the receiving soil. High Salts + low AgIndex is indicative of a compost low in nutrients with high concentrations of sodium and/or chloride. Limit the application rate according to the toxicity level of thesodium and/or chloride. Low salts indicates that the compost can be applied without risking salt toxicity, is likely a good source of organic matter, and that nutrients will release slowly over time.

Lime Content (lbs. per ton)

4.1 Low lime content Compost high in lime or carbonates are often those produced from chicken manure (layers) ash materials, and lime products. These are excellent products to use on a receiving soil where lime has been recommended by soil analysis to raise the pH. Composts with a high lime content should be closely considered for pH requirements when formulating potting mixes.

Physical Properties

Percent Ash

48.1 Average ash content Ash is the non-organic fraction of a compost. Most composts contain approximately 50% ash (dry weight basis). Compost can be high in ash content for many reasons including: excess minerilzation(old compost), contamination with soil base material during turning, poor quality feedstock, and soil or mineral products added. Finding the source and reducing high ash content is often the fastest means to increasing nutrient quality of a compost.

Particle Size % > 6.3 MM (0.25")

31.2 May restrict use Large particles may restrict use for potting soils, golf course topdressings, seed-starter mixes, and where a fine size distribution is required. Composts with large particles can still be used as excellent additions to field soils, shrub mixes and mulches.

Particle Size Distribution

Each size fraction is measured by weight, volume and bulk density. These results are particularly relevent with decisions to screen or not, and if screening, which size screen to use. The bulk density indicates if the fraction screened is made of light weight organic material or heavy mineral material. Removing large mineral material can greatly improve compost quality by increasing nutrient and organic concentrations.

Appendix:		
	Estimated available nutrients for use when calculating application rates	
Plant Available Nitrogen (PAN) calculations:		lbs/ton (As Rcvd.)
PAN = (X * (organic N)) + ((NH4-N) + (NO3-N))		
X value = If BAC < 2 then X = 0.1	Plant Available Nitrogen (PAN)	2.8
If BAC =2.1 to 5 then X = 0.2	Ammonia (NH4-N)	0.34
If BAC =5.1 to 10 then X = 0.3	Nitrate (NO3-N)	0.00
If BAC > 10 then X = 0.4	Available Phosphorus (P2O5*0.64)	3.2
Note: If C/N ratio > 15 additional N should be applied.	Available Potassium (K2O)	12.0

ANALYTICAL CHEMISTS
and
BACTERIOLOGISTS
Approved by State of California

SOIL CONTROL LAB

42 HANGAR WAY
WATSONVILLE
CALIFORNIA
95076
USA

TEL: 831-724-5422
FAX: 831-724-3188
www.compostlab.com

Account #: 5100583-2/2-5971
Group: Oct.15 C #24
Reporting Date: October 28, 2015

Yolo County Central Landfill
44090 County Road 28H
Woodland, CA 95776-9101
Attn: Ramin Yazdani

Date Received: 16 Oct. 15
Sample Identification: Compost Windrow South #1- #3
Sample ID #: 5100583 - 2/2

Nutrients	Dry wt.	As Rcvd.	units
Total Nitrogen:	1.1	0.69	%
Ammonia (NH_4-N):	230	150	mg/kg
Nitrate (NO_3-N):	< 1.0	< 0.6	mg/kg
Org. Nitrogen (Org.-N):	1.1	0.69	%
Phosphorus (as P_2O_5):	0.39	0.24	%
Phosphorus (P):	1700	1100	mg/kg
Potassium (as K_2O):	0.98	0.61	%
Potassium (K):	8200	5100	mg/kg
Calcium (Ca):	1.1	0.68	%
Magnesium (Mg):	0.99	0.62	%
Sulfate (SO_4-S):	38	24	mg/kg
Boron (Total B):	28	17	mg/kg
Moisture:	0	37.4	%
Sodium (Na):	0.16	0.099	%
Chloride (Cl):	0.25	0.16	%
pH Value:	NA	7.11	unit
Bulk Density :	22	34	lb/cu ft
Carbonates ($CaCO_3$):	3.6	2.3	lb/ton
Conductivity (EC5):	2.9	NA	mmhos/cm
Organic Matter:	48.8	30.5	%
Organic Carbon:	23.0	14.0	%
Ash:	51.2	32.1	%
C/N Ratio	21	21	ratio
AgIndex	6	6	ratio

Stability Indicator:		Biologically
CO2 Evolution	Respirometery	Available C
mg CO_2-C/g OM/day	3.2	3.5
mg CO_2-C/g TS/day	1.6	1.7
Stability Rating	*stable*	*stable*

Maturity Indicator: Cucumber Bioassay

Compost:Vermiculite(v:v)	1:2
Emergence (%)	100
Seedling Vigor (%)	110
Description of Plants	*healthy*

Pathogens	Results	Units	Rating
Fecal Coliform	48	MPN/g	*pass*
Salmonella	< 3	MPN/4g	*pass*

Date Tested: 16 Oct. 15

Inerts	% by weight
Plastic	0.21
Glass	< 0.5
Metal	< 0.5
Sharps	ND

Metals	Dry wt.	EPA Limit	units
Aluminum (Al):	14000	-	mg/kg
Arsenic (As):	5.3	41	mg/kg
Cadmium (Cd):	1.1	39	mg/kg
Chromium (Cr):	64	1200	mg/kg
Cobalt (Co)	9.2	-	mg/kg
Copper (Cu):	36	1500	mg/kg
Iron (Fe):	19000	-	mg/kg
Lead (Pb):	16	300	mg/kg
Manganese (Mn):	370	-	mg/kg
Mercury (Hg):	< 1.0	17	mg/kg
Molybdenum (Mo):	< 1.0	75	mg/kg
Nickel (Ni):	79	420	mg/kg
Selenium (Se):	< 1.0	36	mg/kg
Zinc (Zn):	91	2800	mg/kg

Size Distribution

MM	% by weight
> 50	0.0
25 to 50	1.3
16 to 25	5.0
9.5 to 16	11.4
6.3 to 9.5	10.1
4.0 to 6.3	11.7
2.0 to 4.0	20.2
< 2.0	40.4

Analyst: Assaf Sadeh

*Sample was received and handled in accordance with TMECC procedures.

Account No.: 5100583 - 2/2 - 5971
Group: Oct.15 C No. 24

Date Received 16 Oct. 15
Sample i.d. Compost Windrow South #1- #3
Sample I.d. No. 2/2 5100583

INTERPRETATION:

Is Your Compost Stable?

Respiration Rate
3.2 mg CO2-C/ g OM/day

Biodegradation Rate of Your Pile

++++++++++++
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Biologically Available Carbon (BAC) Optimum Degradation Rate
3.5 mg CO2-C/ g OM/day

++++++++++++++
< Stable >|<Moderately Unstable>|< Unstable >|< High For Mulch

Is Your Compost Mature?

AmmoniaN/NitrateN ratio
2100 Ratio

++
VeryMature>|< Mature >|< Immature

Ammonia N ppm
230 mg/kg dry wt.

++++++++++++++++++++++++++
VeryMature>|< Mature >|< Immature

Nitrate N ppm
< 1.0 mg/kg dry wt.

+
< Immature >|< Mature

pH value
7.11 units

++
< Immature >|< Mature >|< Immature

Cucumber Emergence
100.0 percent

++
< Immature >|< Mature

Is Your Compost Safe Regarding Health?

Fecal Coliform
< 1000 MPN/g dry wt.

+++++++
< Safe >|< High Fecal Coliform

Salmonella
Less than 3 /4g dry wt.

+++++++
<Safe (none detected) >|< High Salmonella Count(> 3 per 4 grams)

Metals US EPA 503
Pass dry wt.

+++++++++
<All Metals Pass >|< One or more Metals Fail

Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)
2.5 Percent dry wt.

++++++++++++++++++
<Low >|< Average >|< High Nutrient Content

AgIndex (Nutrients / Sodium and Chloride Salts) ((N+P2O5+K2O) / (Na + Cl))
6 Ratio

++++++++++++++++++++++++++++++++
Na & Cl >|< Nutrient and Sodium and Chloride Provider >|< Nutrient Provider

Plant Available Nitrogen (PAN) Estimated release for first season
3 lbs/ton wet wt.

++++++++++++
Low Nitrogen Provider>|< Average Nitrogen Provider >|<High Nitrogen Provider

C/N Ratio
21 Ratio

++
< Nitrogen Release >|< N-Neutral >|< N-Demand>|< High Nitrogen Demand

Soluble Available Nutrients & Salts (EC5 w/w dw)
2.9 mmhos/cm dry wt.

+++++++++++++++
SloRelease>|< Average Nutrient Release Rate >|<High Available Nutrients

Lime Content (CaCO3)
3.6 Lbs/ton dry wt.

+++++
< Low >|< Average >|< High Lime Content (as CaCO3)

What are the physical properties of your compost?

Percent Ash
51.2 Percent dry wt.

++
< High Organic Matter >|< Average >|< High Ash Content

Sieve Size % > 6.3 MM (0.25")
27.8 Percent dry wt.

++
All Uses >|< Size May Restrict Uses for Potting mix and Golf Courses

Account No.:		Date Received	16 Oct. 15
5100583 - 2/2 - 5971		Sample i.d.	Compost Windrow South #1- #3
Group:	Oct.15 C No. 24	Sample I.d. No.	2/2 5100583

INTERPRETATION:

Is Your Compost Stable?

Respiration Rate

3.2 Low: Good for all uses mg CO2-C/g OM/day

The respiration rate is a measurement of the biodegradation rate of the organic matter in the sample (as received). The respiration rate is determined by measuring the rate at which CO2 is released under optimized moisture and temperature conditions.

Biologically Available Carbon

3.5 Low: Good for all uses mg CO2-C/g OM/day

Biologically Available Carbon (BAC) is a measurement of the rate at which CO2 is released under optimized moisture, temperature, porosity, nutrients, pH and microbial conditions. If both the RR and the BAC test values are close to the same value, the pile is optimized for composting. If both values are high the compost pile just needs more time. If both values are low the compost has stabilized and should be moved to curing. BAC test values that are higher than RR indicate that the compost pile has stalled. This could be due to anaerobic conditions, lack of available nitrogen due to excessive air converting ammonia to the unavailable nitrate form, lack of nitrogen or other nutrients due to poor choice of feedstock, pH value out of range, or microbes rendered non-active.

Is Your Compost Mature?

AmmoniaN:NitrateN ratio

2100 immature

Ammonia N ppm

230 mature

Nitrate N ppm

< 1.0 immature

pH value

7.11 mature

Composting to stabilize carbon can occur at such a rapid rate that sometimes phytotoxins remain in the compost and must be neutralized before using in high concentrations or in high-end uses. This step is called curing. Typically ammonia is in excess with the break-down of organic materials resulting in an increase in pH. This combination results in a loss of volatile ammonia (it smells). Once this toxic ammonia has been reduced and the pH drops, the microbes convert the ammonia to nitrates. A low ammonia + high nitrate score is indicative of a mature compost, however there are many exceptions. For example, a compost with a low pH (<7) will retain ammonia, while a compost with high lime content can lose ammonia before the organic fraction becomes stable. Composts must first be stable before curing indicators apply.

Cucumber Bioassay

100.0 Percent

Cucumbers are chosen for this test because they are salt tolerant and very sensitive to ammonia and organic acid toxicity. Therefore, we can germinate seeds in high concentrations of compost to measure phytotoxic effects without soluble salts being the limiting factor. Values above 80% for both percent emergence and vigor are indicative of a well-cured compost. Exceptions include very high salts that affect the cucumbers, excessive concentrations of nitrates and other nutrients that will be in range when formulated to make a growing media. In addition to testing a 1:1 compost: vermiculite blend, we also test a diluted 1:3 blend to indicate a more sensitive toxicity level.

Is Your Compost Safe Regarding Health?

Fecal Coliform

< 1000 / g dry wt.

Fecal coliforms can survive in both aerobic and anaerobic conditions and is common in all initial compost piles. Most human pathogens occur from fecal matter and all fecal matter is loaded in fecal coliforms. Therefore fecal coliforms are used as an indicator to determine if the chosen method for pathogen reduction (heat for compost) has met the requirements of sufficient temperature, time and mixing. If the fecal coliforms are reduced to below 1000 per gram dry wt. it is assumed all others pathogens are eliminated. Potential problems are that fecal coliform can regrow during the curing phase or during shipping. This is because the conditions are now more favorable for growth than during the composting process.

Salmonella Bacteria

Less than 3 3 / 4g dry wt.

Salmonella is not only another indicator organism but also a toxic microbe. It has been used in the case of biosolids industry to determine adequate pathogen reduction.

Metals

Pass

The ten heavy metals listed in the EPA 503 regulations are chosen to determine if compost can be applied to ag land and handled without toxic effects. Most high concentrations of heavy metals are derived from woodwaste feedstock such as chrome-arsenic treated or lead painted demolition wood. Biosolids are rarely a problem.

Does Your Compost Provide Nutrients or Organic Matter?

Nutrients (N+P2O5+K2O)

2.5 Average nutrient content

This value is the sum of the primary nutrients Nitrogen, Phosphorus and Potassium. Reported units are consistent with those found on fertilizer formulations. A sum greater than 5 is indicative of a compost with high nutrient content, and best used to supply nutrients to a receiving soil. A sum below 2 indicates low nutrient content, and is best-used to improve soil structure via the addition of organic matter. Most compost falls between 2 and 5.

Account No.:		Date Received	16 Oct. 15
5100583 - 2/2 - 5971		Sample i.d.	Compost Windrow South #1- #3
Group:	Oct.15 C No. 24	Sample I.d. No.	2/2 5100583

INTERPRETATION: Page three of three

AgIndex (Nutrients/Na+Cl)

6 Average nutrient ratio Composts with low AgIndex values have high concentrations of sodium and/or chloride compared to nutrients. Repeated use of a compost with a low AgIndex (< 2) may result in sodium and/or chloride acting as the limiting factor compared to nutrients, governing application rates. These composts may be used on well-draining soils and/or with salt-tolerant plants. Additional nutrients form another source may be needed if the application rate is limited by sodium or chloride. If the AgIndex is above 10, nutrients optimal for plant growth will be available without concern of sodium and/or chloride toxicity. Composts with an AgIndex of above 10 are good for increasing nutrient levels for all soils. Most composts score between 2 and 10. Concentrations of nutrients, sodium, and chloride in the receiving soil should be considered when determining compost application rates. The AgIndex is a product of feedstock quality. Feedstock from dairy manure, marine waste, industrial wastes, and halophytic plants are likely to produce a finished compost with a low AgIndex.

Plant Available Nitrogen (lbs/ton)

3 Low N Provider Plant Available Nitrogen (PAN) is calculated by estimating the release rate of Nitrogen from the organic fraction of the compost. This estimate is based on information gathered from the BAC test and measured ammonia and nitrate values. Despite the PAN value of the compost, additional sources of Nitrogen may be needed during he growing season to off-set the Nitrogen demand of the microbes present in the compost. With ample nutrients these microbes can further breakdown organic matter in the compost and release bound Nitrogen. Nitrogen demand based on a high C/N ratio is not considered in the PAN calculation because additional Nitrogen should always be supplemented to the receiving soil when composts with a high C/N ratio are applied.

C/N Ratio

21 Indicates immaturity As a guiding principal, a C/N ratio below 14 indicates maturity and above 14 indicates immaturity, however, there are many exceptions. Large woodchips (>6.3mm), bark, and redwood are slow to breakdown and therefore can result in a relatively stable product while the C/N ratio value is high. Additionally, some composts with chicken manure and/or green grass feedstocks can start with a C/N ratio below 15 and are very unstable. A C/N ratio below 10 supplies Nitrogen, while a ratio above 20 can deplete Nitrogen from the soil. The rate at which Nitrogen will be released or used by the microbes is indicated by the respiration rate (BAC). If the respiration rate is too high the transfer of Nitrogen will not be controlable.

Soluble Nutrients & Salts (EC5 w/w dw - mmhos/cm)

2.9 Average salts This value refers to all soluble ions including nutrients, sodium, chloride and some soluble organic compounds. The concentration of salts will change due to the release of salts from the organic matter as it degrades, volatilization of ammonia, decomposition of soluble organics, and conversion of molecular structure. High salts + high AgIndex is indicative of a compost high in readily available nutrients. The application rate of these composts should be limited by the optimum nutrient value based on soil analysis of the receiving soil. High Salts + low AgIndex is indicative of a compost low in nutrients with high concentrations of sodium and/or chloride. Limit the application rate according to the toxicity level of thesodium and/or chloride. Low salts indicates that the compost can be applied without risking salt toxicity, is likely a good source of organic matter, and that nutrients will release slowly over time.

Lime Content (lbs. per ton)

3.6 Low lime content Compost high in lime or carbonates are often those produced from chicken manure (layers) ash materials, and lime products. These are excellent products to use on a receiving soil where lime has been recommended by soil analysis to raise the pH. Composts with a high lime content should be closely considered for pH requirements when formulating potting mixes.

Physical Properties

Percent Ash

51.2 Average ash content Ash is the non-organic fraction of a compost. Most composts contain approximately 50% ash (dry weight basis). Compost can be high in ash content for many reasons including: excess minerilzation(old compost), contamination with soil base material during turning, poor quality feedstock, and soil or mineral products added. Finding the source and reducing high ash content is often the fastest means to increasing nutrient quality of a compost.

Particle Size % > 6.3 MM (0.25")

27.8 May restrict use Large particles may restrict use for potting soils, golf course topdressings, seed-starter mixes, and where a fine size distribution is required. Composts with large particles can still be used as excellent additions to field soils, shrub mixes and mulches.

Particle Size Distribution

Each size fraction is measured by weight, volume and bulk density. These results are particularly relevent with decisions to screen or not, and if screening, which size screen to use. The bulk density indicates if the fraction screened is made of light weight organic material or heavy mineral material. Removing large mineral material can greatly improve compost quality by increasing nutrient and organic concentrations.

Appendix:

Plant Available Nitrogen (PAN) calculations:
PAN = (X * (organic N)) + ((NH4-N) + (NO3-N))
X value = If BAC < 2 then X = 0.1
If BAC =2.1 to 5 then X = 0.2
If BAC =5.1 to 10 then X = 0.3
If BAC > 10 then X = 0.4
Note: If C/N ratio > 15 additional N should be applied.

Estimated available nutrients for use when calculating application rates

	lbs/ton (As Rcvd.)
Plant Available Nitrogen (PAN)	3.0
Ammonia (NH4-N)	0.30
Nitrate (NO3-N)	0.00
Available Phosphorus (P2O5*0.64)	3.2
Available Potassium (K2O)	12.3

CHAIN-OF-CUSTODY

5166583

Page _1_ of _1_

Laboratory Information		Original Copy of Report Sent To:		Special Instructions:
Laboratory	Soil Control Lab	Company:	Yolo County Planning & Public Works	
Address:	42 Hangar Way : Watsonville, CA 95076	Contact:	Ramin Yazdani	
	Phone: (831) 724-5422 Fax: (831) 724-3188	Address1:	44090 County Road 28H	
Person from your company to be contacted with questions		Address2		
Name:	Kyuhwan Shim	City, St. Zip	Woodland, CA 95776	
Phone #s:	530-681-7063	Phone:	530-666-8848 Fax:	
Information on facility that the sample was drawn from		**E-mail Reports To: (in box below fill in up to 3 address)**		
Company:	Yolo County Planning & Public Works	kshim@yolocounty.org		
Contact:	Ramin Yazdani	ryazdani@yolocounty.org		
Address1:	44090 County Road 28H	**Invoice Sent To:**		
Address2		Company:	Yolo County Planning & Public Works	
City, St. Zip	Woodland, CA 95776	Contact:		
E-mail Addr:	ryazdani@yolocounty.org	Address1:	44090 County Road 28H	
Phone:	530-666-8848	City, St. Zip:	Woodland, CA 95776	
Sampler'sPrinted Name:	**Kyuhwan Shim**	**PO#:**		

Sample Identification	Date & Time Sampled	Complete Compost Pkg STA	Complete Compost Pkg No STA	Other Analyses Requested	Lab Use Only: Sample Condition
1. Compost Windrow North #1 - #3 C1	10/15/2015 10:00	V			
2. Compost Windrow South #1 - #3 C2	10/15/2014 10:30	V			

Lab Use Only: Storage Location, Freezer #, Refrigerator #, Shelf #, Shipper

*Optional: Help us in our research. Please list your feedstock and approximate % used, process, and age of material. Thank you.

	Manure type & %	Biosolids %	MSW %	yard waste %	Foodwaste	Industrial type & %	Other type & %	Comp. Process	Age of material
Sample 1									
Sample 2									
Sample 3									
Sample 4									
Sample 5									

Released By (Signature and Printed Name):	Date/Time:	Received By (Signature and Printed Name):	Date/Time:
Kyuhwan Shim	10/15/15 1:30 PM	Unreadable	10/16/15 10:20

Appendix F: Leachate Sampling Parameters and Test Methods (Table F1), and Leachate Test Results During Anaerobic and Aerobic Phase (Table F2)

Table F1. Leachate sampling parameters and test methods

Parameter	Test Method
pH	U.S. EPA 150.1
Biochemical Oxygen Demand	U.S. EPA 405.1
Chemical Oxygen Demand	U.S. EPA 410.4
Ammonia as Nitrogen	U.S. EPA 350.3
Total Kjeldahl Nitrogen	U.S. EPA 351.3
Chloride, Nitrate, Sulfate	U.S. EPA 300
Sulfide	U.S. EPA 376.2
Total Organic Compound (TOC)	U.S. EPA 415.1
Alkalinity	SM 2320B
Phosphorus, Total	U.S. EPA 365.3
Total Dissolved Solids (TDS)	U.S. EPA 160.1
Metals (Al, Sb, As, Ba, C6H6, Be, Cd, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, K, Se, Si, Ag, Na, S, Sn, V, Zn	U.S. EPA 6010B/6020
Hg	U.S. EPA 7470A
Volatile Organic Compounds (VOCs)	U.S. EPA 8260B

Table F2. Cell leachate test results during anaerobic and aerobic phase

Dissolved metal or Inorganic parameter	Min. (mg/L)	Max. (mg/L)	Average (mg/L)	St. Dev. (mg/L)
Dissolved Calcium	87	1,100	298	330
Dissolved Magnesium	400	1,000	601	189
Dissolved Sodium	930	1,400	1,151	182
Dissolved Potassium	4,400	7,000	5,563	1,049
Bicarbonate	190	15,000	5,663	6,082
Carbonate	200	390	295	134
Hydroxide	ND	ND	ND	ND
Total Alkalinity as $CaCO_3$	160	12,000	4,745	5,043
Chloride	2,700	4,600	3,613	738
Sulfate	12	440	92	171
Ammonia as NH_3	890	1,600	1,144	260
Nitrate as N	ND	ND	ND	ND
Nitrite as N	ND	ND	ND	ND
Total Kjeldahl Nitrogen	920	1,600	1,186	269
Total Phosphate	51	180	102	40
Total Phosphorus	17	57	32	12
Total Sulfide	14	14	14	0
Dissolved Antimony	0.0036	0.0087	0.0053	0.0023
Dissolved Arsenic	0.04	0.11	0.06	0.02
Dissolved Barium	0.091	0.180	0.117	0.03169
Dissolved Boron	1.8	4.5	4.0	0.9
Dissolved Cadmium	0.00092	0.00240	0.00143	0.00084
Dissolved Chromium	0.028	0.048	0.038	0.008
Dissolved Cobalt	0.050	0.100	0.075	0.021
Dissolved Copper	0.015	0.260	0.088	0.077
Dissolved Iron	11	81	25	23
Dissolved Lead	0.0028	0.0290	0.0096	0.0094
Dissolved Manganese	0.640	23.000	4.193	7.614
Dissolved Molybdenum	0.020	0.022	0.021	0.001
Dissolved Nickel	0.260	0.480	0.368	0.080
Dissolved Selenium	0.026	0.064	0.043	0.012
Dissolved Vanadium	0.020	0.022	0.021	0.001
Dissolved Zinc	0.062	0.230	0.131	0.068

Development Status Questionnaire

California Energy Commission Energy Innovations Small Grant (EISG) Program **PROJECT DEVELOPMENT STATUS**	**Questionnaire**

PI Name: Jean VanderGheynst & Ramin Yazdani
Grant #: 57826A/13-09G

Overall Status

Questions	Comments:
1) Do you consider that this research project proved the feasibility of your concept?	*Yes. Gas production was near the expected range. Lower methane yield was related to the feedstock mixture used, which will be modified in commercial size. Overall the project produced methane close to the expected range and compost produced was good quality compost and the economics of the project for a commercial size cell had an MIRR > 15%.*
2) Do you intend to continue this development effort towards commercialization?	*Yes.*

Engineering/Technical

3) What are the key remaining technical or engineering obstacles that prevent product demonstration?	*None.*
4) Have you defined a development path from where you are to product demonstration?	*Yes. We are working with Yolo County to develop a commercial size demonstration project.*
5) How many years are required to complete product development and demonstration?	*One year.*
6) How much money is required to complete engineering development and demonstration?	*$50,000 to $100,000. The construction of the digester cell is a known technology.*
7) Do you have an engineering requirements specification for your potential product?	*Yes. The construction of such a digester projects is a known technology and can easily be constructed as designed.*

Marketing

8) What market does your concept serve?	*Both the commercial and residential organic waste markets. Large producers of organic waste from the residential and commercial sectors.*
9) What is the market need?	*The market need is for a low-cost option for treatment of green waste and food waste, which we demonstrated here. California has 9.2 million tons of compostable organic waste annually.*
10) Have you surveyed potential customers for interest in your product?	*No, but have been in discussion with cities in Yolo County and other adjacent counties that are looking for options for organics diversion from the landfill and are interested in such a project to construct at a landfill.*
11) Have you performed a market analysis that takes external factors into consideration?	*No, but we recommend a statewide analysis of the market. Currently there are only a few options for treatment of organic waste using German tank digester technology or covered composting. The technology presented here will increase the potential projects in California and reduce the cost.*
12) Have you identified any regulatory, institutional or legal barriers to product acceptance?	*We don't believe there are any major barriers other than cost of implementation. This demonstration project has provided a good basis for a potential commercial size project.*
13) What is the size of the potential market in California for your proposed technology?	*In California, 9.2 million tons of food waste and green waste are disposed in landfills. In addition, agricultural and food processing facilities generate biodegradable waste streams that are also good sources of energy generation. Application of this technology to the source-separated organic fraction of municipal solid waste alone is capable of providing approximately 1.2% of the total electricity demand of the households in State of California.*
14) Have you clearly identified the technology that can be patented?	*Yes. Appendix G discusses the potential IP from this project.*
15) Have you performed a patent search?	*In progress but not completed yet.*
16) Have you applied for patents?	*Not yet.*
17) Have you secured any patents?	*No.*
18) Have you published any paper or publicly disclosed your concept in any way that would limit your ability to seek patent protection?	*No.*

Commercialization Path	
19) Can your organization commercialize your product without partnering with another organization?	*No. .*
20) Has an industrial or commercial company expressed interest in helping you take your technology to the market?	*No.*
21) Have you developed a commercialization plan?	*No.*
22) What are the commercialization risks?	*We don't believe there are any major risks in commercialization of this project. The project developer must secure a waste source, product market and long-term contract before implementation.*
Financial Plan	
23) If you plan to continue development of your concept, do you have a plan for the required funding?	*Yes. Funding would be provided by the developer of the project.*
24) Have you identified funding requirements for each of the development and commercialization phases?	*Yes. The cost of building the Anaerobic Digester Cells.*
25) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?	*Not at this time.*
26) What are the go/no-go milestones in your commercialization plan?	*NA*
27) How would you assess the financial risk of bringing this product/service to the market?	*This risk is based on the economics and success of each project.*
28) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?	*No.*
Public Benefits	
29) What sectors will receive the greatest benefits as a result of your concept?	*Waste management, energy generation, GHG reduction and local air pollution reduction, and agricultural sectors*
30) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.	*Reduction in the cost of treating and disposing organic waste for Californians while generating renewable energy, reducing local air emissions, and greenhouse gas emissions. We show all assumptions used in calculations in the report.*

31) Does the proposed technology reduce emissions from power generation?	*NA*
32) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?	*No. As long as methane produced is collected and flared or combusted in an IC engine the emissions would be same as natural gas to electricity facility.*
Competitive Analysis	
33) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?	*Less costly to construct and operate for longer retention times for decomposition of organic waste and reduction of overall gas emissions before composting of the residual waste. Permitting such a facility at a landfill site. Most landfills must have a gas collection and either destruction or power generation facility, which can be utilized for gas collection and power generation at a fraction of a cost than developing a new project site.*
34) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?	*The facility will require more land because of longer retention time for treatment of waste but it would allow for higher gas production per ton of waste and result in lower overall emissions for treatment of organic waste.*
Development Assistance	
The EISG Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.	
35) If selected, would you be interested in receiving development assistance?	*Yes. EPIC funding or SB-1122 for project.*