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Contractor's Report

Landfill-Based Anaerobic Digester-Compost Pilot Project at Yolo County Central Landfill

Produced Under Contract by:

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Executive Summary

Introduction

Over the past two decades, significant progress has been made in the diversion of recyclables and the separation of some sort-separated organic waste from landfill. Legislation and financial incentives have been the main motivators for diversion of waste from landfills. In California (2007 data), about 20.6 million metric tons (22.7 million tons) of biologically origin organic waste are still disposed in landfills annually (1). This organic waste is mixed with other types of waste, which degrades over time to produce biogas that, in many cases, is utilized as a renewable source of power at landfills. However, when biodegradation is complete, the residuals remains in the landfill and are not recovered for beneficial reuses, such as compost or soil amendment. This is mainly due to the added cost and difficulty of mining and sorting the impurities from mixed municipal solid waste (MSW). Currently, only low-tech organics recycling systems like windrow composting and biomass combustions are able to compete with low disposal fees of landfills. Anaerobic digesters have been in operation in Europe over the past 20 years, mainly because of the enacted waste management policies which are required and have led to relatively high landfill fees, as compared to California's tipping fees.

In California and the U.S., there is a need for a cost-effective anaerobic digestion technology that would produce renewable energy and marketable compost. Such a system could be constructed at a landfill site in order to take advantage of the existing infrastructure. Locating such a facility at an existing landfill reduces the need to purchase additional land; reduces permitting time and costs; reduces organic waste transport costs; reduces the need for additional infrastructure for gas collection and leachate storage and handling; reduces energy use; increases renewable energy production; and reduces odor and gas emissions from composting operation. A digestion technology should achieve these benefits at cost lower than the well-documented high cost of the European vessel-based systems.

The goal of this project was to construct a pilot-scale project to demonstrate these benefits and determine if such a technology could be an appropriate technology for the treatment of organic waste in California. Over the past 15 years, Yolo County has been conducting similar research for treatment of mixed MSW (2-5). The landfill bioreactor technology has successfully been implemented for full-scale landfill cells at the Yolo County Central Landfill (4). This has inspired many other private and public landfill owners and operators to implement similar projects worldwide. The landfill-based anaerobic digester-compost pilot project (digester cell) presented here is based on the technology that has been developed at the Yolo County Central Landfill, as part of a full-scale demonstration project.

Project Objectives

The main goal of this project was to assess the capabilities of a new type of digester cell to generate electricity, produce quality compost, achieve emissions less than those of current aerobic composting technology, and be cost-effective given California's waste disposal fee structure. The demonstration project will determine the viability of this new technology as part of a solution to California's organic materials recycling capacity.

The main objectives of this demonstration project were:

a) Design and construct a digester cell on an existing lined landfill;

b) Fill the digester cell with green waste and aged manure;

c) Operate the digester cell anaerobically by adding water and recirculating leachate;

d) Measure biogas volume and composition and calculate rate of methane production;

e) Measure volume of water added, leachate recirculated, and quality of leachate;

f) Determine the net energy produced;

g) Measure gas emissions during the aerobic phase;

h) Determine the rate of waste decomposition;

i) Excavate the compost, test samples, and evaluate the final compost; and

j) Evaluate the economics of the project.

Project Results

The results of the project were:

a) During the anaerobic operation phase of the digester cell, the average waste temperature in the upper layer was mostly in the mesophilic range (32-42 °C). The rate of heat loss to the atmosphere could have been reduced if cover soil was placed over the liner to keep heat from escaping. Adding soil to increase the insulation could have increased the gas generation rate since this increase in temperature could increase microbial activity and population.

b) Leachate data during the anaerobic phase collected showed the expected pattern where the majority of the acids were consumed and the concentration of total VFAs were reduced from over 9,000 mg/L to an average of 400 mg/L. During the anaerobic phase, the ammonia levels reached as high as 2,400 ppm but these levels did not appear to have inhibited anaerobic activity during the biogas production phase. Because of the aged manure and high pH groundwater used in this project, there was adequate alkalinity to counter the low pH leachate.

c) During the anaerobic phase of digester cell operation, 52.7 cubic meters of methane per dry metric tons of solids (1,680 ft3/dry ton) was collected. The average methane content of the gas was 45.4 percent ± 0.3percent.

d) The exhaust gases from the digester during the aerobic operation were tested and gas emissions estimates were presented in the report. The best destruction efficiencies were observed for carbon monoxide, some of VOC compounds such as aromatic compounds, and ketones. The total mass of VOCs in the gas stream accounted for about 34 percent of the total non-methane organic compounds (NMOC) present. The overall destruction efficiency of the NMOCs was 67.4 percent ± 21.0 percent.

e) The rate of solid decomposition was tracked by sampling and testing solids from the digester cell over time. The Biochemical Methane Potential (BMP), cellulose, hemicellulose, lignin, and volatile solids content decrease showed an increase in the degree of waste decomposition

over time. During the course of anaerobic and aerobic phases, BMP for all layers combined decreased 83 percent from 73.85 mL/g at filling phase to 12.27 mL/g at cell excavation. Cellulose, hemicellulose, lignin, and volatile solids also showed similar decrease trend over time. This indicates that material degraded as expected and performance of the anaerobic and aerobic phase was satisfactory.

f) After excavation of decomposed material, the quality of the digester cell compost was evaluated using the US Compost Council's Seal of Testing Approval Standards (STA). Digester compost achieved satisfactory results for stability, with low readings for both respiration rate and biological available carbon tests and a C/N ratio in the range of 13-15. Furthermore, digester compost achieved mixed results for maturity. Plant bioassay results showed 100 percent seedling emergence, 100 percent seedling vigor, and healthy plant descriptions for all samples tested and for both treatments, strongly indicating that phytotoxic effects were absent and that the compost was mature. However compost from lower layers of the digester showed signs of immaturity with higher ammonia levels, lower nitrate levels, and a higher pH than the better-aerated upper layers of the digester. Additionally, the bottom layer showed higher salt content than the upper layers. These distinctions may be explained by leachate accumulation, as well as suboptimal aeration at the bottom of the cell when compared with the more porous, less compacted upper layers of the cell. Bottom layers may need to be mixed with other material to increase the porosity and improve aeration and leachate movement.

g) After compost was cured in windrows, it was tested again and met STA standards for both salmonella and fecal coliform levels, indicating that the additional curing stage was sufficient for adequate pathogen destruction. Compost also passed EPA 503 regulations for all heavy metals listed and can be legally marketed based on national safety standards for metals content.

h) Compost meets the USCC standards for organic matter content with 39.9 to 45.6 percent OM. Digester compost had very high lime content, which may be due to horse manure present as well as the limestone additions during cell construction. For this reason, the compost would be a favorable addition in a soil program aimed at raising the pH of the soil.

i) The total digester cell volume reduction was calculated to be 31.2 percent compared to the original volume at after waste filling. The compaction of the material increased to 901 kg per cubic meter (1,519 pounds per cubic yard) after 675 days, at the end of the project from the initial compaction of 620 kg per cubic meter (1,045 pounds per cubic yard). This indicates that increase in compaction could reduce the ability to better aerate waste in the cell, especially waste at the lower elevation of the digester cell. Field observations during the excavation of the cell confirmed this behavior. It may be necessary to mix the material in the bottom layers with bulking agent to reduce the impact of compaction and increase porosity for better liquid and gas movement.

j) The carbon balance data show that approximately 37 percent of the waste carbon was biodegraded. Of the carbon degraded, about 26 percent was by conversion to methane. Since methane generation was still continuing at encouraging rates as the anaerobic phase ended, more conversion of carbon to methane could undoubtedly have occurred had the anaerobic phase continued. However time constraints and the project schedule required that the anaerobic phase be ended even though higher conversions could have been obtained.

k) The energy balance for the project showed that 48 percent of the total energy produced from the biogas was used for aeration and less than 6 percent of the energy produced was used for all other operations. Extending the anaerobic phase of operation from one year to two years will increase total methane produced and reduce energy used by blowers for aeration. This will improve project economics and reduce greenhouse gas emissions.

l) Based on the assumptions made in this project a full-scale digester operation can be profitable assuming that there are long-term contracts in place for the disposal of material. The estimated minimum attractive rate of return (MARR) for this full-scale project as described here would be between 16-20 percent at a minimum waste disposal fee of $30 per ton. Each project must be evaluated independently based on the level of risk on the investment and whether there are contracts to ensure the estimated revenue streams.

Conclusions and Recommendation

A digester cell was successfully constructed, monitored, and operated, first anaerobically for methane production, and then aerobically for compost production. A methane generation model was developed to characterize the kinetics and yield of methane produced over time. The decomposed solids were sampled and tested to further characterize the decomposition. During the aeration phase the digester cell and biofilter exhaust gases were sampled and tested to determine the destruction efficiency of VOCs, ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S)nitrous, oxide (N_2O), and carbon dioxide (CO) gas emissions, prior to venting to the atmosphere. Solids analyses were performed to determine the rate of decomposition of solids in the waste over time. An economics model was developed and optimized for various waste disposal fees and the internal rate of return was calculated.

The following recommendations are made, based on the operation, monitoring and analysis of this demonstration project:

a) Given the success of this pilot-scale project, additional pilot-scale projects should be studied to overcome the technical challenges of high moisture waste, such as food waste. The addition of food waste to a green waste digester can increase the total methane production three to four times per unit dry food solids when compared to a green waste-only digester. The addition of food waste will also create other challenges that need further study. For example, food waste is very high in moisture content and is readily degradable so it must be handled different than green waste. The waste-filling phase of a food digester must be short compared to a green waste digester to avoid odors and undesirable emissions of valuable methane. Design and construction of a food waste digester must take into account these factors.

b) To better understand the air flow pattern change as the material decomposes over time, gas tracer tests should be conducted (6). This is an important issue since poor aeration could lead to high anaerobic activity within the cell and result in higher gas emission during the aerobic phase of operation. Such field studies were performed on a municipal solid waste anaerobic bioreactor landfill at the Yolo County Central Landfill. Field tests coupled with modeling are needed to improve gas well spacing design and moisture addition and recirculation

techniques for such high solids anaerobic digesters, as described in this study.

c) Currently there are some published data on emissions from composting operations (7-14). However, there are very few published data on forced aeration composting and the associated emissions. We recommend further study to better quantify the total emissions from the green waste aerobic composting phase as studied here to compare with the available data on typical windrow composting. Also, air emission testing should be conducted for a food waste digester during the aerobic phase since NMOC emissions from food waste (15) are more likely going to be higher than green waste because of known features of food waste decomposition by bacteria.

d) The full-scale implementation of this project could benefit California as more organic waste is diverted from the landfill where methane is often not well controlled and remnants are unusable. The beneficial use of methane can increase diversion, produce renewable energy, and help increase organic content of soil for agriculture or horticulture use. Training is needed for operators and designers so that all aspects of the project are performed properly. The type of feedstock, cell design, waste filling, and operational issues are some of the major key issues that should be addressed. Careful consideration to details of the project will prevent technical problems that could lead to operations and environmental problems.

Introduction

The Landfill-Based Anaerobic Digester-Compost Project (digester cell) is a new technology that has been developed, based on the landfill bioreactor technology at the Yolo County Central Landfill. This technology has been tested at the landfill over the past 12 years and offers a new high-solids batch reactor anaerobic digestion process for the recycling of clean organic waste, based on proven bioreactor technology.

In addition to the development of a renewable energy source, this technology maximizes the benefits and increased the net energy gained from organic waste while reducing air emissions and producing quality compost for agricultural and horticultural use. The digester cell project utilizes space on an existing lined landfill area to create a large inexpensive digester cell with a synthetic cover to recover methane gas, while decomposing organic material is turned into compost product after the aerobic phase of operation.

Placing the anaerobic digester on top of a lined landfill has several advantages. First, the underlying groundwater is better protected. Second, by utilizing the on-site gas collection facility and other liquid and gas collection piping, the project requires less capital cost, making this project more cost-effective. Third, after the methane generation and organic material decomposition rates attenuate, the system is operated aerobically under synthetic cover to cure the residual decomposed organics.

During the aerobic phase of operation the system is operated in such a way that the exhaust gases from the aerobic composting are filtered through a biofilter in order to destroy VOCs, ammonia (NH_3) and nitrous oxide (N_2O), and carbon dioxide (CO) gas emissions prior to venting to the atmosphere. Once the aerobic phase of the project is complete, the material from the cell is excavated to remove the compost for the curing stage, and the cell is reused to receive the next batch of organic waste. The compost can either be used on-site as soil amendment for agricultural and horticultural purposes.

This report presents the findings of this demonstration project and the following issues are discussed in detail: design, permitting, construction, operating, gas generation modeling, moisture balance, energy balance, carbon balance, emissions calculations, analyses of compost quality, and full-scale project economics.

Permitting, Design and Construction

Permitting

Under Title 27 California Code of Regulation Section 21665, in May 2007 the Yolo County Central Landfill's Report of Facility Information (RFI) was amended to allow the construction and operations of this project. The RFI amendment permits the construction and operation of this project on top of an existing lined landfill cell. The composted material can be used on-site as described in the RFI amendment. The composting activity is exempt from the composting regulations and there is no volume to time restriction.

Base Liner System

The digester cell base liner was built on top of an existing landfill cell (Unit 6D Phase 2). The foot print of the digester cell was 27.4 m (90 feet) by 33.5 m (110 feet) by maximum 7.3 m (24 feet) high. Prior to installation of the base liner system, the 30.5 cm (one foot) of cover soil below the liner was compacted and graded to drain to the lowest point of the cell. A 305 cm (10 foot) wide by 122 cm (4 foot) high compacted clay levee was constructed around the entire cell (Picture 1).

Picture 1: Compacted clay below the digester base liner

A 241 gram (8.5 ounce) non-woven geotextile was installed under the liner to protect the liner from damage. The 20 mil high-strength polyethylene film laminated with reinforced bonding layer liner was placed over the geotextile and was secured in place inside a 2 feet deep anchor trench in the levee. A 241 gram (8.5 ounce) geotextile was installed directly on top of the 20 mil polyethelene liner to protect it from damage during waste filling. The anchor trench was backfilled to secure both the geotextile and liner (Picture 2).

Picture 2: Installation of base liner and protective geotextile

Waste Placement and Instrumentation

The digester cell was filled between June 28, 2007, and Aug. 17, 2007, with about 1,718 metric tons (1,894 tons) of green waste, 31 metric tons (34 tons) of wood chips as part of a base gas collection system, 118 metric tons (130 tons) of aged horse manure, and 23 metric tons (25 tons) of limestone (Picture 3). (See Table 1 below for further details). The green waste passed through a 76 mm (3 inch) screen prior to placement in the cell. Waste was placed in five separate layers with an average thickness of 122 cm (4 feet). (See Figure 1). During filling, the first two layers of green waste were mixed with horse manure and limestone. All green waste layers were compacted with a Caterpillar D6 model bulldozer. All side slopes were constructed at approximately 2 to 1 ratio (horizontal to vertical).

Picture 3: Placement and compaction of green waste with D6 bulldozer

Table 1: Digester cell feedstock and sensors data

Layer	Thickness	Filling Date	Green Waste	Aged Manure or Woodchips	Lime-stone	Number of Sensors
0		6/19/07 through 6/27/07	N/A	31.2 metric tons (34.35 tons) of wood chips	N/A	6 sets
1	91 cm (3 ft)	6/28/07 through 7/2/07	381.6 metric tons (431.71 tons)	41.0 metric tons (45.22 tons) of aged manure	11.1 metric tons (12.25 tons)	
2	152 cm (5 ft)	7/24/07 through 7/27/07	625.7 metric tons (689.73 tons)	77.1 metric tons (85.0 tons) of aged manure & 16.9 metric tons (18.58 tons) of woodchips	11.1 metric tons (12.25 tons)	6 sets
3	152 cm (5 ft)	7/31/07 through 8/7/07	431.8 metric tons (475.96 tons)	None	None	
4	152 cm (5 ft)	8/10/07 through 8/15/07	197.6 metric tons (217.80 ton s)	None	None	6 sets
5	161 cm (6 ft)	8/16/07	71.5 metric tons (78.79 tons)	None	None	

***** Each location received a temperature sensor, a 6.4 mm ID (0.25 inch) linear low-density polyethylene (LLDPE) tubing for pressure and internal gas composition measurement, and an electrical resistance moisture sensor to monitor the degree of waste wetness.

Samples of the green waste and manure were collected from each layer for moisture content, organic solids, cellulous, hemicellulouse, lignin, and biochemical methane potential (BMP) testing.

As each layer of waste was placed, sensors were installed during the construction to monitor the digester cell. Sensors were installed at the base of digester cell (layer 0) and on top of waste layer 2 and 4 (see Figure 1). Nine temperature sensors were installed at the base layer (layer 0), six on top of layer 2 and six on top 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, Idaho), a 6.4 mm ID (0.25 inch) linear low-density polyethylene (LLDPE) tubing for pressure and internal gas composition measurement, and an electrical resistance moisture sensor to monitor the degree of waste wetness. A total of 21 thermistor, 21 LLDPE tubes and 21 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 23 cm (9 inch) thick layer of wood chips was placed over the entire base layer to protect it from further damage during waste filling (Picture 4).

Electrical resistance moisture sensors developed and produced by Yolo County staff (2,16) were

installed at the base of the digester (layer 0) cell and on top of waste layer 2 and 4. Moisture sensors were also installed at each location where temperature sensors were installed and were then protected from damage as described above.

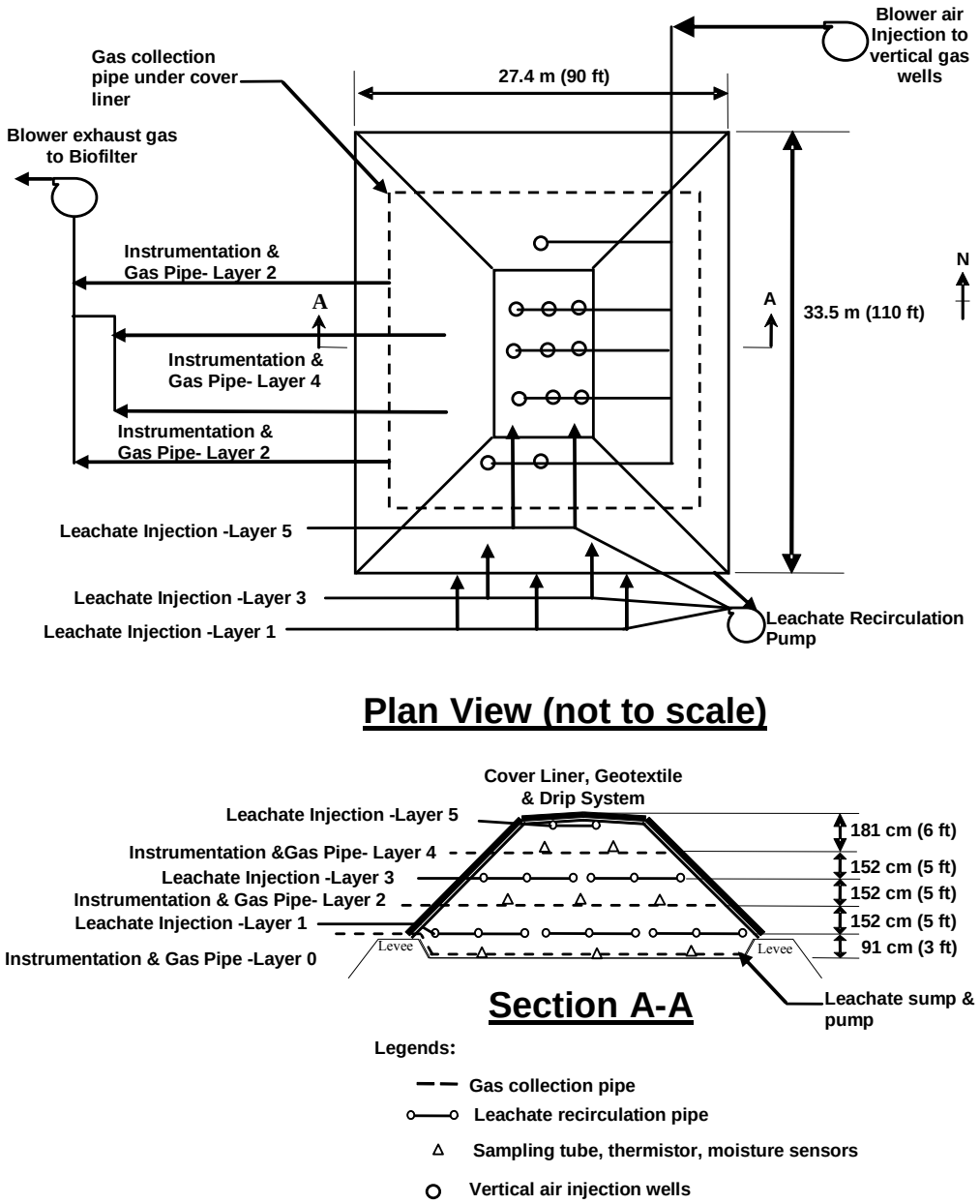


Figure 1: Digester cell plan view and cross-section

Picture 4: Placement of wood chips over the base liner

Liquid Injection and Recirculation System

Horizontal liquid injection and recirculation lines (Picture 5) were installed on top of layers 1, 3 and 5 of the waste (see Figure 1). In addition, a drip system was installed directly on top of the waste for the initial addition of water under the surface liner system. The low flow drip tape with (1 liter per minute per 30.5 m or 0.27 gpm per 100 feet) was only used when fresh water was added to the cell (Picture 6).

The injection lines within the waste were placed at approximately 3 m (10 foot) spacing. Each injection line consisted of a 50.8 mm ID (2 inch) high-density polyethylene (HDPE) pipe which extended completely through the waste. Each injection line was perforated by drilling a 2.4 mm (3/32-inch) hole every 1.5 m (5 feet). A total of 457 m (1,500 feet) of injection piping was installed.

Picture 5: Horizontal liquid injection and recirculation system

Each of the injection laterals was connected to a 10 cm-ID (4 inch) HDPE injection header. The total volume of leachate injection to the digester was measured using a magnetically driven flow meter (1"PMM, Sensus Meters, Uniontown, Penn). 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, Penn.).

Picture 6: Drip irrigation system installed directly on waste

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 sump was constructed to allow 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, Calif.) was used to pump the leachate that collected in the sump and was pumped 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 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, Fla.) 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 between each layer of waste during the anaerobic phase of operation. The horizontal gas collection lines were installed on the bottom of the cell and on top of layer 2 and 4. The bottom of the cell gas collection line consisted of a 6 inch schedule 40 PVC pipe with four lateral lines spaced at 26 feet apart. The four lateral lines were perforated by 3/8 inch diameter holes at every two feet near the bottom of the pipe. On top of layers 2 and 4 the gas collection system consisted of three 4-inch perforated (3/8 inch at 2 feet on-center) HDPE lines, spaced at 33 feet and 17 feet, respectively. The gas header pipes were equipped with a valve for flow control and an orifice plat for flow rate measurement.

Picture 7: Gas collection lateral above layer 4 of waste

All gas laterals were connected to a main 12-inch solid PVC pipe header that conveyed the gas to the on-site landfill gas to energy facility. The total gas flow rate from the cell was measured using a positive displacement meter (Roots Meters Series B3, Model 5M175 Roots, Houston, Texas). Gas composition was monitored daily for concentrations of methane, carbon dioxide and oxygen using a Landtec GEM 2000.

The waste aeration system was initially designed for horizontal air collection lines between each layer of waste. The horizontal aeration lines were installed on top of layers 1 and 3. They consisted of two 4" HDPE solid pipes (pipe ends inside the cell were left open), spaced evenly, at each layer, which were terminated in a shredded tire piles about 5 feet in diameter and 5 feet high. Shredded tires were used as the permeable material for aeration of waste.

During the aerobic phase of operation, additional vertical gas wells were installed to increase aeration in the cell because horizontal gas wells were ineffective in uniformly aerating the waste due to high waste moisture content of the waste.

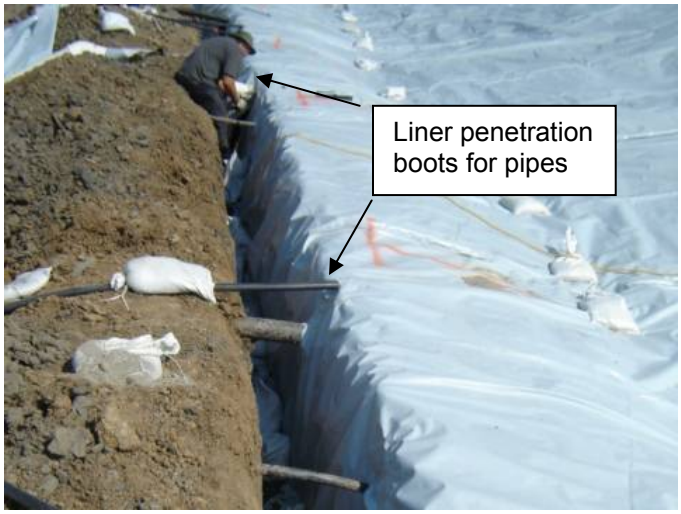
Picture 8: Horizontal air injection wells on layer 1 and 5.

Cover Liner

The surface liner, which completely covered the digester cell, was a 0.51 mm (20 mil) high-strength reinforced polyethylene (Dura Skrim R20DDK, Raven Industries, Sioux Falls, S.D.) 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, Ohio). The outer edges of the geotextile and liner were placed in the outer anchor trench and backfilled with soil. A system of tires and ropes set on strips of textured 1 mm (40 mil) double-textured LLDPE liner (GSE Lining Technology, Houston, Texas) was constructed on top of the surface liner. The 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 one-foot lengths of pipe, placing the pipe and rope in the trench, and then backfilling the trench with soil.

Picture 9: Completed surface liner system

The ropes across the top surface of the liner, attached to the tires, held the tires and textured liner in place. The textured liner strips were used to protect the underlying 1mm (40 mil) surface liner from the tires rubbing against it, and to provide traction for a safe walking surface during rainy season. Holes were cut in the geotextile and liner for any pipe penetrations. In the anchor trench, bentonite granules were placed around these holes to prevent any gas leaks. Liner penetration boots were constructed around the pipes to minimize gas leakage near boots (Picture 10).



Picture 10: Pipe penetration through liner in outer anchor trench

Picture 11: Bentonite placed around pipe penetrations to seal potential gas leaks

Biofilter Construction

Two existing biofilters which were used for the treatment of exhaust gases from the aerobic bioreactor cells were used to treat the digester cell exhaust gases during the aerobic phase of operation. The size of the first biofilter was approximately 30.5 m (100 feet) long by 6.1 m (20 feet) wide and the second biofilter was 36.6 m (120 feet) long by 6.1 m (20 feet) wide. The biofilter media used was composed of mature compost mixed with wood chips, less than 7.6 cm (3 inch) in size, and limestone. Limestone was used as a buffering agent to balance the pH of the biofitler media. Approximately six parts (measured by volume) wood chips to one part compost were used to create the compost media. In each biofilter five, 15.2 cm ID (6 inch) perforated PVC

pipes were installed to distribute the gas under the biofilter media uniformly. For each biofilter the perforated gas distribution pipes were connected to a 20.3 cm ID (8 inch) PVC solid header pipe and valves were installed to control the flow rate to both ends of the biofilter gas header line.

Picture 12: Biofilter #1 gas pipe installed prior to placement of biofilter material

Picture 13: Biofilter #2 gas pipe installed prior to placement of biofilter material

Picture 14: Biofilter cover liner installed and sealed around edges

After biofilter material was placed over the perforated pipe, the entire biofilter was covered with a (0.15 mm) 6 mil reinforced high-strength polyethylene film (Dura-Skrim 6BB, Sioux Falls, S.D.). On top of the biofilter liner a 12-inch hole was cut and a 12-inch pipe was installed for sampling exhaust gas.

Waste Excavation and Windrow Construction

Digester materials were excavated beginning on April 30, 2009. First, the cover liner was removed and the composted material was excavated using an excavator (Caterpillar 325CL) and truck (caterpillar D400), starting on the north side and proceeding to the south.

Picture 15: Excavation of digester cell

First, layers 3, 4, and 5 (green waste only) were removed and placed into three windrows. Second, layers 1 and 2 (a mixture of aged manure and green waste) were removed and placed into two additional windrows. Windrows were about 8 feet high and 15-20 feet wide at the base and were constructed on top of a closed landfill cell. Twelve days later (May 12, 2009) after the windrow construction, the piles were turned using a front-end loader (Caterpillar high lift waste handler, Model No. CAT0924) to ensure exterior materials were incorporated into the hot core of the piles. The windrows were turned again after 20 days (June 1, 2009) of curing, for the second time.

Picture 16: Trucking the finished excavated compost for final curing

Picture 17: Windrow of compost for further curing

Monitoring and Data Analysis

Waste Temperature and Moisture Sensors

Following initial installation, sensors were read manually weekly utilizing a handheld multimeter (Model 26 III Multimeter, Fluke Corporation, Everett, Wash.). Beginning on Nov. 19, 2007, readings were collected continuously using the on-site Supervisory Control and Data Acquisition (SCADA) system.

The electrical resistance moisture sensors were not designed to measure the actual moisture content of the waste but rather give an indication of moisture arrival at each location. A reading of less than 40 percent corresponded to an absence of free liquid, between 40-80 percent corresponded to the presence of free liquid but less than saturated conditions, and readings greater than 80 percent indicated saturated conditions, i.e., the sensor is full of liquid.

Leachate Quality

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, Calif.) 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. Monthly, frozen leachate samples were placed in a cooler and maintained at 4 °C (40 °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 between Sept. 26, 2007 and Oct. 9, 2008: acetic, propionic, isobutyric, butyric, isovaleric, valeric, isocaproic, and hexanoic. The total VFAs concentrations were calculated as acetic acid using the following equation (A):

$$[TVFAs] = [Acetic] + 60.05 \times \left(\frac{[propionic]}{74.08} + \frac{[Isobutyric + Butyric]}{88.11} + \frac{[Isovaleric + Valeric]}{102.13} + \frac{[Isocaproic + Hexanoic]}{116.16} \right)$$

where:

Total VFAs (TVFAs) 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.

At least quarterly or more frequently, additional leachate parameters were analyzed by an independent laboratory for the parameters listed in Table 2 below.

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

Table 2: Leachate sampling parameter and test method

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

Gas Volume, Composition and Methane Generation Rate

Anaerobic Phase—During the anaerobic phase of operation, the digester 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 a positive displacement meter (Roots Meters Series B3, Model 5M175 Roots, Houston, Texas). Weekly the main header line and the individual gas well flow rate, composition, and well suction was monitored and recorded by a GEM^{TM} 2000 landfill gas analyzer (CES Landtec Inc., Colton, Calif.). The GEM^{TM} 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). A second GEM^{TM} 2000, which was also calibrated weekly, was set up to automatically measure main header gas composition hourly from the digester cell main header gas pipe.

Aerobic Phase—During the aerobic phase of operation, the total gas volume from the cell was continuously monitored using a thermal gas flow meter (Model 8840MP, Eldridge Products, Inc. Monterey, Calif.). Two blowers, one under suction and one blowing ambient into the digester

cell, were used to aerate the static pile. One flow meter was used to monitor the flow rate of ambient air into the main header line and another flow meter was used to monitor the flow rate of gases removed. Both flow meters were calibrated by the manufacturer for the expected mixture of gases. Weekly the main header lines and the individual gas wells flow rate, composition, and well suction were monitored and recorded by a GEM™ 2000 landfill gas analyzer after field calibration. Weekly, the exhaust gases filtered through the biofilters for treatment were monitored for gas composition.

An automatic gas sampling system was set up to automatically sample and log gas composition from the exhaust gases from the main header and each of the biofilters by attaching a 6.4 mm (¼ inch) ID HDPE sampling tubes at each location. The automatic gas sampling system was installed at the instrumentation shed. The automatic gas sampling system consists of a sampling pump (Model 35.1.2TTP, KNF Neuberger, Trenton, N.J.), a programmable multi-position electronic actuator and rotary valve (Model EMTAMA-CE, Houston, Texas), gas conditioning and condensate removal system, and a non-dispersive infrared gas analyzer (California Analytical Instrument (CAI) L Series, Orange, Calif.) to measure gas composition continuously. The 4-20 mA output signal from the CAI was automatically logged via a data input card using the Supervisory Control and Data Acquisition (SCADA) system. The CAI was set up to calibrated automatically daily against gas standards (100 percent N_2; 50 percent CH_4, 35 percent CO_2 and 15 percent N_2; 45 percent CO_2, 21 percent O_2 and 34 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 (17):

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

where Q_n = CH_4 collection rate (m^3-CH^4/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 (1/yr), j is the deci-year time increment, and t = time (yr). AP-42 default values for k and L_0 for conventional landfills are 0.04 1/yr and 100 m^3-CH^4/yr (18).

The digester cell was filled and covered quickly such that most of the gas produced was collected and the 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 (19) from Eq. (C) which is the integral form of Eq. (B),

$$V = L_o M \left(1 - e^{-kt}\right) \qquad \text{(C)}$$

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), and other terms are as in Eq. (B). 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 five samples of green waste and two samples of aged manure collected during filling phase sampling event. The decay rate value was optimized by minimizing the sum of squared errors (SSE) of Eq. (D).

$$SSE = \left(\ln\left(\frac{L_o - V/M}{L_o} \right) - \left(-kt\right) \right)^2 \qquad \text{(D)}$$

Gas Emissions Testing & Analysis

Anaerobic Phase—During the anaerobic phase of operation, the gas from the digester cell was sampled from the main header gas line on Oct. 1, Oct. 17, and Dec. 17, 2007 and Jan. 29, 2008. These gas sampling events corresponded to the start up of gas collection and moisture addition and two months and three months 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 B.

Aerobic Phase—During the aerobic phase of operation the gas collected from the Digester Cell was sampled from the main header gas line and the gas exhaust pipes for biofilters #1 and #2. Gas sampling was performed on Oct. 2, Oct. 27, Nov. 14, and Dec. 17, 2008. Gas samples were taken using 6 liter (0.2 cubic feet) 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. Prior to gas sampling, the sampling train was leak-tested by plugging the sample inlet and opening the canister's valve to apply vacuum. Then, the valve was closed and the pressure drop over one minute was observed. A pressure drop of less than 13 cm (5 inches) of mercury was considered satisfactory. The sampling was initiated and in 24 hours the canister with at least 10 cm (4 inches) of mercury vacuum was capped and shipped to the laboratory with a chain of custody. The gas parameters and test methods used are listed in Table 3 and 4 below. Results of aerobic phase gas sampling events are shown in Appendix C.

In addition to the evacuated samples canisters collected for VOCs and fixed gases analysis, samples were also collected with a 60 mL plastic syringe inserted into a stopcock installed at the main header and biofilter gas exhaust pipe. The syringe was flushed with 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 20 minutes of each other and were wrapped in aluminum foil to keep out sunlight. Samples were shipped to North Carolina State University for analysis. Gas concentration of N_2O were determined on a Hewlett-Packard 5890 gas chromatograph (GC) equipped with a Carbonplt, 30 m length x 0.32 mm ID widebore with a 3 mm film thickness column, an electron capture detector (ECD). The temperature of the column oven and column were 300ºC and 60ºC isotemp for 2.5 min, respectively. Helium (He) was used as carrier gas. The column pressure was set at 100 kPa (15 psi) at 3 mL/min for the carrier gas.

Gas samples from the main header and the biofilter's exhaust pipes were monitored for CO, NH_3, and H_2S with indicator tubes (Carbon monoxide, ammonia and hydrogen sulfide detector tubes (SKC West Inc., Fullerton, Calif.) on an average of every three days. A hand-help pump (DRAGER Model No. 6400000, SKC West Inc., Fullerton, Calif.) with a carbon filter was used to extract the gas sample from the pipe.

Table 3: List of parameters and test methods

Parameter	Test Method
Volatile Organic Compounds (VOCs)	U.S. EPA TO-15
Fixed Gases (CO_2, CO, H_2, CH_4, N_2, O_2)	U.S. EPA 25/3C

Parameter	Test Method
Total Non-Methane Hydrocarbons as Methane	U.S. EPA 25/25C
Ethane	U.S. EPA 3C
Sulfur Compounds	U.S. EPA 15/16

Table 4: List of VOC parameters tested

Name of Compound		
Dichlorodifluormethane	2-Butanone (MEK)	Dibromochloromethane
Chloromethane	Chloroform	1,2-Dibromoethane (EDB)
1,2-Dichloro-1,1,2,2-tetrafluoroethane	1,1,1-Trichloroethane	Chlorobenzene
Vinyl Chloride	Carbon Tetrachloride	Ethylbenzene
Bromomethane	Benzene	Total Xylenes
Chloroethane	1,2-Dichloroethane	Styrene
Trichlorofluoromethane	Trichloroethene	Bromoform
1,1-Dichlorethene	1,2-Dichloropropane	1,1,2,2-Tetrachloroethane
Carbon Disulfide	Bromodichloromethane	Benzyl Chloride
1,1,2-Trichloro-1,2,2-trifluoroethane	cis-1,3-Dichloropropene	4-Ethyltoluene
Acetone	4-Methyl-2-Pentanone (MIBK)	1,3,5-Trimethylbenzene
Methylene Chloride	Toluene	1,2,4-Trimethylbenzene
trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	1,3-Dichlorobenzene
1,1-Dichloroethane	1,1,2-Trichloroethane	1,4-Dichlorobenzene
Vinyl Acetate	Tetrachloroethene	1,2-Dichlorobenzene
cis-1,2-Dichloroethene	2-Hexanone	1,2,4-Trichlorobenzene
Hexachlorobutadiene		

Data Analysis—Equation (E) was used to calculate the mass flow rate for each of the detected compounds shown in Tables 3 & 4 from the main gas header line and the exhaust gas from the biofilters.

$$R[lb/hr] = \frac{C[ppmv] \times MW[lb/lb-mole] \times Q[scfm] \times 60[min/hr]}{V_{ideal} \times 10^6 [ft^3]} \quad \text{(E)}$$

Where:

C = pollutant concentration in parts per million volume dry, lb-mole pollutant/10^6 lb-mole

MW= molecular weight of pollutant, ppmv = lb-mole pollutant/ 10^6 lb-mole pollutant

Q = gas flow rate, standard cubic feet per minute (when both biofilters were operated, the individual biofilter flowrates were determined by multiplying the mainline flow rate by 0.6 and 0.4 for Biofilters 1 and 2, respectively)

V_{ideal} = one lb-mole of ideal gas will occupy a volume of 386.5 ft^3 at 70 ºF (21 ºC) and 29.92 inches of Hg (1 bar)

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

$$DE_{Combined}[\%] = \frac{R_{in} - (R_{outBF1} + R_{outBF2})}{R_{in}} \times 100\% \quad \text{(F)}$$

Where:

R_{in} = mass flow rate into the biofilters, lb/hr

R_{outBF1} = mass flow rate out of biofilter #1, lb/hr

R_{outBF2} = mass flow rate out of biofilter #2, lb/hr

Equation (G) was used to calculate the total emission yield (lbs) for NH_3, N_2O, and CO during the aerobic operation of the digester cell.

$$Y[lb] = 24[hr/day] \times \sum_{d=1}^{d=24} R[lb/hr] \quad \text{(G)}$$

Where:

R = emission mass flow rate, lb/hr

Y = total emission yield, lbs

Solids Sampling & Testing

Waste samples were collected for solids testing during the filling phase prior to liquid addition, during the anaerobic and aerobic phases of operation, and after excavation during the windrow curing stage. 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 Appendix A and B. Table 5 below shows the dates of sampling events during each phase of operation as well as the sampling method. 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 the Table 6.

Table 5: Dates of solids sampling and sampling method

Phase of Operation	Sampling Date[a]	Sampling Method
Filling	7/12/2007	Grab samples of different materials were taken from the surface as each layer was constructed.[c]
	7/25/2007	
	8/9/2007	
	8/20/2007	
Anaerobic	3/20/2008	Sampling was done using either a gas-power-driven auger or a smaller soil sampling auger by drilling into the cell to different depths.[d]
	5/18/2008	
	8/19/2008	
Aerobic	10/17/2008	
	11/25/2008	
	12/5/2008	
Windrow (Curing)	5/7/2009[b]	TMECC[e] 02.01-B procedures for composite sampling of compost windrows were used (i.e. 5 sampling locations per windrow).
	7/31/2009[b]	

a. Samples were sent to North Carolina State University for analysis of moisture, cellulose, lignin, hemicellulose, organic solids, and biochechemical methane potential (BMP).

b. These samples were sent to Soil Testing Laboratory for analysis of stability, maturity, pathogens, inerts, size distribution, chemical composition, nutrient content, and metals. The sampling on July 31, 2009, was only tested by Soil Testing Lab and not by North Carolina State University.

c. Moisture contents given by the lab were not representative of the entire layer and most likely less than the actual because layers were constructed during the hot summer months, when material at the exterior of the layer was likely to dry out.

d. The gas-powered auger utilized a Briggs and Stratton 825 Series Engine (190 cc; 8.25 gross torque). The hand auger was the 0230D3-100 Soil Auger Bucket (3" diameter) from Soil Moisture Equipment Corp.

e. Test Method for the Examination of Composting and Compost (TMECC) developed by The Composting Council Research and Education Foundation

Additionally, during the windrow curing phase, temperatures of the windrows at different depths were monitored to determine if pathogen reduction targets were could be met. The specific temperature measuring device used was a ReoTemp Heavy Duty Compost Thermometer (Model A60PF- 60" long probe, San Diego, Calif.). Windrow temperatures were taken at 1, 3, and 11 weeks after excavation at four to five locations for each windrow and at depths of 31, 61, 91, 122, and 152 cm (1, 2, 3, 4, and 5 feet) .

Table 6 below shows the compost quality parameters tested and the corresponding test methods.

Table 6: 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

Parameters	Test Method
	< 3 MPN/4 grams dry wt.
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

Parameters	Test Method
Carbonates	TMECC 04.05-Ca lb/ton

Digester Settlement

The top cover liner and the levee around the digester cell were monitored for settlement at the beginning and end of anaerobic and aerobic phases of operations using a GPS measurement of surface elevation (See Appendix G-Topographic Surveys). GPS surveying was performed using a Trimble R8 Model 2 GNSS with horizontal accuracy of ± 3 mm (0.12 in.) and vertical accuracy of ± 3.5 mm (0.14 in). The survey points were within a grid of at least 10 feet on center. The grid spacing was reduced in order to capture all of the grade breaks.

Volume calculation was performed using AutoCAD Civil 3D version 2010 (AutoCAD) package. For each survey, a grid surface was created in AutoCAD from GPS survey points. A grid surface consists of a sampled array of elevations for a number of ground positions at regularly spaced intervals. A differential grid surface based on initial base survey of the digester cell was used to calculate volume for each phase of its operation.

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 equation (H) below.

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

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 using a digital energy monitor (Model No. ELF 3234-3 Class 1.0, Karnataka, India) which 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 11,700 Btu per kWhr was used in the energy calculation.

Carbon Balance

Two samples were collected from the digester cell during the filling phase -- one from aged manure in layer 2 and another composite sample from green waste in layers 1 through 5. At the end of the project, five compost samples were collected from the excavated compost windrows. Samples were shipped to North Carolina State University for total carbon analysis. Samples were prepared in the lab per method described in Appendix C. Organic elemental analyzer (Perkin-Elmer Corporation-2400 Series II CHNS/O) was used to combust a known amount of the sample at 925°C (1697°F) in a pure oxygen environment. The resultant gas was passed through several chemicals to scrub out unwanted gases and convert all forms of carbon to CO_2. The gas was then passed through a detector column which measured the total amount of carbon. The attached microprocessor then converted the information previously entered and calculated the percentage of carbon in the sample.

The total carbon released during the anaerobic and aerobic phase of operation was calculated from the measured gas volumes and gas composition during each phase of operation. Equation (I), was used to calculate the total carbon based on the gas volume. The assumed initial moisture content of the solids was 40 percent (wet basis).

$$C = V_{gas} \times \frac{28.3L}{ft^3} \times \frac{1mole}{22.4L} \times \frac{12.0107gC}{mole} \times \frac{1lb}{453.6g} \qquad \text{Eq. (I)}$$

Where

C = Carbon weight, lbs

V_{gas}= volume of gas (CH_4 or CO_2), ft^3

1 mole of gas at STP (0 °C and 1 atmosphere) = 22.4 liters.

Results and Discussion

The results and discussion section is divided in several sections. In the first section, the results of waste temperature and moisture monitoring are presented, followed by the results of leachate volume, chemistry, and moisture balance calculations. In the second section, the results of the gas monitoring during the anaerobic phase and aerobic phase are presented. In the third section, the results of solids testing during the anaerobic and aerobic phase and the final compost are presented. Finally, in the last section, the cell waste settlement analysis, carbon, and energy balance are presented.

Waste Temperature & Moisture

The average monthly temperature for each layer in the digester is shown in Figure 2. The average monthly temperature, ranging from 31-74ºC (88-165ºF), was well above the ambient air outside of the digester. During the filling phase of the digester, the temperature reached a maximum of 74ºC (165ºF) which indicates aerobic activity was initially dominant. The temperature elevation was due to exothermic (heat-generating) biochemical reactions that take place as green waste decomposition proceeds.

Shortly after waste filling, during the anaerobic phase of operation, between September 2007 and May 2008, the temperature within the waste decreased. The temperature in layers 0 and 2 remained in the thermophilic range (50ºC or 122 ºF) until May 2008 when it changed to mesophilic range (45 ºC or 113 ºF). After two months of anaerobic operation the temperature in layer 4 dropped to mesophilic range (40 ºC or 120ºF) and remained constant until the system turned aerobic. The drop in the temperature is related to the combination of heat loss to the atmosphere and the addition of cool groundwater to the cell for increasing the waste moisture content.

Towards the end of the anaerobic phase of operation, between May 2008 and September 2008, the temperature within the digester increased. The rate of temperature increase for layers 2 and 4 was 0.4ºC/month (0. 6ºF/month) and 0.6ºC/month (1.1ºF/month), respectively. However, in layer 0 the rate of temperature decreased by 0.9ºC/month (1.6ºF/month). The main gas collection system for the digester was in layer 0, which could explain the reduction in temperature due to a higher rate of heat removal through the gas collection piping. Waste temperature in layer 4 was influenced by the ambient temperature more than the other layers. This indicates that heat loss to the atmosphere was responsible for the temperature loss. However, waste temperature deeper than 1.5 m (5 ft) from the surface of the digester cell did not respond as much to the ambient temperature changes.

During the first month of digester aeration (October 2008) the rates of temperature increase in layers 2 and 4 were 12ºC (21.6ºF) and 21ºC (37.8ºF), respectively. The rate of temperature increase for the same time period for layer 0 was only 2ºC (3.6ºF). Waste samples from layer 0 showed high level of moisture which inhibited full aeration of this layer. Six vertical gas wells were installed in November 2008 to increase the effectiveness of aeration. Following the installation of these new vertical wells, the temperature decreases in layers 2 and 4 were 6.0ºC (10.8ºF) and 5.2ºC (9.4ºF), respectively. In February 2009, the blower flow rate was reduced in order to increase the internal temperature of the waste. As shown in Figure 2, once the flow rate was reduced, the temperature increased back into the themophilic range.

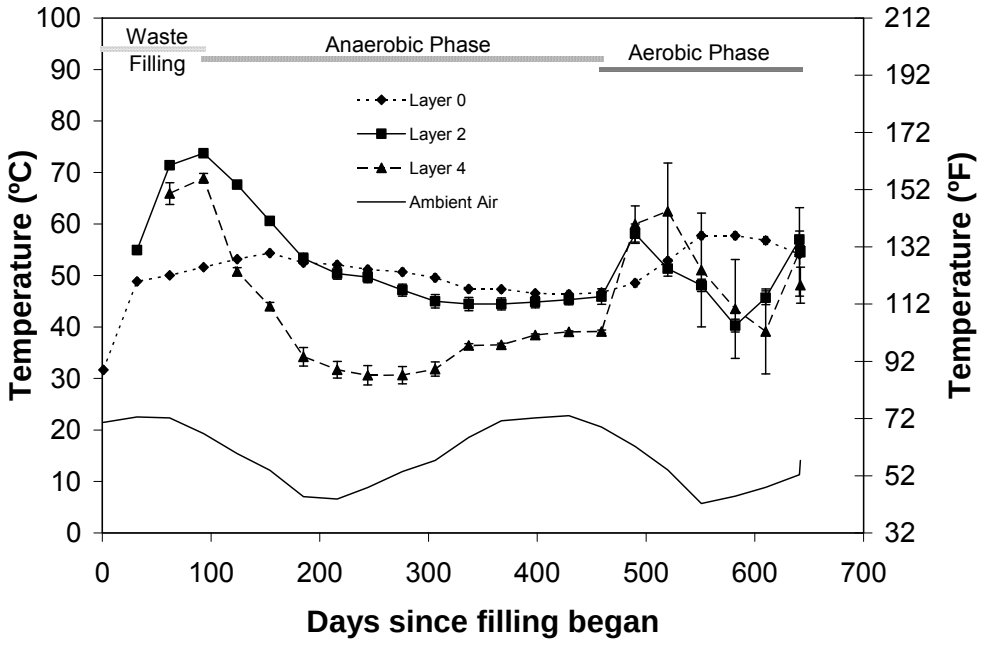


Figure 2: Digester monthly average waste temperature for different layers.

Water addition started in mid-September 2007, where all sensors indicated increase in moisture. The moisture level continued to increase over the entire anaerobic phase except Layer 0 where the moisture level sharply increased, and in November 2007 the moisture level continued to decrease slowly. The data indicates that layer 0 was saturated during the anaerobic phase of operation and slowly decreased towards the end of this phase. This could indicate that the base layer of the digester received more moisture than the rest of the areas. It is important to note that leachate addition was stopped by mid-April 2008 but leachate recirculation continued until the beginning of the aerobic phase. During the aerobic phase of operation, no water or leachate was recirculated back into the digester until April 2009, when water was added to the cell and recirculated to cool off a few hot spots in layer 2. Figure 3 shows that the moisture level in layer 2 had reached close to the starting point. Although these sensors did not provide the actual moisture content of the waste, they were very useful for indicating the general trend of the digester moisture content for water management and liquid addition and recirculation.

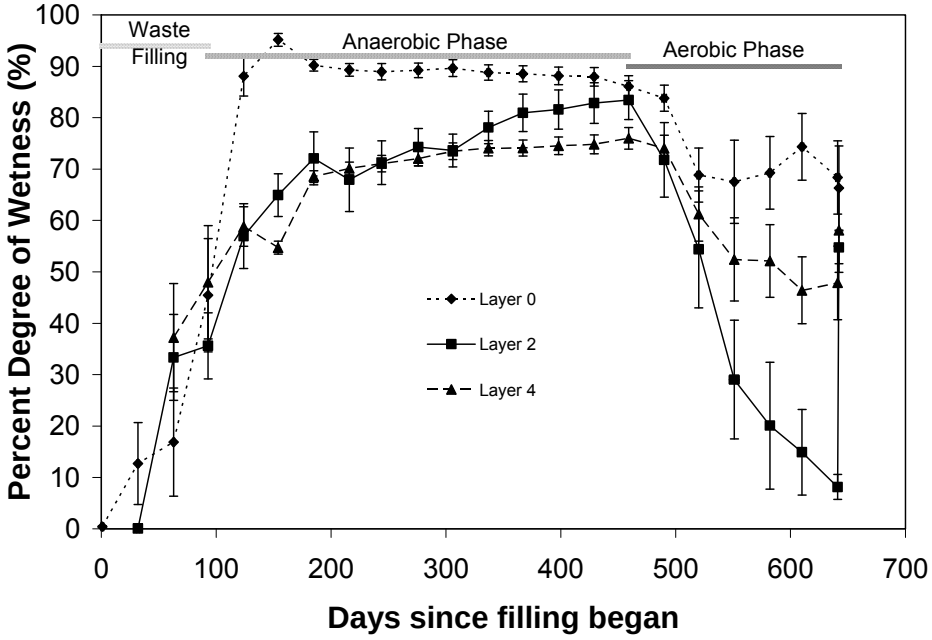


Figure 3: Digester monthly average percent degree of wetness for different layers.

Leachate Quality

In this section ,digester cell leachate quantity and quality analysis and interpretation of data are presented. In Appendix G a complete list of leachate data collected is presented. Some of the leachate parameters discussed below are: pH, total volatile fatty acids as acetic acid, total alkalinity, total dissolved metals and inorganics, ammonia as nitrogen, BOD_5, and COD.

pH & Total VFAs—During the early stages of the anaerobic decomposition phase, volatile fatty acids (VFAs) were formed (Figure 5) which is indicated by the slight decrease in the pH (Figure 4). 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 metanogens is increased, the leachate pH is expected to increase. This expected pattern is seen in Figure 5, where the majority of the acid is consumed and the concentration of total VFAs is reduced from more than 9,000 mg/L to an average value of 400 mg/L. On day 397, total VFAs was zero and stayed zero for the rest of the anaerobic phase and continued undetected in the leachate during the aerobic phase of operation. The average pH of leachate was 7.9.

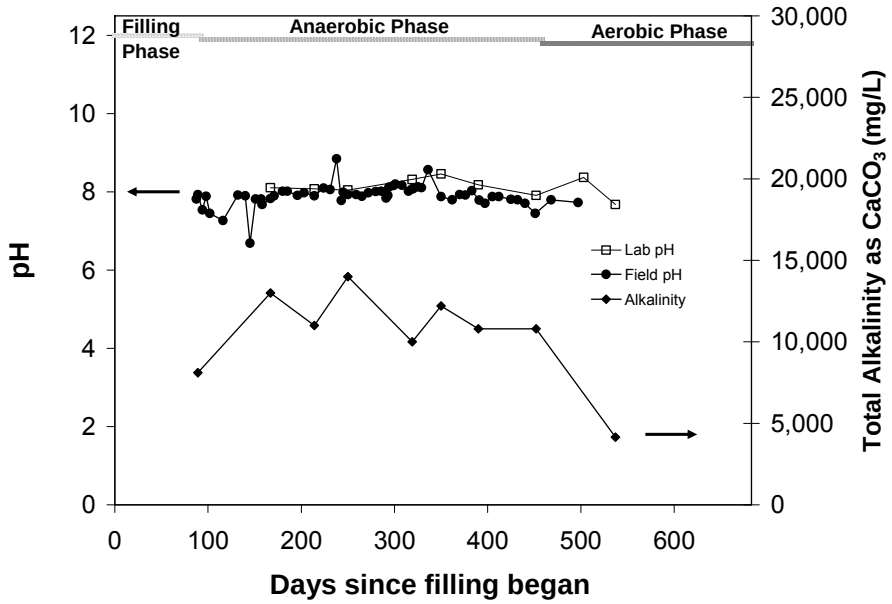


Figure 4: Digester cell leachate pH and total dissolved solids analysis over time

Total Alkalinity as $CaCO_3$—The average total alkalinity of leachate was 11,238 mg/L during the anaerobic phase and sharply decreased during the aerobic phase of operation to 4,150 mg/L. The sharp decrease is likely in large part due to reduction in weaker organic acids (acetate, propionate, others) which, as dissolved anions with counter ions, contribute to measured alkalinity.

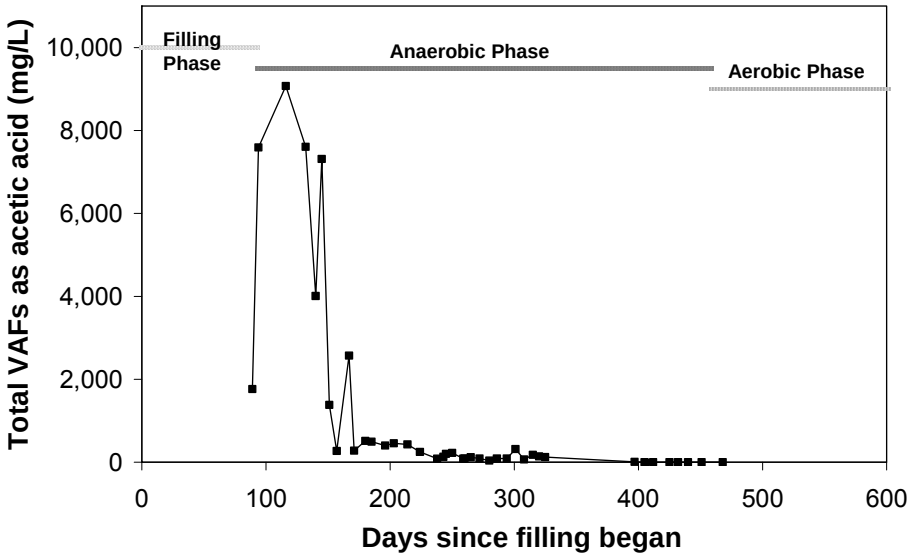


Figure 5: Digester leachate total VFAs as acetic acid over time

Table 7: Summary leachate test results for dissolved metals and inorganic parameters

Dissolved Metal or Inorganic parameter	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Error (mg/L)
Aluminum	0.18	2.20	1.43	0.23
Barium	0.03	0.37	0.17	0.04
Beryllium	0.00	0.05	0.01	0.00
Boron	6.90	11.10	9.29	0.44
Calcium	29.10	250	88.33	20.81
Chromium	0.01	0.19	0.13	0.02
Iron	2.70	15.30	6.61	1.13
Magnesium	325.00	980	536.60	59.42
Manganese	0.16	1.80	0.73	0.19
Potassium	2320	6000	4535	417
Sodium	383	780	578	43
Tin	0.00	0.81	0.25	0.12
Vanadium	0.02	0.15	0.05	0.01
Zinc	0.06	1.70	0.43	0.15
Total Kjeldahl Nitrogen (TKN)	550	2500	1775	254
Alkalinity as CaCO3	4150	14000	10450	972.75
Carbonate Alkalinity as CaCO3	0.85	2.00	1.43	0.19
Ammonia (as N)	26	2400	1330	235.19
Biochemical Oxygen Demand	150	4300	1587	387
Chemical Oxygen Demand	3000	18000	11720	1427
Chloride	1600	4100	3011	284
Nitrate (as N)	0.28	6.00	2.21	0.65
Phosphorus, Total	0.06	31.00	14.92	3.17
Sulfate	4.0	2300	270	226
Sulfide, Total	0.04	40.00	9.22	4.45
Total Dissolved Solids	9880	77000	23548	6125
Antimony	0.00	0.01	0.01	0.00
Arsenic	0.12	0.25	0.17	0.03
Cadmium	0.00	0.01	0.00	0.00
Cobalt	0.02	0.09	0.06	0.01
Copper	0.03	0.14	0.07	0.02
Lead	0.00	0.01	0.01	0.00

Dissolved Metal or Inorganic parameter	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Error (mg/L)
Mercury	0.00	0.00	0.00	0.00
Nickel	0.29	870	174	174
Selenium	0.003	1100	220	220
Silver	0.0004	1100	275	275
Thallium	0.01	0.01	0.01	0.00
Hydroxide (as CaCO3)	0.85	0.85	0.85	0.00

Metals and other inorganics—Table 7 presents the minimum, maximum, and average values for leachate tested from the digester cell. Detailed test results are shown in Appendix A. 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 2,400 ppm (Figure 6) but its levels did not appear to have inhibited anaerobic activity during the biogas production phase. The level of ammonia sharply decreased once the cell was aerated during the aerobic phase of operations. The level of ammonia dropped from 1,500 mg/L to 26 mg/L in 85 days of aeration. This was evident as the exhaust gas from the digester cell was monitored for ammonia level, which is discussed in the gas emissions section of the report.

BOD & COD—As shown in Figure 7, generally leachate BOD_5 was expected to decrease faster than COD (COD includes recalcitrant organic compounds) as organic material decomposed in the digester cell. Both BOD_5 and COD concentrations showed a decreasing trend. BOD_5 values reached a high value of 4,300 mg/L at the start of water addition and recirculation, but quickly dropped to an average value of 1,000 mg/L until reaching a low value of 350 mg/L on day 537 during the aerobic phase of operation.

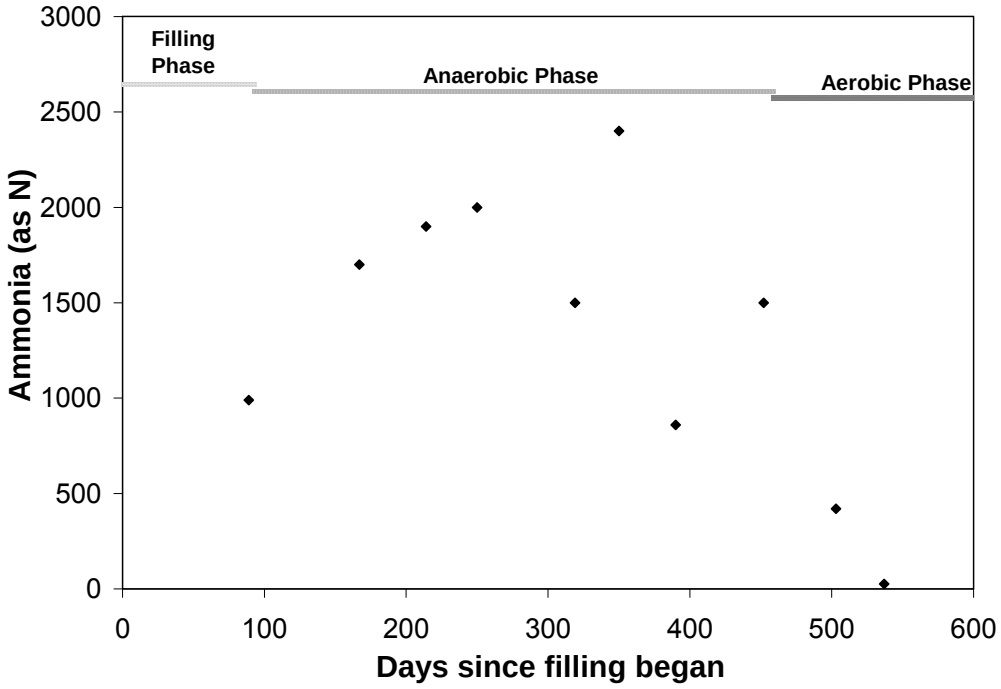


Figure 6: Ammonia level in leachate over time

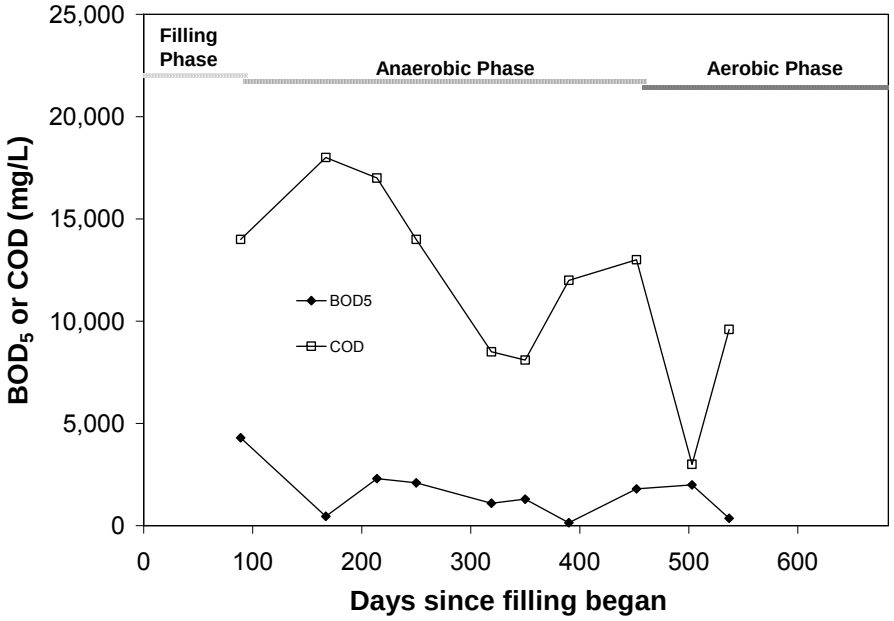


Figure 7: BOD and COD results over time

Moisture Balance

A moisture balance calculation was performed for the digester during the anaerobic and aerobic phases of operation. For the initial moisture content of the feedstock (green waste and aged manure) the weighted average moisture content was calculated based on the initial moisture content determined by laboratory from samples collected during the filling phase and it was calculated to be 15.9 percent (wet basis). The moisture contents given by the laboratory were not representative of the entire layer and were most likely less than the actual because layers were constructed during the hot summer months, when material at the exterior of the layer was dry during sampling. Samples were collected only from the top 30.5 cm (1 foot) which resulted in bias low initial moisture content. A more reasonable, higher assumed initial moisture content of 40% was used for the initial moisture content and in the moisture balance analysis which also agrees well with the typical green waste moisture content values given in the literature (20).

Equation (J) below was used to calculate the moisture balance. In equation (J), the "Liquid Added" value is the total amount of water added. The "Liquid Removed" value is leachate and gas condensate removed from the leachate collection sump and gas condensate sumps. The total amount of gas condensate removed from the cell was calculated based on the amount of water lost as water vapor (20) and the calculated value was used in the moisture balance calculation. The difference between Liquid Added and Liquid Removed, ΔS, represents the change in moisture content due to liquids addition.

The moisture content curve in Figure 8 was calculated based on equation (J) and was determined to be 40 percent (wet basis). The initial assumed moisture content was varied by ±10 percent and plotted against time. The calculated moisture content was plotted against the actual moisture content of samples collected during the anaerobic and aerobic phase (see Figure 8).

$$Moisture\ Content = M_i + \frac{\Delta S}{M_w} \times 100 \qquad \text{(J)}$$

Where:

M_i = Initial moisture content (%);

ΔS = Change in storage (tons of water); and

M_w = Wet weight of waste (metric tons).

The amount of water vapor escaping the digester cell was also calculated using the ideal gas law (20). During the initial anaerobic phase of operation 754,966 liters (199,441 gallons) of fresh water was added to increase the moisture content of waste. The calculated volume of water vapor based on an average gas temperature of 39ºC (102ºF) and total gas volume of 147,696 m^3 (5,215,855 ft^3) was 7,207 liters (1,904 gallons). A total of 14,491 liters (3,828 gallons) of leachate was removed during the anaerobic phase through the leachate collection system. The calculated moisture content at the end of the anaerobic phase was 57 percent.

During the aerobic phase of operation 772,883 liters (204,172 gallons) of condensate and leachate were removed. The amount of condensate removed was calculated using the ideal gas law (20) at an average exhaust gas temperature of 55ºC (131ºF) and a total gas volume of 4,091,102 m^3

(4,091,102 ft^3). The total amount of condensate removed through the gas system was 68 percent of the total liquid removed from the digester cell. A total of 181,821 liters (48,032 gallons) of water was added towards the end of the aeration phase in order to control several hot spots that developed during the aeration process. The final calculated moisture content at the end of the aerobic phase was 44 percent. Samples collected from the digester at the end of the aerobic phase had moisture content ranging between 43 percent and 53 percent.

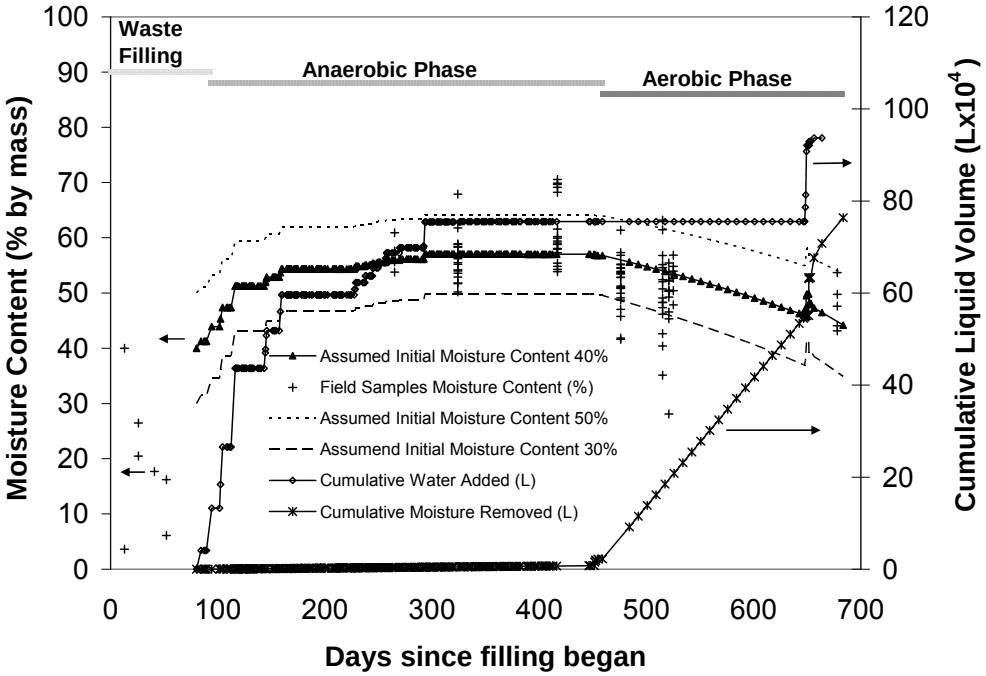


Figure 8: Digester cell moisture content versus cumulative water added and removed

Gas Volume, Composition, and Methane Generation Rate

Anaerobic Phase Gas Volume—During the anaerobic phase, the total volume of biogas generated was 1.48 x 10^5 cubic meter (5.2 x 10^3 cubic feet). The total amount of methane produced was 6.07x10^4 cubic meter of methane (2.14x10^3 cubic feet) as shown in Figure 9. This equated to 52.7 liters of methane produced per kg of dry solids (0.84 ft^3/ dry lbs) from the digester cell during the anaerobic phase of operation (Figure 10).

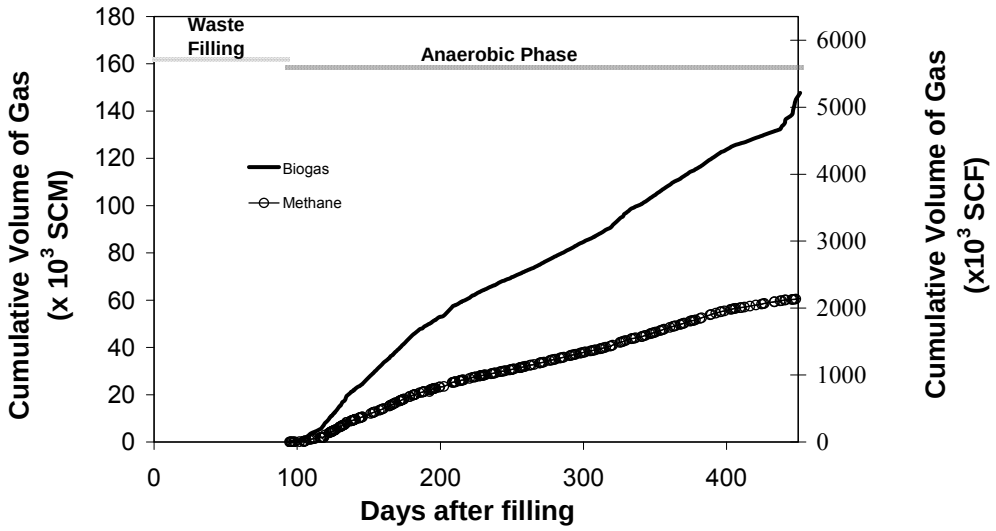


Figure 9: Cumulative volume of biogas and methane collected from digester cell over time

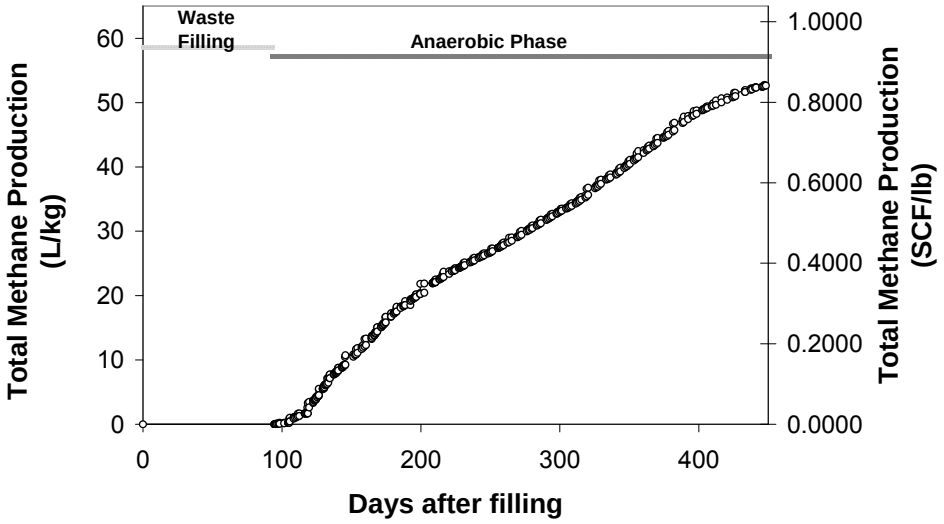


Figure 10: Total methane production per mass of waste

Aerobic Phase Gas Volume—As shown in Figure 11, the weekly average flow rate from the blower station was not constant during the aeration period. At the start of the aeration phase aeration was done by injection of air through several vertical gas wells and collection of gas through a series of pipes at the base of the digester cell. During this operation period the flow rate through the blower was an average of 9.3 SCMM (327 SCFM). In order to increase the gas flow rate additional vertical gas wells were installed and a 10.2 cm (4 inch) perforated PVC pipe was installed in a looped configuration underneath the cover on the side slopes, which increased the collected gas flow rate to an average of 17.6 SCMM (623 SCFM). Vertical gas wells were used to forced air into the waste mass under positive pressure. In February 2009, the gas flow rate was

reduced to 13.1 SCMM (463 SCFM). Total volume of gas collected during the aerobic phase of operations was 4.09 x105 cubic meter (1.45 x 108 cubic feet).

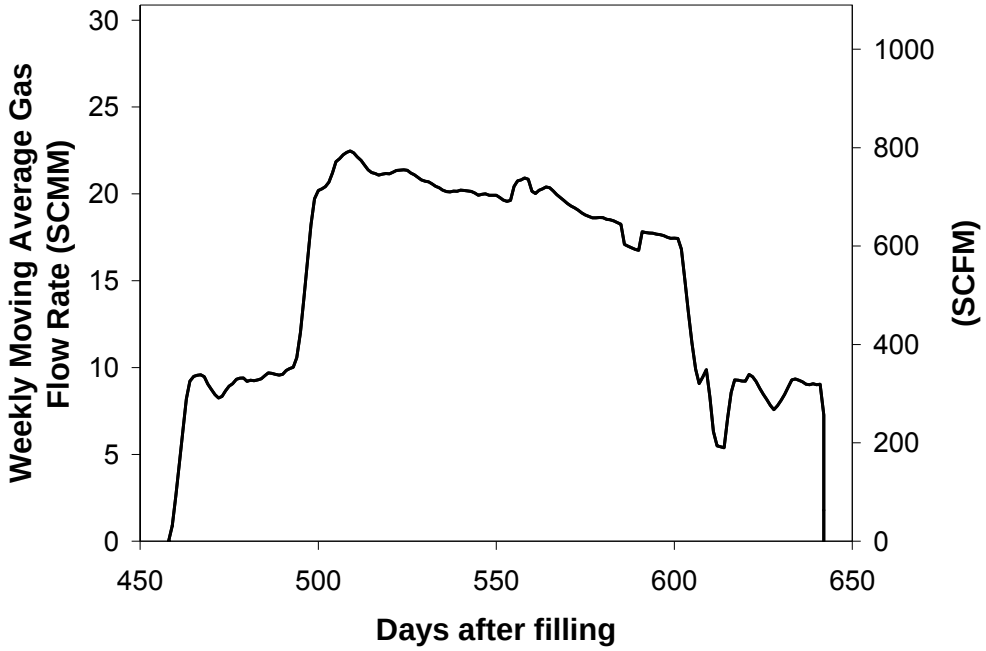


Figure 11: Weekly moving average gas flow rate over time

Anaerobic Phase Gas Composition—The average methane gas content during the anaerobic phase of operation was 45.4 percent ± 0.33 percent SE, as shown in Table 8. The gas composition varied between 57.4 percent to 25.5 percent methane content. The digester cell was operated to minimize any gas leaks. Gas suction under the liner was kept lower than the atmospheric pressure in order to prevent gas leaks through the liner anchor trench or small leaks that would develop over time around pipe penetration booths as the cell settled. Figure 12 shows the digester cell gas composition during the anaerobic and aerobic phase of operation.

Table 8: Summary statistics for gas composition during digester's anaerobic phase of operation

Parameter	CH_4 (%)	CO_2 (%)	O_2 (%)	Balance (%)
Average ± Standard Error	45.4 ± 0.33	45.4 ± 0.26	0.26 ± 0.05	8.86 ± 0.40
Maximum	57.4	60.0	6.6	32.9
Minimum	25.5	29.7	0	0

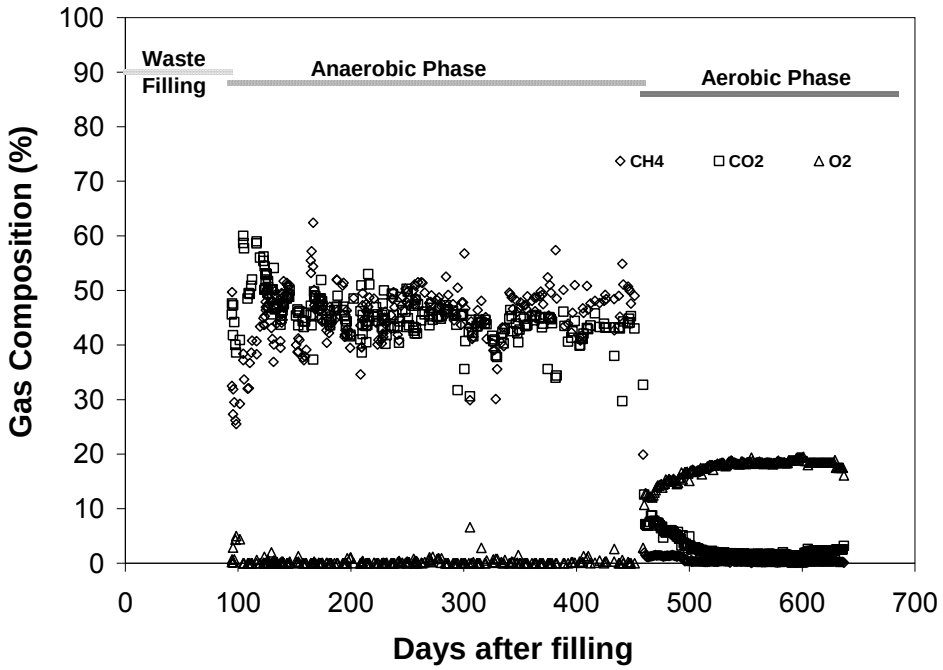


Figure 12: Digester cell gas composition over time during anaerobic and aerobic phase of operations

Aerobic Phase Gas Composition—The average methane gas content during the aerobic phase of operation was 0.73 percent ± 0.16 percent SE, as shown in Table 9. The gas composition varied between 0.01 percent to 19.9 percent methane content. The maximum methane content at the start of the air injection was 19.9 percent and dropped to less than 2 percent within 24 hours (Figure 13). The average concentration of oxygen in the cell was 16.88 ± 0.20SE, with a minimum value of 2.8 percent. The gases collected from the cell were injected into the biofilters' inlet pipes for further emissions treatment.

Table 9: Summary statistics for gas composition during digester's aerobic phase of operation

Parameter	CH_4 (%)	CO_2 (%)	O_2 (%)	Balance (%)
Average ± Standard Error	0.73 ± 0.16	3.20 ± 0.31	16.88 ± 0.20	79.5 ± 0.28
Maximum	19.9	32.7	19.4	81.9
Minimum	0.01	0.3	2.8	44.6

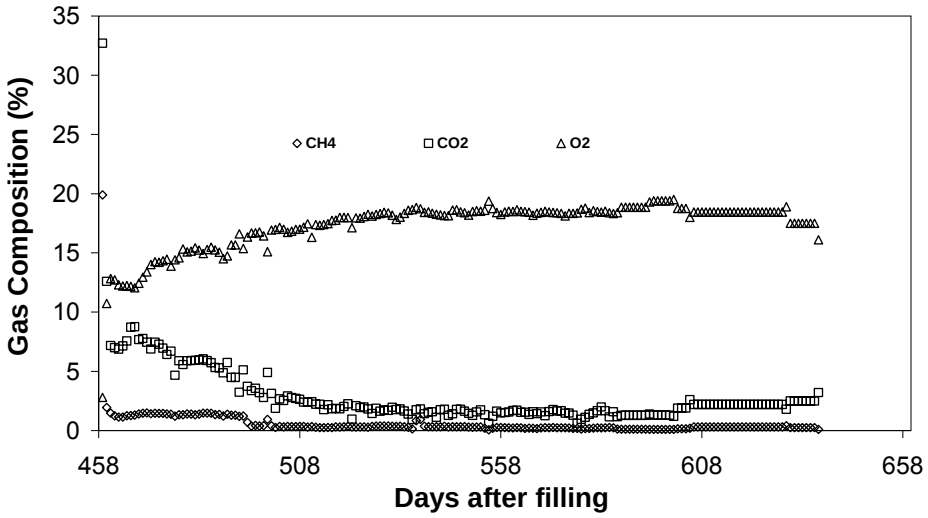


Figure 13: Digester cell gas composition over time during the aerobic phase of operation

Based on the actual gas volumes, a first-order gas generation model was fitted to the data. The estimated decay rate at L_0 of 73 m^3-CH_4/Mg was calculated to be 1.16 yr^{-1} with a half life of 0.6 years.

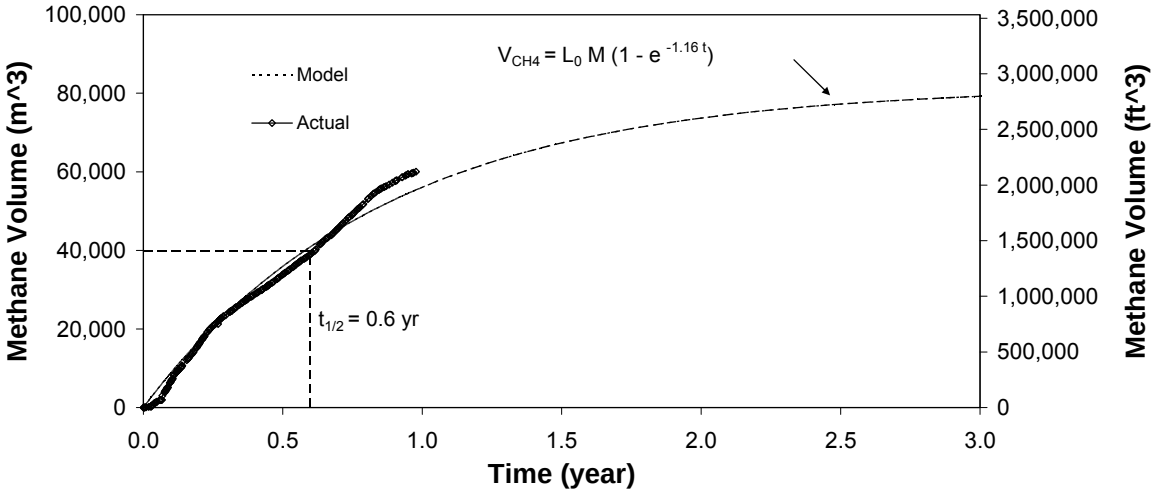


Figure 14: Methane generation model compared to actual field data over time

Gas Emissions and Biofilter Destruction Efficiency

CH_4 and N_2O Gas Emissions—Table 10 shows the calculated total tons of greenhouse gas emission for the first 126 days of a total 180 days of digester cell aerobic operation. Emission calculations were only done for the first 126 days since reliable gas data was only available

during this period and are presented in pounds per wet tons. Based on the mass balance on the nitrogen gas (tracer gas) measured in the biofilters, it was determined that some of the gas might have leaked from the biofilter around the edges of the cover liner. The estimated leakage rate is 7.9 ± 6.4 percent SE. Therefore, the results presented in this section are within the accuracy permitted given the leakage rate mentioned here.

The overall destruction efficiency of N_2O was 10.0 percent. At times, concentration of N_2O was higher in the biofilter than in the inlet. This indicates that the biofilter might have been producing more N_2O than destroying it. N_2O is produced during the oxidation of organic matter under aerobic or anaerobic condition. During the aerobic condition 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). Because ammonia is very soluble in water, it is possible that portions of the biofilters were anoxic and therefore producing N_2O as a byproduct of the denitrification process (21).

The overall destruction efficiency of methane in the biofilter was 31.8 percent. The destruction efficiency of methane was also calculated in the following section under, "VOCs destruction efficiency." Results from these tests (Table 11) showed a higher (51.1 percent ± 16.8 percent SE) destruction efficiency than presented here.

Table 10: Greenhouse gas emission rates and combined destruction efficiency for biofilters

Location	N_2O (lbs/wet ton)	CH_4 (lbs/wet ton)
Input to Biofilters	0.0311	11.55
Output from Biofilters	0.0280	7.88
Destruction Efficiency (%)	10.0	31.8

Ammonia, Carbon Monoxide, and Hydrogen Sulfide Gas Emissions—Table 11 below summarizes the results of other gas emission rates and destruction efficiencies. Ammonia gas was detected in the gas stream during the first 49 days of aeration. After this, no ammonia was detected from the gas streams. However, during the excavation of the solids, the bottom layers (layers 1 and 2) had ammonia odor. This could have been due to poor aeration at the bottom of the digester cell in layers where moisture content was high and material was more compacted than the layers above (layers 3, 4 and 5). The overall destruction efficiency of ammonia was about 27 percent.

Carbon monoxide gas was detected in the main header gas collection line during the entire time of aerobic phase but was only detected from exhaust gas from biofilter #2 for the first six days of operation. No CO was detected from biofilter#1. The overall destruction efficiency for CO was more than 99 percent.

No hydrogen sulfide was detected from either the digester cell main gas line or the biofilters during the aerobic operation phase.

Table 11: Other gas emission rates and biofilter destruction efficiencies

Location	NH_3 (lbs/wet ton)	CO (lbs/wet ton)	H_2S (lbs/wet ton)
Input to Biofilters	0.0127	0.0837	0
Output from Biofilters	0.0092	0.0008	0
Destruction Efficiency (%)	27.3	99.1	NA

VOCs Destruction Efficiency—Table 12 below presents the results of the biofilters' combined destruction efficiency of VOCs and other compounds. The aromatic compounds destruction efficiency ranged between 58.73 percent (1,4-Dichlorobenzene) to 93.02 percent (Toluene). Ketones had the highest destruction efficiency of all VOCs, with highest destruction efficiency of 98.19 percent (Acetone) and lowest of 95.55 percent (2-Hexanone). The chlorinated compounds had the lowest destruction efficiency because they are more stable and less degradable aerobically. The range of destruction efficiencies was from 9.14 percent (Dichlorodifluoromethane) to 86.79 percent (Chloromethane). Sulfides destruction efficiencies ranged from a low of 45.96 percent (Carbonyl Sulfide) to a high of 74.84 percent (Dimethyl Disulfide).

The total mass of VOCs in the gas stream from the main header line accounted for about 34 percent of the total non-methane organic compounds (NMOC) present. The destruction efficiency of the NMOCs was 67.4 percent ± 21.0 percent SE.

Table 12: Destruction Efficiencies for the Biofilters for VOCs, methane and other gases

Compound Name	Combined Biofilters Destruction Efficiency (DE) (%)				Average DE ± Standard Error (%)		
	10/2/2008 (Qt=329scfm)	10/27/2008 (Qt=329scfm)	11/14/2008 (Qt=778scfm)	12/17/2008 (Qt=710scfm)			
Aromatics							
4-Ethyltoluene	92.5	91.6	78.2	0	65.6	±	22.1
1,3,5-Trimethylbenzene	95.6	93.7	89.5	70.2	87.3	±	5.8
1,2,4-Trimethylbenzene	97.2	94.8	94.8	76.6	90.9	±	4.8
Styrene	99.4	98.0	98.8	95.3	97.9	±	0.9
1,4-Dichlorobenzene	91.4	69.3	0	74.2	58.7	±	20.1
Benzene	75.8	89.7	74.2	73.7	78.3	±	3.8
Ethylbenzene	93.3	85.9	91.6	94.6	91.3	±	1.9
Xylenes (total)	93.9	87.7	86.8	92.8	90.3	±	1.8
Toluene	96.4	94.4	89.7	91.6	93.0	±	1.5

Compound Name	Combined Biofilters Destruction Efficiency (DE) (%)				Average DE ± Standard Error (%)		
	10/2/2008 (Qt=329scfm)	10/27/2008 (Qt=329scfm)	11/14/2008 (Qt=778scfm)	12/17/2008 (Qt=710scfm)			
Ketones							
2-Hexanone	98.1	98.5	97.5	88.0	95.6	±	2.5
4-Methyl-2-Pentanone	91.9	99.2	95.8	96.0	95.7	±	1.5
2-Butanone	99.9	99.3	95.4	95.8	97.6	±	1.2
Acetone	99.7	99.3	97.0	96.7	98.2	±	0.8
Chlorinated Compounds							
c-1,2-Dichloroethene	91.8	81.6	0	0	43.4	±	25.1
Chlorobenzene	92.2	96.6	0	0	47.2	±	27.3
Chloroform	92.1	70.9	0	0	54.3	±	27.8
Trichloroethene	20.0	15.4	1.2	0	9.1	±	5.0
Dichlorodifluoromethane	82.7	0	69.0	0	50.6	±	25.6
Tetrachloroethene	99.1	15.0	0	76.0	47.5	±	23.8
Chloromethane	95.9	87.8	88.3	75.2	86.8	±	4.3
Sulfides							
Carbonyl Sulfide	91.9	0	92.0	0	46.0	±	26.5
Carbon Disulfide	98.7	60.1	50.7	62.3	68.0	±	10.6
Dimethyl Sulfide	99.7	99.7	98.7	0	74.5	±	24.8
Dimethyl Disulfide	99.8	100.0	99.7	0	74.8	±	25.0
Other							
Vinyl Acetate	92.0	99.8	99.5	98.1	97.3	±	1.8
TGNMO	98.7	95.2	67.9	7.8	67.4	±	21.0
Methane	100.0	40.0	41.2	23.2	51.1	±	16.8

Rate of Solid Decomposition

The primary parameters used to assess the extent of decomposition were Biochemical Methane Potential (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 measures the amount of decomposition that is possible for a particular waste sample under ideal anaerobic conditions. Figure 15 below shows the BMP

results over the course of the project for layers with and without aged manure. During the course of anaerobic and aerobic phases, BMP for all layers combined decreased 83 percent from 73.85 mL/g at filling phase to 12.27 mL/g at cell excavation. As shown in Figure 15, the BMP of layers with aged manure decreased 59 percent during the anaerobic phase (from 71.76 mL/g to 29.11 mL/g) and another 22 percent during the aerobic phase to 13.52 mL/g). The BMP of layers without aged manure decreased 65 percent during the anaerobic phase (from 75.19 mL/g to 26.08 mL/g) and another 21 percent during the aerobic phase to 10.32 mL/g).

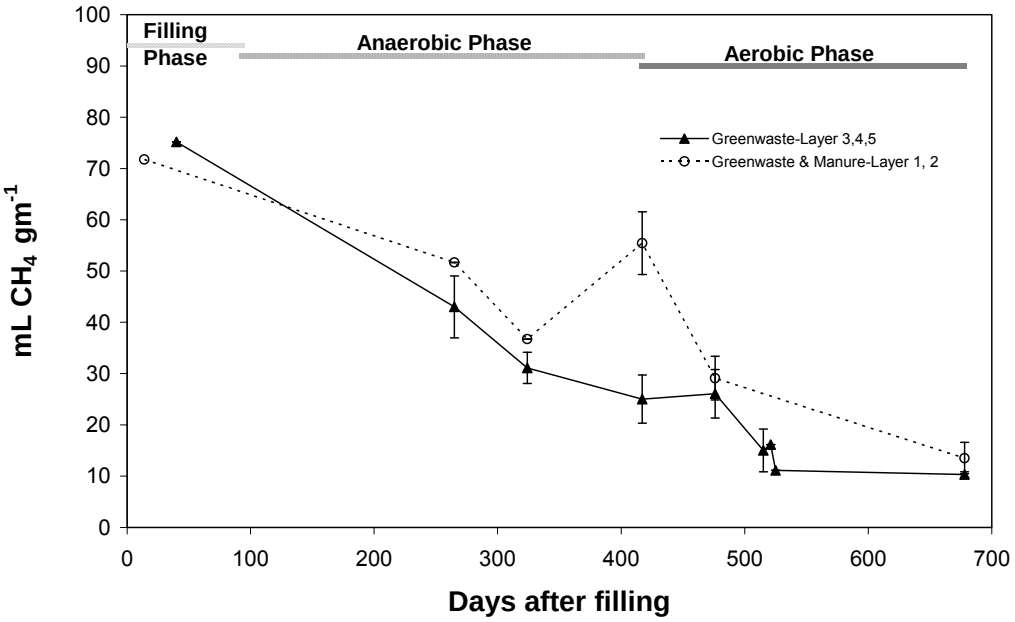


Figure 15: Biochemical Methane Potential (BMP) over time

Cellulose, Hemicellulose, Lignin, and Volatile Solids—Figure 16 shows how the digester composition changed in terms of the percentages of cellulose, hemicellulose, lignin, and volatile solids over the course of both anaerobic and aerobic phases. During the course of the anaerobic phase, the digester solids initially were composed of 18 percent cellulose, 11 percent hemicellulose, and 23 percent lignin and, after the anaerobic phase, were composed of 10 percent cellulose, 5 percent hemicellulose, and 25 percent lignin. The decrease in cellulose and hemicellulose fractions and increase in lignin fractions was an expected result, as cellulose and hemicellulose fractions can degrade under anaerobic conditions while lignin can only degrade under aerobic conditions. Furthermore, after the aerobic phase of operation, the digester solids were composed of 7 percent cellulose, 3 percent hemicellulose, and 21 percent lignin, indicating that all three fractions had degraded during the aerobic phase. These parameters were not measured during the curing phase; however, it is expected that further degradation of lignin by aerobic microorganisms would occur. Also indicated by Figure 16, during the filling phase, the initial materials averaged 68 percent volatile solids. At the end of the anaerobic and aerobic phases, this had reduced to 50 percent and 37 percent, respectively, reflecting significant degradation of the volatile solids fraction of the digester feedstock.

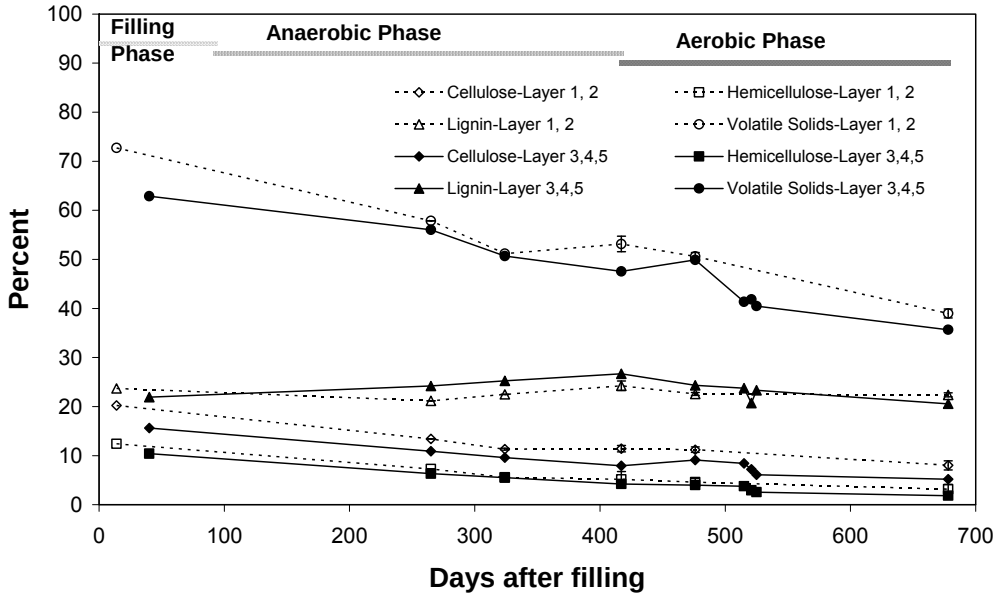


Figure 16: Cellulose, hemicellulose, lignin, and volatile solids content by layers

Ratio of Cellulose and Hemicellulose to Lignin—Another indicator of degradation is the ratio of Cellulose (C) plus Hemicellulose (H) to lignin (L). As shown in Figure 17, this ratio was 1.28 during the filling phase and decreased to 0.57 by the end of the anaerobic phase, indicating that cellulose and hemicelluse degraded at a much faster rate than did lignin. The ratio reduced further to 0.37 at the end of the aerobic phase, indicating that lignin still degraded more slowly than cellulose and hemicellulose under aerobic conditions.

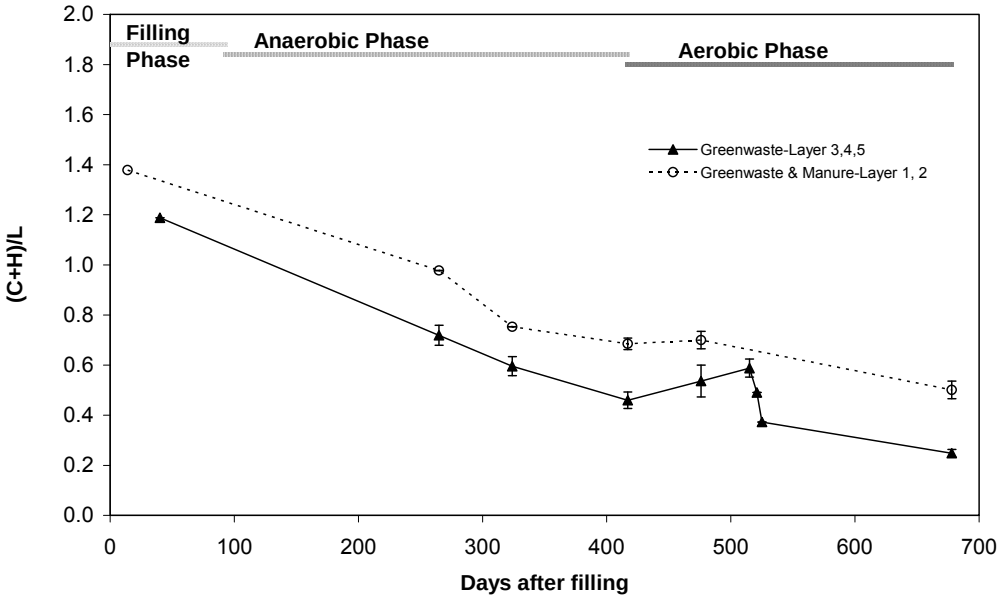


Figure 17: Ratio of (Cellulose + Hemicellulose) to Lignin by layers

Compost Biological, Chemical, and Physical Testing

Table 13 below shows the results of compost tests after excavation of digester material at the conclusion of aerobic operation (before curing), and the US Compost Council's Seal of Testing Approval Standards (or other standards for properties where the USCC did not have standards). In the results and discussion below, results for the digester compost are given in ranges to better illustrate the variability in compost quality from different layers of the digester cell. Definitions of compost quality parameters given below are those provided by the US Composting Council at its Web site. Some interpretations of test results are based on those provided by Soil Control Lab, which sampled the digester compost for all parameters provided below, unless indicated otherwise. In addition, for a comparison of digester compost with that of other North American compost samples, please see Appendix I, which includes average values for more than 3,000 compost samples from North American compost facilities. Data was provided by Soil Control Lab.

Stability of Compost—Stability refers to a specific stage or state of organic matter decomposition during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material (US Composting Council Web site). The stability of a given compost is important in determining the potential impact of the material on nitrogen availability in soil or growth media, and for maintaining consistent volume and porosity in container growth media. Most uses of compost require a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media. Two parameters used to measure stability are Respiration Rate (RR) and Biologically Available Carbon (BAC).

Respiration Rate—RR 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. The digester compost had a respiration rate in the range of 1.1 to 2 mg CO2-C/g OM/day, which is considered a low and stable level (TMECC Respirometry 05.08) and is acceptable for all uses.

Respiration tests were also performed at the University of California at Davis. The results and testing protocols are shown in Table 13 below and in Appendix H, respectively. Final Carbon Dioxide Evolution Rates (CER) ranged from 1.15 to 6.56 mg CO2 day^{-1} gdw^{-1}. According to the UC Davis lab, this is comparable to activities observed during stabilization of green waste composts which have respiration on the order of 5 mg CO2 day^{-1} gdw^{-1}. Particularly, the sample from layer 1 (bottom lift) showed high respiration levels throughout the incubation indicating the presence of compounds that support active microbial communities. Samples from layer 1 had nearly three times higher respiration rates compared to layer 5, 4 and 3. Layer 5, 4 and 3 had the lowest respiration rates. The UCD lab concluded that this data indicates microbial activity levels similar to stable green waste compost and that the respiration approach employed was able to detect significant differences between samples. The results from the Soil Control Lab and the UC Davis lab are different in that the latter found high respiration rates for the bottom two layers whereas the former found low respiration rates for all samples; however, other parameters measured by Soil Control Lab also indicate that the bottom layers were less mature than other layers in terms of ammonia levels, nitrate levels, and pH. The difference in the respiration results were due to two different test methods used for respiration test. During excavation of the digester cell strong odors we noticed when layers 1 and 2 were excavated. This observation supports the results shown in Table 13 for layers 1 and 2.

Table 13: Average respiration and cumulative respiration of samples after excavation

Layer No.	Average Respiration for time > 125 Hours (mg CO_2 day^{-1} g TS^{-1})*	Cumulative Respiration after 150 Hours (mg CO_2 day^{-1} g TS^{-1})*
Layer 1	6.56 A	90.78 A
Layer 2	2.82 B	52.42 B
Layer 3	1.15 C	28.12 C
Layer 4	1.25 C	26.83 C
Layer 5	1.97 BC	36.26 BC

* n=3. Means followed by the same letter within columns are not statistically different at α=0.05

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 material is considered 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 had stalled. This could be due to anaerobic conditions, excessive air, lack of available nitrogen or other key nutrients, pH value out of range, or microbes rendered non-active. Digester compost had a BAC in the range of 1.6 to 2.3 mg CO2-C/g OM/day, which is considered low and stable level (TMECC Respirometry 05.08) and good for all uses. Since the digester compost had low readings for both the RR and BAC, it was ready for curing at the time of excavation.

Table 14: Compost Quality Standards and Digester Results

Property		Units	Standards	Yolo Digester range [e]
Stability	Total Respirometry:	(mg CO2-C/gOM/day)	TMECC[d]: stable: < 4	1.1 - 2
		(mg CO2-C/g TS/day)	TMECC[d]: stable: < 4	0.46 - 0.81
	Biologically available Carbon	(mg CO2-C/g OM/day)	TMECC[d]: stable: < 4	1.6 - 2.3
		(mg CO2-C/g TS/day)	TMECC[d]: stable: < 4	0.69 - 0.95
	Stability rating	(Rating)	Stable or Very Stable	all Very Stable
Maturity	Emergence	(%)	80 or above [b]	all 100
	Seedling vigor	(%)		all 100
	Description of plants	(Description)		all Healthy
Pathogens	Fecal coliform	(MPN/g)	< 1000 [a]	> (1500 - 1800)[f]
	Salmonella	(MPN/4g)	< 3 [a]	all < 3
Inerts	Plastic	(% by weight)	< 1 % [a]	all < 0.5
	Glass	(% by weight)		all < 0.5
	Metal	(% by weight)		Four samples at < 0.5 One sample at 0.55
	Sharps	(% by weight)		all Non Detected
Size Distribution	<2.0 mm	(% by weight)	98% pass through 3/4" (19.050 mm) or smaller [a]	53.5 - 61.3
	2.0-4.0 mm	(% by weight)		14.5 - 22.6
	4.0-6.3 mm	(% by weight)		6.9 - 10.7
	6.3-9.5 mm	(% by weight)		2.9 - 5.6
	9.5-16 mm	(% by weight)		4.1 - 6.2
	16 to 25 mm	(% by weight)		0 - 11.7
	25-50 mm	(% by weight)		0 - 9.9
	>50 mm	(% by weight)		0
Chemical	Conductivity (EC5)	(mmhos/cm)	< 10 [a]	3.2 - 6
	Organic matter	(%)	30 - 65 [a]	39.9 - 45.6
	C/N Ratio	(ratio)	< 17:1 [c]	13 - 15
	Moisture	(%)	30 - 60 [a]	47 - 55
	pH value	(unit)	5.0 - 8.5 [a]	7.49 - 8.29

a. These numbers are from the US Composting Council's Seal of Testing Assurance Program ('STA') and can be found in the "Soil Amendment - Compost Specification" sheet accessed through the US Composting Council Web site: http://www.compostingcouncil.org/programs/sta/specifying.php

b. These values represent requirements set forth by Caltrans in "SSP 20-055 Erosion Control (Compost Blanket)" accessed through http://www.dot.ca.gov/hq/LandArch/ec/organics/compost_blanket.htm

c. These values are from the "Quality Standards for Finished Compost" put forth by CalRecycle, accessed through http://www.calrecycle.ca.gov/organics/Products/Quality/CQStandards.htm

d. Test Method for the Examination of Composting and Compost (TMECC) developed by The Composting Council Research and Education Foundation

e. These represent the range of values for all windrow compost samples. All parameters are reported on dry weight basis, with the exception of moisture content and pH.

f. After another 84 days of curing, the windrow whose sample had 1800 MPN/g for fecal coliform (the worst result of all samples), was sampled again, and fecal coliform had reduced to < 2.0, a passing rating.

Compost Maturity—Maturity is the degree or level of completeness of composting. Maturity is not described by a single property and therefore, maturity is best assessed by measuring two or more compost characteristics. Some immature composts may contain high amounts of free ammonia, certain organic acids or other water-soluble compounds which can limit seed germination and root development, or cause odor. All uses of compost require a mature product free of these potentially phytotoxic components. Immature composts must go through a curing phase, in which the phytotoxins become neutralized, before the compost can be used in high concentrations or in high-end uses.

The Soil Control Lab used a combination of ammonia and nitrate concentrations/ratios and pH as well as a Cucumber Bioassay (seed germination and growth test) to assess the maturity of the Digester Cell compost.

Ammonia—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. 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.

Results for the digester cell compost ranged from 250 to 400 ppm ammonia (dry wt.) for four of the five samples with the remaining sample testing at unusually high 1,300 ppm ammonia. This latter sample had originated from the bottom lift (layer 1 and 2) of the digester cell and was much higher in ammonia than the other four samples possibly because it was not aerated as successfully as were higher lifts due to lower porosity from compaction and leachate accumulation. Furthermore, closer examination of the data reveals that the sample with the lowest ammonia concentration of 2.3 ppm was material from layer 5 (uppermost layer) of the digester cell, possibly because this was the zone of greatest aeration due to an expectedly higher porosity.

Nitrate—Furthermore, nitrate levels of the digester compost ranged from a low of 0.11 ppm (dry

wt.) to a high of 110 ppm, with only two of the five samples achieving a mature score for this category; these two mature samples originated from the upper layers of the digester. In terms of the Ammonia/Nitrate ratio alone, only the uppermost digester layer achieved a test result indicating maturity, according to Soil Control Lab.

pH—The pH values of digester cell compost ranged from 7.49 (from layer 5) to 8.29 (from layer 1), with four of the five samples considered mature. The 8.29 pH reading was expected as that sample was material from the bottom layer (layer 1), where ammonia concentrations were highest and thus had an increasing effect on the pH.

It is suspected that the bottom layers of the digester cell achieved higher ammonia and pH values and lower nitrate levels due to leachate accumulation as well as suboptimal aeration at the bottom of the cell when compared with the more porous, less compacted upper layers of the cell.

Cucumber Bioassay—The plant bioassay is a direct way to determine whether compost is mature enough for plant growth. Cucumbers were chosen for the Plant Bioassay test because they are salt tolerant and very sensitive to ammonia and organic acid toxicity. Therefore, one can germinate seeds in high concentrations of compost to measure phytotoxic effects without soluble salts being the toxic factor. Values above 80 percent 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, the lab also tested a diluted 1:3 blend to indicate a more sensitive toxicity level. Results for digester cell compost indicated 100 percent emergence, 100 percent seedling vigor, and healthy plant descriptions for all five samples tested and for both treatments; this strongly indicates that phytotoxic effects were not present in the compost samples. It also indicates that the digester cell compost was well-cured, in terms of maturity, at the time of digester cell excavation before the curing phase.

Pathogens—Pathogens are disease-causing organisms including, bacteria, viruses, fungi, helminths, and protozoa which may be present in raw wastes or by-products. Both plant and human pathogens are found in living organisms and are present at some background levels in the environment. Therefore, the composting process must eliminate or reduce pathogens to a level that is below the threshold where the danger of transmitting diseases will occur. Weed seeds and pathogens are inactivated or destroyed by elevated temperatures over a period of time within the composting process.

Salmonella—Salmonella is not another indicator organism but also a toxic microbe. It has been used in the case of the biosolids industry to determine adequate pathogen reduction. Digester compost results showed safe levels of salmonella (below 3 MPN/4g) for all samples.

Fecal coliforms—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 weight, 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. The digester compost sampling revealed unsafe levels of fecal coliform, ranging between 1500-1800 MPN/g, where anything below 1000 MPN/g is considered safe according to USSC STA standards. Due to this concern, the windrow that had the highest fecal coliform count (1800

MPN/g), which was composed of material originally from layers 1 and 2 in the digester cell (the only layers that included aged horse manure), was sampled again 84 days later, and fecal coliform counts had dropped drastically to < 2.0 MPN/g, much lower than what is required under the USCC STA standards. This may indicate that digester cell compost may require more than 2 months in windrows after cell excavation for adequate pathogen destruction. Thus, the presence of a high number of fecal coliforms in the digester compost after aerobic operation gives reason for a pasteurization phase even though maturity tests indicated compost was already well-cured at the time of excavation.

Windrow Temperatures—Because temperatures are one important component of pathogen destruction, temperatures of the digester cell compost windrows were measured on three occasions during the curing phase at windrow depths of 0 to 5 feet. Temperatures of the windrows ranged between 30º C and 67º C over the course of two and a half months. Average temperatures achieved were 49º C, 51º C, and 54º C at 1 week, 3 weeks, and 11 weeks into windrow operation, respectively. Thus, not all of the temperature measurements taken fell in the 55-77º C (131-170º F) range typically used as a meter for adequate pathogen destruction. More successful aeration techniques during the aerobic or windrow phase may address the requirements for adequate pathogen destruction. One such technique is to install additional vertical wells for aeration and operate the cell such that the internal waste temperature is kept at an optimum for pathogen destruction. Another technique is to increase the turning frequency of the material and/or monitoring moisture levels in the material. A third consideration is that material was already very advanced in the composting process by the time it was excavated and turned into windrows; at that point, most of the readily degradable organic matter was already stabilized and so high windrow temperatures were unlikely to occur. We suspect that excavating material at an earlier stage (shortening the aeration phase) before readily available organics are used up would have encouraged higher windrow temperatures necessary for pathogen destruction.

Trace and Heavy Metals—Trace metals are elements whose concentrations are regulated due to the potential for toxicity to humans, animals, or plants. Regulations governing the heavy metal content of composts derived from certain feedstocks have been promulgated on both the State and federal levels. Similar limits have even been developed for fertilizers and certain other horticultural and agricultural products. Specific trace elements, often referred to as heavy metals, include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. The quantity of these elements are measured on a dry weight basis and expressed as mg/kg (milligram per kilogram) or ppm (parts per million). Many of these elements are actually needed by plants for normal growth, although in limited quantities. Therefore, measuring the concentration of these elements, as well as other plant nutrients, can provide valuable management data relevant to the fertilizer requirements of plants and subsequent fertilizer application rates. Certain heavy metals and trace elements are also known to cause phytotoxic effects in plants (when available in very high quantities), and specific plant species are known to be more sensitive than others. These elements include boron, manganese, molybdenum, nickel, and selenium. However, these elements are not typically found in compost in detrimental quantities. All composts that contain regulated feedstocks must meet national and/or State safety standards in order to be marketed.

Table 15: Trace and Heavy Metals

Property	Units	US Composting Council STA Compost Specifications [a]	Yolo Digester range [b]
Aluminum (Al)	(mg/kg)	---	8600 - 13000
Arsenic (As)	(mg/kg)	<41	4.2 - 6.2
Boron (B)	(mg/kg)	---	25 - 43
Cadmium (Cd)	(mg/kg)	<39	1.7 - 2
Chromium (Cr)	(mg/kg)	<1200[c]	27 - 49
Cobalt (Co)	(mg/kg)	---	6.8 - 8.8
Copper (Cu)	(mg/kg)	<1,500	34 - 69
Iron (Fe)	(mg/kg)	---	15000 - 18000
Lead (Pb)	(mg/kg)	<300	45 - 200
Manganese (Mn)	(mg/kg)	---	290 - 440
Mercury (Hg)	(mg/kg)	<17	all < 1.0
Molybdenum (Mo)	(mg/kg)	<75	1.2 - 2.2
Nickel (Ni)	(mg/kg)	<420	38 - 95
Selenium (Se)	(mg/kg)	<100	all < 1.0
Zinc (Zn)	(mg/kg)	<2800	130 - 170

a. These Physical Requirements for Compost for Compost Used as a Soil Amendment are found in the "Soil Amendment - Compost Specification" sheet accessed through the US Composting Council Web site: http://www.lowimpactdevelopment.org/epa03/saspec_print.htm. All these agree with the EPA 503 regulations, with the exception of selenium, which the EPA regulates at < 36 mg/kg.

b. All parameters are reported on dry weight basis.

c. These figures are listed in the EPA 503 regulations and used by the Soil Testing Lab for comparisons.

Table 15 above displays the metals results for the digester cell compost as well as the EPA 503 regulations used by the US Composting Council. The 10 heavy metals listed in the EPA 503 regulations are chosen to determine if compost can be applied to agricultural land and handled without toxic effects. These regulated metals are arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and znc. Most high concentrations of heavy metals are derived from woodwaste feedstock such as chrome-arsenic treated or lead painted demolition wood. The digester cell compost easily passed all 10 of the requirements listed by the US Composting Council and EPA specifications. Thus, compost produced could be legally marketed based on national safety standards for metals content.

Nutrients and Organic Matter

The Organic Matter content, NPK sum, AgIndex, Plant Available Nitrogen, C/N ratio, Soluble Nutrients & Salts, and Lime Content of the digester compost are evaluated below. Table 16 below show the values found for the digester cell compost.

Table 16: Nutrients and other characteristics

Property	Units	Yolo County Green Waste Digester (range of values for windrow compost samples) [b]
Primary Nutrients Sum (N+P2O5+K2O)	(%)	2.5 - 3.2
Total Nitrogen	(%)	1.1 - 1.5
Ammonia (NH4-N)	(mg/kg)	250 - 1300
Nitrate (NO3-N)	(mg/kg)	0.11 - 110
Org. Nitrogen (Org-N)	(%)	1.1 - 1.5
Phosphorus (P2O5)	(%)	0.44 - 0.57
Phosphorus (P)	(mg/kg)	1900 - 2500
Potassium (K2O)	(%)	0.86 - 1.3
Potassium (K)	(mg/kg)	7100 - 10000
Calcium (Ca)	(%)	1.3 - 6.5
Magnesium (Mg)	(%)	0.7 - 0.92
Sulfate (SO4-S)	(mg/kg)	220 - 630
Boron (total B)	(mg/kg)	25 - 43
Moisture	(%, wt. weight)	47 - 55
Sodium (Na)	(%)	0.068 - 0.1
Chloride (Cl)	(%)	0.24 - 0.4
pH value	(pH units weight wt.)	7.49 - 8.29
Bulk Density (wet)	(lb/cu ft)	40 - 47
Bulk Density (dry)	(lb/cu ft)	21 - 22
Carbonates ($CaCO_3$)	(lb/ton)	23 - 200
Conductivity (EC5)	(mmhos/cm)	3.2 - 6
Organic Matter	(%)	39.9 - 45.6
Organic Carbon	(%)	17 - 22
Ash	(%)	54.4 - 60.1
C/N Ratio	(ratio)	13 - 15
AgIndex	(ratio)	6 - 8
Plant Available Nitrogen	(lbs/ton wt weight)	3 - 6

a. These Physical Requirements for Compost for Compost Used as a Soil Amendment are found in the "Soil Amendment--Compost Specification" sheet accessed through the US Composting Council Web site: http://www.lowimpactdevelopment.org/epa03/saspec_print.htm

b. All parameters are reported on dry weight basis unless indicated otherwise.

Organic Matter—Organic matter content is the measure of carbon-based materials in compost. Organic matter content is typically expressed as a percentage of dry weight. Organic matter is an important ingredient in all soils and plays an important role in soil structure, nutrient availability, and water-holding capacity. Being aware of a product's organic matter content is useful for

estimating the age and physical properties of the compost. It may also be necessary for determining compost application rates on certain applications, such as turf establishment and agricultural crop production. In these applications, standard agricultural soil test kits are often used to determine recommended application rates of organic matter. However, these application rates are specified as the quantity of organic matter needed on a per acre basis. Therefore, the organic matter content of the compost must be known in order to convert the suggested application rate into a usable form (tons/acre). There is no ideal organic matter content for compost, and it may vary widely, ranging from 30 to 70 percent. The range for the digester cell compost was 39.9 to 45.6 percent organic matter, which is within the standard accepted range of the US Composting Council.

Macronutrients (NPK)—A typical value used to indicate the nutrient content of compost is the sum of the primary nutrients nitrogen (N), phosphorus (P, usually expressed as P2O5), and potassium (K, usually expressed as K20), which are the three nutrients utilized by plants in the greatest quantities, and therefore, are the nutrients most often contained in commercial and retail fertilizers. When purchased in bags of fertilizer, these three nutrients are measured and expressed on a dry weight basis, in the form of a percentage. In compost, nutrient content may be expressed on a dry or wet weight (as received) basis. Knowing the content of these nutrients will help you make correct decisions regarding the addition of supplemental fertilization. Although concentrations of nutrients found in compost are typically not high, in comparison to most fertilizer products, compost is usually applied at much greater rates, and therefore, can represent a significant cumulative quantity. The nutrient content of compost products varies widely; however, biosolids and animal manure-based composts typically contain more total nutrition. The use of certain composts may reduce or eliminate the necessity to fertilize certain plants during the first 6-12 months following its application. In general, nutrients found in compost are in an 'organic' form and thus released slowly as the compost decomposes. A sum (N+P+K) greater than 5 percent is indicative of a compost with high nutrient content, and best used to supply nutrients to a receiving soil. A sum below 2 percent 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 percent. Results for the digester cell compost ranged from 2.5 to 3.2 percent, indicating an average nutrient content compared with other composts.

AgIndex—Composts with low AgIndex (Nutrients/Na+Cl) 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 from 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 for 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. AgIndex results for the digester cell compost ranged from 6-8, which is an average nutrient ratio.

Plant Available Nitrogen—Plant Available Nitrogen (PAN) (lbs/ton) is calculated by estimating the release rate of nitrogen from the organic fraction of the compost and is an estimated release of nitrogen for the first season. 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 the growing season to offset the nitrogen demand of the microbes present in the compost. With ample nutrients these microbes can further break down

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. Values for the digester cell compost ranged from 3 to 6 lbs/ton (wt weight), which indicates it is an average to low Nitrogen Provider. Plant Available Nitrogen (PAN) is calculated using the following equation (K):

$$PAN = (X * (\text{organic N})) + ((NH4\text{-}N) + (NO3\text{-}N)) \quad (K)$$

where,

X = 0.1 if BAC < 2

X = 0.2 if BAC = 2.1 to 5

X = 0.3 if BAC = 5.1 to 10

X = 0.4 if BAC > 10

C/N Ratio—As a guiding principle, 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 break down 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 controllable. The digester compost had a C/N ratio in the range of 13 to 15, indicating that the compost was nitrogen-neutral. This result can also indicate that the compost was relatively stable. This result also meets the compost quality standard of 17:1 put forth by CalRecycle on its Web site.

Soluble Salts—Soluble salts refers to all soluble ions including nutrients, sodium, chloride and some soluble organic compounds. The concentration of soluble ions is typically estimated by determining the solution's ability to carry an electrical current, i.e., electrical conductivity. The units of measure for soluble salts are either mmhos/cm or dS/m (they are 1:1 equivalent). Plant essential nutrients are actually supplied to plants in a salt form. While some specific soluble salts, (e.g., sodium, chloride) may be more detrimental to plants, most composts do not contain sufficient levels of these salts to be a concern in landscape applications. Plant species have a salinity tolerance rating and maximum tolerable quantities are known. Excess soluble salts can cause phytotoxicity to plants. Compost may contribute to, or dilute, the cumulative soluble salts content of a growing media or soil. 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 composts high in readily available nutrients. The application rate of these composts should be limited to the level at which released sodium and/or chloride are acceptable. High salts + low AgIndex is indicative of a compost low in nutrients with high concentrations of sodium and/or chloride. The application rate of these composts should be limited according to the toxicity level of sodium and/or chloride. Reduction in soluble salts content can be achieved through thorough watering at the time of planting. Low salts indicate that the compost can be applied without risking salt toxicity, that it is likely a good source of organic matter, and that nutrients will release

slowly over time. Most composts have a soluble salt conductivity of 1.0 to 10.0 dS/m, whereas typical conductivity values in soil range from 0 to 1.5 in most areas of the country.

Digester cell compost resulted in a range of 3.2 to 6 mmhos/cm on a dry weight basis, indicating an average nutrient release rate that meets the standards given by the US Composting Council. Interestingly, this value was higher for material sourced from bottom layers than it was for the higher layers. We suspect that the soluble salts concentrated in the material at the bottom of the cell as leachate percolated downwards in the cell, resulting in a gradient of nutrient and salt levels.

Lime Content—Composts 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. Digester cell compost had lime content in the range of 23 to 200 lbs/ton, indicating very high lime content. Note that, typically, animal stalls add lime to reduce odor which might have been the case in horse manure used in this project. In addition, 24.5 tons of limestone was added as a way to prevent acidic conditions from developing in the cell during leachate recirculation and operation. We suspect that this compost could be beneficially used in a soil program aimed at raising the pH of the soil.

Physical Properties of the Compost:

Moisture content (Percent)—Moisture content is the measure of the quantity of water present in a compost product; expressed as a percentage of total weight. The moisture content of compost affects its bulk density (weight per unit volume) and, therefore, affects handling and transportation. Overly dry compost (35 percent moisture, or below) can be dusty and irritating to work with, while very wet compost (55 to 60 percent) can become heavy and clumpy, making its application more difficult and delivery more expensive. A preferred moisture percent for finished compost is 40-50 percent. The moisture content of digester cell compost at the time of excavation was between 47 and 55 percent. During the curing stage no water was added to the windrows. After 84 days of curing, the moisture content was between 38 and 47 percent, still at an ideal moisture for handling and transportation.

Percent ash—Ash is the non-organic fraction of composts. Most composts contain approximately 50 percent ash (dry weight basis). Compost can be high in ash content for many reasons, including: excess mineralization (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 compost. Digester compost had an ash content in the range of 54.4 to 60.1 percent, indicating an average ash content.

Particle size—Each size fraction is measured by weight, volume and bulk density. These results are particularly relevant with decisions to screen or not, and if screening, which size screen to use. Particle size distribution measures the amount of compost meeting a specific particle size range, by using a series of sieves (screens) to capture compost particles of a specific size. A compost product's particle size may also determine its usability in specific applications. 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. Presence of large particles in the compost 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. For example, a compost product with a maximum particle size of 1/2 inch or greater may not be acceptable as a turf top-dressing, whereas a product with a maximum particle size of 1/4 to 3/8 inch or less could be acceptable. Most composts that are used as soil amendments are screened through a 3/8 or 1/2 inch screen. Digester cell compost, which was sampled as is and not screened, ranged from 9.5 to 22.9 percent large particles >6.3 mm (0.25") by dry weight. For a full scale-operation, compost from the digester would be screened to a size appropriate for its application. If left unscreened, the compost may still be used, as mentioned above, for field soil applications, shrub mixes, mulches, landfill biocover, or where a fine size distribution is not necessary.

Bulk density—The bulk density of digester compost ranged from 21 to 22 lbs/ft^3.

Man-made inerts—These consist of materials created by humans and may be a part of the waste stream. These include: textiles, glass, plastic, and metal objects. When put into the composting process, these materials are not decomposed but may be degraded to some extent in physical characteristics, primarily through size reduction. These materials can decrease the value of the finished compost product because they offer no benefit to the compost and, in many cases, are aesthetically offensive. A common means of controlling man-made inerts is to minimize their entry into the waste stream being composted. Control is also accomplished through separation at the source during feedstock recovery at the composting facility, or during product refinement, (e.g., screening, ballistic separation). Other 'non' man-made inerts, such as stones, rocks, and twigs, may also be found in compost and are considered to be aesthetically offensive. Digester cell compost samples had less than 1 percent plastic, glass, and metal content, and no detected sharps, thus meeting the USCC STA Specifications for compost. Composting of food waste with green waste could have significant amount of contamination if source separated waste in not collected and processed properly.

Cell Waste Settlement

Table 17 below shows the volume reduction and waste compaction of the digester cell during the course of both anaerobic and aerobic phases. After the initial loading of the waste, the compaction of the material was calculated to be 620 kg per cubic meter (1,045 pounds per cubic yard). The compaction of the material increased to 737 kg per cubic meter (1,243 pounds per cubic yard) by the end of the anaerobic phase, partly due to water addition and partly due to anaerobic waste decomposition. This is associated with a 15.9 percent total volume reduction of digester materials (See Appendix J for topographic surveys of the cell). Compaction increased to 901 kg per cubic meter (1,519 pounds per cubic yard) by the end of the aerobic phase, due to aerobic waste decomposition. Over the course of both anaerobic and aerobic phases, the total volume of digester materials reduced by 31.2 percent.

Table 17: Digester cell volume reduction and waste compaction

Date & Phase of Operation	Cell Volume Between Phases of Operation (cubic meter) [cubic yard]	Volume Reduction as Compared to Initial Volume (%)	Number of Days Between Each Phase	Waste Compaction (kg per cubic meter) [pounds per cubic yard]
June 4, 2007- Prior to filling	N/A	NA	NA	
September 13, 2007-After waste filling at start of anaerobic phase	2,957 [3,867]	NA	101	620 [1,045]
August 19, 2008-End of anaerobic phase and start of aerobic phase	2,485 [3,251]	15.9	341	737 [1,243]
April 9, 2009-End of aerobic phase and prior to waste excavation	2,033 [2,659]	31.2	233	901 [1,519]

Carbon Balance

The initial carbon content of the solids in the digester cell was determined to be 336,539 Kg on a dry basis, or 29.24 percent of the digester contents. This was based on total dry weight of material in the cell from known weighed inputs and sampling as described in earlier sections. The total amount of gas collected during the anaerobic phase and then aerobic phase was used to calculate the total amount of carbon lost and the carbon remaining at the end of the anaerobic and aerobic phase. The carbon left at the end of the anaerobic and aerobic phases are shown Table 18. Shown as well in Table 18 are the calculated percentages of original carbon remaining after each phase, based on initial measured carbon and the carbon losses in CO_2 and CH_4 in the anaerobic and aerobic phases.

Testing of grab samples for carbon content at the end of each phase was also performed using methods described earlier. The measured percentage of carbon (averaged from multiple samples at completion of each phase) is also shown in the Table 18. Because the total dry weight at the end of each phase was unknown, the total weight and total solids weight losses of the digester contents are both uncertain. This is because with each pound of carbon destroyed, the weight of other constituents of materials destroyed can vary widely. For example for each unit weight of carbon with molecular weight of 12 destroyed in cellulose (with CH_2O monomer subunits) up to 1.5 unit weights of empirical formula H_2O with molecular weight of 18 are lost. Conversely, when the carbon in lignin is lost, the weight ratio of non-carbon contents lost (H and O) to carbon lost may be less than 0.5. Therefore the total weight loss and total treated waste weight at end of each phase is unknown.

Aside from indeterminate composting waste dry weight changes there are other sources of uncertainty (principally waste heterogeneity) whose detail is omitted. With the available information the carbon content of resultant compost can only stand as one useful parameter to

characterize the compost. However, even with the uncertainties, the data show that approximately 37 percent of the waste carbon was biodegraded. Of the carbon degraded, about 26 percent was by conversion to methane. Since methane generation was still continuing at encouraging rates as the anaerobic phase ended, more conversion of carbon to methane could undoubtedly have occurred had the anaerobic phase continued. However time constraints and the project schedule required that the anaerobic phase be ended even though higher conversions could have been obtained

Table 18: Digester cell carbon balance during and after anaerobic and aerobic phase

Phase of operation	Carbon content lost as CH_4 gas, kg (tons)	Carbon content lost as CO_2 gas, kg (tons)	Total calculated carbon in waste, kg (tons)	% of initial carbon remaining in waste	% carbon measured or calculated in waste (dry basis)
Initial carbon during waste filling in solids tested	---		336,539 (371)	100	29.2 (measured)
Calculated carbon lost and carbon remaining after anaerobic Phase	32,556 (35.9)	32,498 (35.8)	271,484 (299)	80.7	25.0 (calculated)
Calculated carbon lost and carbon remaining after aerobic phase	8,706 (9.6)	52,016 (57.3)	210,716 (232.3)	62.6	19.3 (calculated)
Final carbon in compost tested	---				16.5 (measured)

Energy Balance

Table 19 below shows the total energy used during the anaerobic and aerobic phase of operation for the various operations. The total parasitic load during the anaerobic and aerobic phases of operation was 5.8 percent and 48.3 percent, respectively. In order to collect adequate data for the analysis of emission, the project was operated aerobically over six months. However, the aerobic phase operation could have been reduced once adequate degradation was realized. The overall parasitic load would have reduced from 48.3 percent to about 33 percent for the aerobic phase. This would have increased the overall net energy produced from 42 kWh to 56kWh. Comparing this to a typical tank digester which is equipped with heating coil, pump for feeding and recirculation and tank mixture the total parasitic load only for the anaerobic phase can be as high

as 50 percent to 70 percent (22). The total parasitic load for tank digester is will also depend on the size of tank, amount of tank and pipe insulation used and local ambient air temperature.

Table 19: Energy balance for anaerobic and aerobic phase of digester cell

Type of Operations	Anaerobic Phase (kWh/ton)		Aerobic Phase (kWh/ton)	
Liquid Management	**Input**	**Output**	**Input**	**Output**
Liquid Addition Pumping	(2.58)	NA	(0.46)	NA
Leachate Recirculation Pumping	(1.89)	NA	0.00	NA
Gas Condensate Pumping	(0.02)	NA	(1.32)	NA
Biogas & Aeration System	**Input**	**Output**	**Input**	**Output**
Gas Collection & Removal	(0.84)	91.62	(23.26)	NA
Air Injection	NA	NA	(19.26)	NA
Total	**(5.33)**	**91.62**	**(44.30)**	
Net Energy Produced	**41.99**			

Project Economics

Capital Costs

This section discusses the project economics for both the anaerobic and aerobic phases of the project. The project capital costs are based on the actual cost for the demonstration project (0.2 acre footprint and 2,020 wet tons of waste). The total capital costs for the digester cell during the contract interval are shown in Table 20. Explanation for the derivation of each capital cost items (Table 20) are discussed below. Please note that this project was constructed as a small demonstration project and certain units cost are higher than if constructed at a full-scale system, which will be discussed in the following sections.

Table 20; Summary of capital cost for the digester cell during the contract interval

Description	Capital Cost	Cost per ton
Subgrade Preparation and Perimeter Levee Construction	$11,400	$5.64
Base Liner System	$10,000	$4.95
Instrumentation	$13,100	$6.49
Liquid Injection and Recirculation System	$5,000	$2.48
Gas Collection System	$9,000	$4.46
Aeration System	$5,000	$2.48
Cover Liner	$11,500	$5.69
Biofiltration System	$2,000	$0.99
Project Design and Permitting	$15,000	$7.42
TOTAL CAPITAL COST	**$82,200**	**$40.60**

Subgrade Preparation and Perimeter Levee Construction—This cost is associated with the following work: clearing existing vegetation at subgrade; compacting the underlying soil layer; grading the bottom of the cell to drain to a low spot; installing a leachate sump; constructing a levee to contain the leachate drained at the bottom of the cell, and installing an anchor trench for the base liner.

Base Liner System—This includes the materials cost and installation of a protective geotextile above the base liner and backfilling and anchoring the liner and the geotextile.

Instrumentation—The instrumentation cost includes the cost of materials and installation for the temperature and moisture sensors installed in each layer of waste and all other associated instrumentation for collection of data and operation of the pumps. The existing Supervisory Control And Data Acquisition (SCADA) system was utilized to collect and operate the system which was not included as an additional cost here.

Liquid Injection and Reicrculation System—This includes the cost of the leachate piping, valves, flow meters, pneumatic pump, surface drip irrigation system and all other items related to installation of the water and leachate addition and recirculation system.

Gas Collection Piping—This includes the cost of materials and installation for the gas collection system for both the anaerobic and aerobic phase. These include the pipes, flow meters, gas condensate sumps and other related fitting and valves. The existing gas collection system at the

landfill was used therefore, there was additional cost associated with blower station. One benefit of using a landfill site is that an existing gas system can be utilized to collected biogas and produce energy.

Aeration System—In this project the aeration system was designed such that air could be injected and then collected (push-and-pull method) through two blowers with series of gas wells. The cost associated with the aeration system only includes the gas piping installed and not the two existing blowers.

Cover Liner—The cost of the material and installation includes the cover liner, protective geotextile, strips of textured liner on top of cover liner for access to the top for routine field measurement, and ballast system using tires and ropes to protect the liner from ballooning and wind damage.

Biofiltration System—The only cost associated with the biofiltration system was the additional liner placed over the biofilter for emissions monitoring. The biofiler was already in place and therefore no additional capital cost was incurred.

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

Operations, Maintenance and Monitoring Costs

This section discusses the operations, maintenance and monitoring costs for the demonstration project. Explanation for the derivation of each operations, maintenance and monitoring costs are discussed below. Please note that since this project was constructed as part of a research demonstration project (0.2 acre footprint and 2,020 wet tons of waste) and the level of monitoring is much higher than would be needed for a full-scale project. The details of a full-scale operation will be discussed in the following sections. The total operations, maintenance and monitoring costs for the digester cell during the contract interval are shown in Table 21.

Table 21; Summary of total operations, maintenance and monitoring costs for the digester cell during the contract interval

Description	Operating Cost	Cost per ton
Waste Placement	$10,500	$5.20
Electricity Use for Liquid Injection and Recirculation System	$1,500	$0.74
Electricity Use for Gas Collection and Removal (Anaerobic Phase)	$204	$0.10
Electricity Use for Air Injection and Collection (Aerobic Phase)	$10,300	$5.10
Maintenance and Replacement of Flow Meters	$3,000	$1.49
Maintenance of Liner and Leachate Pump	$2,000	$0.99
Leachate, Gas and Solids Sampling, Monitoring and Testing	$25,000	$12.38
Compost Excavation, Curing and Testing	$17,400	$8.61
Data Collection, Analysis and Reporting	$48,096	$23.81
TOTAL O&M and Monitoring Costs	**$118,000**	**$58.42**

Waste Placement—The cost of waste placement includes: placing one foot (30.5 cm) of wood chips at the bottom of the cell as a drainage and protective layer; pushing and mixing green waste and aged manure into the cell; compacting green waste and grading waste before the cover liner is installed.

Operations and Maintenance Costs—The cost associated with operations of the project include power use for the liquid addition and recirculation system, gas collection, and aeration system. Other routine maintenance costs include calibration and replacement of leachate and gas flow meters; routine repair of tears in the cover liner and repair or replacement of cover liner boots; and routine cleaning of leachate pump intake and the in-line particulate filter to prevent it from clogging.

Monitoring Costs—The monitoring costs include leachate, gas and solids sampling and laboratory testing. The monitoring and data analysis section of this report presents the parameters tested and the frequencies of each parameter in details.

Compost Excavation, Curing and Testing—The cost associated with excavation of the waste from the digester cell, hauling the excavated material, making windrows of the material for curing, and turning the piles twice and sampling material for compost testing as described in the previous sections were include here. Please note that the cost associated with screening the materials after curing were not included in this study.

Data Collection, Analysis and Reporting—The level of data collection, analysis, and reporting presented here are related for a small demonstration cell and would be much less for a commercial scale operation.

Capital Cost for a Full-Scale System

In this section the capital costs for application of a full-scale system are presented (Table 22). For the analysis of a full-scale system presented in this section it is assumed that six one-acre cells will be constructed with an average height of 20 feet. The average daily tonnage received at the facility will be 100 tons per day or a total annual tonnage of 30,000 tons. Each one-acre cell is composed of four 0.25 acre cells, which will be filled and covered within 45 days and within 190 days the entire one-acre cell will be covered and water addition and recirculation will start. The average initial waste compaction is estimated to be 900 to 1,000 pounds per cubic yard and the total tons of waste in each one acre cell will be approximately 15,000 wet tons. The feedstock for each cell will be composed of 13,500 wet tons of processed green waste and 1,500 tons of manure mixed as each cell is filled. The costs for each component of the project are presented in Table 22.

Table 22: Summary of initial capital costs for a full-scale system (100 wet tons per day)

Description	Initial Capital Cost	Capital Cost per Ton
Subgrade Preparation and Perimeter Levee Construction	$75,000	$0.83
Winter Access Road	$75,000	$0.83
Base Liner System	$100,000	$1.11
Instrumentation & Control	$150,000	$1.67

Description	Initial Capital Cost	Capital Cost per Ton
Liquid Injection and Recirculation System	$150,000	$1.67
Gas Collection System	$75,000	$0.83
Aeration System	$115,000	$1.28
Biofiltration System	$37,500	$0.42
Blower Stations and Controls	$120,000	$1.33
Project Design and Permitting	$90,000	$1.00
TOTAL CAPITAL COST	**$ 987,500**	**$ 10.97**

Subgrade Preparation and Perimeter Levee Construction—This cost is associated with the following work: clearing existing vegetation at subgrade; compacting the underlying soil layer; grading the bottom of the cell to drain to a low spot; installing a leachate sump; constructing a levee to contain the leachate drained at the bottom of the cell; and installing an anchor trench for the base liner.

Winter Access Road—This includes the construction of a winterized access road because material will need to be received year-round and good access is required for trucks.

Base Liner System—This includes the materials cost and installation of a protective geotextile above the base liner and backfilling and anchoring the liner and the geotextile.

Instrumentation and Control—The instrumentation cost includes the cost of materials and installation for the temperature and moisture sensors installed in each layer of waste and all other associated instrumentation for collection of data and operation of the pumps. The existing SCADA system will be utilized to collect and operate the system which was not included as an additional cost here. Some SCADA programming was including for the operation and data collection.

Liquid Injection and Recirculation System—This includes the cost of the leachate piping, valves, flow meters, pneumatic pump, surface leachate injection system, and all other items related to installation of the water and leachate addition and recirculation system.

Gas Collection System—This includes the cost of materials and installation for the gas collection system for both the anaerobic and aerobic phase. These include the 20 vertical gas collection wells, flow meters, gas condensate sumps, and other related fitting and valves. The existing gas collection system at the landfill will be used to collect the gas and used for energy generation.

Aeration System—This includes the cost of materials and installation for 30 additional vertical gas wells for waste aeration. Other costs included are gas condensate sumps, valves, fitting, and other gas flow measurement devices for each well.

Blower Stations and Controls—This includes the cost of materials and installation for the blowers and controls used during the anaerobic and aerobic phases of operation.

Biofiltration System—The materials and labor cost associated with the relocation and reconstruction of the existing biofilters were included in this cost. The biofilters will be covered

with a liner on top and on bottom to reduce moisture loose from the bottom and evaporation from top. The existing piping system will be used for the new location.

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

Annual Operation, Maintenance and Monitoring Costs for a Full-Scale System

This section discusses the annual operations, maintenance, and monitoring costs for a six-acre, 100 tons-per-day facility. Explanation for the derivation of each operation, maintenance and monitoring costs are discussed below. Please note that the costs presented below may vary according to the design, monitoring, and testing of the project. Specific site information should be used to determine the appropriate associated costs other than costs listed here. The details of a full-scale operation are discussed in the following sections. The total operation, maintenance, and monitoring costs for a full-scale system are shown in Table 23.

Table 23: Summary of annual operations, maintenance and monitoring costs for a full-scale system

Description	O& M Cost	Cost per ton Received
Access Road Maintenance	$6,000	$0.20
Waste Processing	$285,000	$9.50
Waste Placement and Compaction	$120,000	$4.00
Cover Liner	$48,000	$1.60
Biofilter Maintenance	$5,000	$0.17
Electricity Use for Liquid Injection and Recirculation System	$20,000	$0.67
Electricity Use for Gas Collection and Removal (Anaerobic Phase)	$3,400	$0.11
Electricity Use for Air Injection and Collection (Aerobic Phase)	$76,500	$2.55
Blower Station Maintenance and Repair (Aerobic Phase)	$4,000	$0.13
Maintenance and Replacement of Flow Meters (Anaerobic and Aerobic Phase)	$5,400	$0.18
Maintenance of Liner System and Leachate Injection and Recirculation System	$40,000	$1.33
Leachate, Gas and Solids Sampling, Monitoring and Testing (Laboratory testing)	$70,000	$2.33
Compost Excavation, Curing	$150,000	$5.00
Compost Screening and Testing (assumed 20% mass reduction after composting)	$325,000	$10.83
Field Monitoring, Data Collection and Analysis	$60,000	$2.00
TOTAL O&M and Monitoring Costs	**$1,218,300**	**$40.61**

Access Road Maintenance—This includes the routine grading and adding some gravel to the winterized access road.

Waste Processing—This cost includes the cost of equipment and personnel for grinding the material to less than 3 inches so that it can easily be mixed with manure and placed in the cell. If a grinder is purchased and operated, the purchase price should be budgeted in the capital cost section and only the personnel cost and operating cost of the equipment would be included in this section.

Waste Placement and Compaction—The cost of waste placement includes: placing one foot (31 cm) of wood chips at the bottom of the cell as part of the drainage system and to protect the liner below; pushing and mixing green waste and aged manure into the cell; compacting green waste and grading waste before it is covered with a liner.

Cover Liner—The cost of the material and installation includes the cover liner, protective geotextile, and ballast system using tires and wires to protect the liner from ballooning during high wind weather.

Biofilter Maintenance—This includes the cost to add more compost and wood chip to the biofilter at the end of each year of operation. The biofilter synthetic cover will also be replaced as part of this maintenance activity.

Other Costs—The electrical use cost associated with operations of the project include power use for the liquid addition and recirculation system, gas collection, and aeration system. It is estimated that the aerobic phase of the project would be completed in 90 days. Other routine maintenance costs include calibration and replacement of leachate and gas flow meters; routine repair of tears in the cover liner and repair or replacement of cover liner boots; and routine cleaning of leachate pump intake and the in-line particulate filters.

Monitoring Costs—The monitoring costs include leachate, gas and solids sampling and laboratory testing. The monitoring and data analysis of the full-scale system will be less than the level of monitoring in the demonstration project. Only certain critical parameters will be monitored routinely to ensure successful operation of the full-scale system.

Compost Excavation, Curing and Testing—The costs associated with excavation of the finished compost, hauling the excavated compost, making windrows of the material for final curing were include here. Samples will be taken and tested by an outside independent laboratory to ensure proper curing of the compost.

Compost Screening and Testing—The equipment and personnel cost associated with compost screening (3/8 inch size) and testing samples for quality prior to use are included. If screen is purchased and operated, the purchase price should be budgeted in the capital cost section and only the personnel cost and operating cost of the equipment would be included here.

Field Monitoring, Data Collection, Analysis—The cost associated with personnel and laboratory testing for routine field monitoring, data collection, and data analysis for the operations of the full-scale system were included here.

Annual Revenue from a Full-Scale System

This section discusses the annual revenue generated from operation of a six-acre, 100 tons-per-day facility that would be constructed at the Yolo County Central Landfill. Explanation for the

derivation of each operations, maintenance, and monitoring costs are discussed below. Please note that the revenues presented below may vary according to the design of the project and the assumptions made and could be different than what is presented here. The total revenue for a full-scale system is shown in Table 24. The annual revenues generated from the project are discussed in detail below. An assumed equipment salvage value of $50,000 was used with a project life of 10 years.

Table 24: Annual revenue from full-scale system

Description	Annual Revenue	Revenue per ton Received
Disposal Fee for Green Waste	$900,000	$30.00
Electricity Generation at $0.03/Kwh	$114,000	$3.80
Compost Sold at $18 per ton (mass reduction of 40 percent from initial weight and after decomposition and screening)	$385,714	$12.86
Avoided Carbon Offset (carbon offsets sold at $10 per metric ton of CO_2 e)(23)	$23,114	$0.77
	$ 1,422,828	**$47.43**

Green Waste Disposal Fee—The revenue from disposal of green waste and aged manure is based on typical fees charged for green waste. However, a higher disposal fee would improve the economics of the project significantly as it is discussed in the analysis below.

Electricity Generation Revenue— It is assumed that the exiting on-site methane to electricity facility will use the biogas to produce electricity and therefore the capital cost and operation costs associated with the internal combustion engines were not include in the analysis. However such analysis must be included for a new project without such a facility. The typical revenue from electricity generation would be in the order of $0.05 to $0.06 per kWh without any government incentives or tax credits. However, in this project a lower rate of revenue ($0.03 per kWh) was assumed. This is because only a portion of the electricity sales would be seen as royalty.

Screen Compost Revenue—The excavated compost will be screened and sold at an assumed rate of $18 per ton based on laboratory results. It was also assumed that the overall weight of the material remaining after composting and screening will be reduced by 40 percent. The compost could also be sold at a lower rate per ton without screening it, which could reduce the operation and maintenance cost of the $8 to $10 per ton. This would improve the overall economics of the project.

Avoided Carbon Offset Revenue—The avoided carbon offset was estimated based on the average of 1.341 pounds of carbon dioxide emissions produced per kWh of electricity generated (24). Over the past two years, carbon credit values have varied greatly and currently are below $10 per metric ton. It is estimated that the value of carbon credits will increase with economic recovery and regulatory impetus. The revenue produced from this carbon offset is assumed to be sold on the market for about $10 per metric ton (23).

Full-Scale System Net Present Value and Internal Rate of Return

An economics model was developed to evaluate the net present value and the internal rate of return for a full-scale system discussed earlier in this section. All costs and revenues associated with the full-scale project were considered in a 10-year project life. Figure 18 shows the annual cash flow and cumulative cash flow for this project.

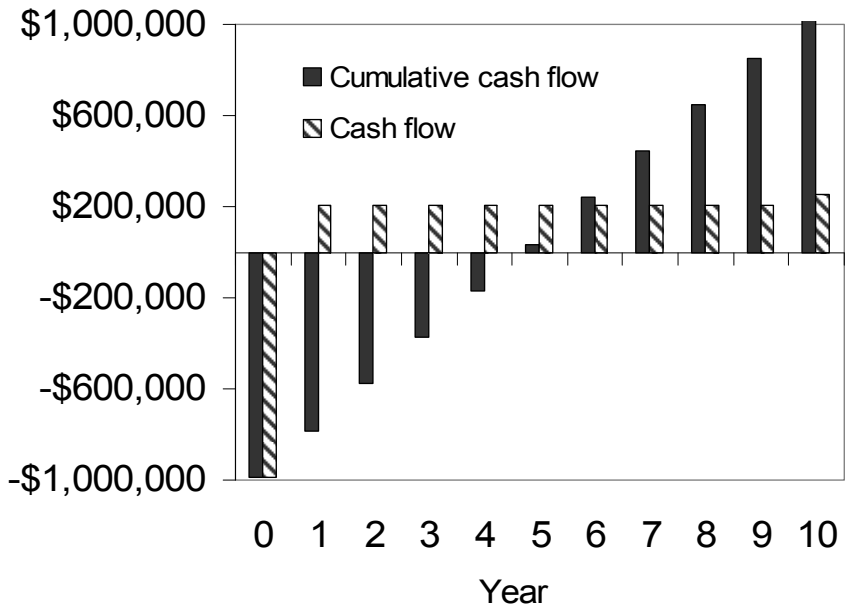


Figure 18: Annual and cumulative cash flow for a full-scale system at $30 per ton disposal fee

The calculated future cash flows (Figure 18) for the full-scale system were discounted into net present value (NPV) using a discount rate and subtracted from the initial capital improvement cost of the project. The discount rate used is adjusted to eliminate the effects of expected inflation. 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 19 shows the project NPV for the various waste disposal fees. In Table 25 the internal rate of return (IRR) for the different waste disposal fees are presented. Assuming that there are long term contracts in place for the disposal of material, the estimated MARR for this project would be between 16 percent to 20 percent at a minimum waste disposal fee of $30 per ton. If contracts are in place for selling the produced compost, the carbon offsets, and the electricity produced, a lower MARR value could be selected with a lower waste disposal fee. Each project must be evaluated independently based on the level of risk on the investment and whether there are contracts to ensure the estimated revenue streams.

Table 25: Internal rate of return for various waste disposal fee options

Waste Disposal Fee	Internal Rate of Return
$27	3.5%
$28	8.1%
$29	12.4%
$30	16.3%
$31	20.1%
$32	23.8%
$33	27.3%

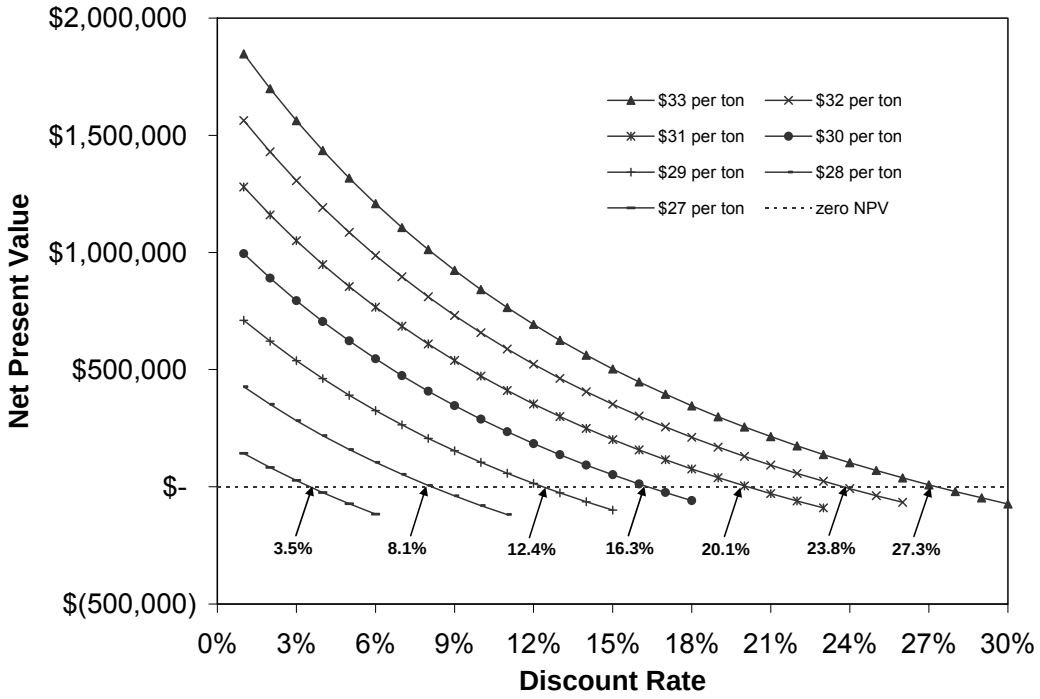


Figure 19: Full-scale system net present value for various discount rates

In a recent report prepared by UC Davis for CalRecycle (25), anaerobic digesters in operation in different regions worldwide were reviewed and the capital cost and operations cost were reported. The capital cost of a 30,000 ton per year facility, similar to a facility discussed here, was reported to be $8 million to $10 million with an operating cost of $36 to $140 per ton (25). Clearly this is much higher investment and capital cost than what has been presented in this report.

Conclusions and Recommendations

A digester cell was successfully constructed, monitored, and operated first anaerobically, for methane production, and then aerobically for compost production. A methane generation model was developed to characterize the kinetics and yield of methane produced over time. The decomposed solids were sampled and tested to further characterize the decomposition. During the aeration phase the digester cell and biofilter exhaust gases were sampled and tested to determine the destruction efficiency of VOCs, ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S)nitrous, oxide (N_2O), and carbon dioxide (CO) gas emissions, prior to venting to the atmosphere. Solids analyses were performed to determine the rate of decomposition of solids in the waste over time. An economics model was developed and optimized for various waste disposal fees and the internal rate of return was calculated. The following recommendations are made, based on the operation, monitoring and analysis of this demonstration project:

- Given the success of this pilot-scale project, additional pilot-scale projects should be studied to overcome the technical challenges of high moisture waste, such as food waste. The addition of food waste to a green waste digester can increase the total methane production three to four times per unit of dry food solids as compared with green waste only digester. The addition of food waste will also create other challenges that need further study. For example, food waste is very high in moisture content and is readily degradable so it must be handled different than green waste to educe air emissions. The waste filling phase of a food digester must be short compared to a green waste digester to avoid odors and undesirable emissions of valuable methane. Design and construction of a food waste digester must take these factors into account such as uniform distribution of moisture for better aeration and reduce development of hot spots.

- Gas tracer tests should be conducted to better understand the air flow pattern change as the material decomposes over time (6). This is an important issue since poor aeration could lead to high anaerobic activity within the cell and result in higher gas emission during the aerobic phase of operation. Such field studies were performed on a municipal solid waste anaerobic bioreactor landfill at the Yolo County Central Landfill. Field tests coupled with modeling are needed to improve gas well spacing design and moisture addition and recirculation techniques for such high solids anaerobic digesters, as described in this study.

- Currently there are some published data on emissions from composting operations (7-14). However, there are very few published data on forced aeration composting and the associated emissions. We recommend further study to better quantify the total emissions from the green waste aerobic composting phase as studied here to compare with the available data on typical windrow composting. Also, air emission testing should be conducted for a food waste digester during the aerobic phase since NMOC emissions from food waste (15) are more likely going to be higher than green waste because of known features of food waste decomposition by bacteria.

- The full-scale implementation of this project could benefit California as more organic waste is diverted from landfills where methane is often not well-controlled and remnants are unusable. The beneficial use of methane can increase diversion, produce renewable energy, and help increase organic content of soil for agriculture or horticulture use. Training is needed for operators and designers so that all aspects of the project are performed properly. The type of feedstock, cell design, waste filling, and operational issues are some of the major

key issues that should be addressed. Careful consideration to details of the project will prevent technical problems that could lead to operational and environmental problems.

Source Reference Notes

(1) CalRecycle In *Total Waste Generated, Diverted and Disposed. 2007*; http://www.calrecycle.ca.gov/lgcentral/GoalMeasure/PerCapDisp.htm, January 2010

(2) Yazdani, R. *Methane enhancement by accelerated anaerobic composting at the Yolo County Central Landfill*; Yolo County Public Works Department, Division of Integrated Waste Management: 1997.

(3) Yazdani, R.; Kieffer, J.; Akau, H.; Augenstein, D. *Monitoring the performance of anaerobic landfill cells with fluids recircuation* Yolo County Planning & Public Works Department, Division of Integrated Waste Management: October 2003.

(4) Yazdani, R.; Kieffer, J.; Sananikone, K.; Augenstein, D. *Full-Scale bioreactor landfill for carbon sequestration and greenhouse emission control* Yolo County Planning & Public Works, Division of Integrated Waste Management: March 2006.

(5) Yazdani, R.; Kieffer, K.; Akau, H. *Full-scale landfill bioreactor project at the Yolo County Central Landfill*; California Integrated Waste Management Board: April 2002.

(6) Han, B.; Imhoff, P. T.; Yazdani, R. Field Application of Partitioning Gas Tracer Test for Measuring Water in a Bioreactor Landfill. *Environ. Sci. Technol.* 2007, *41*, 277-283.

(7) Buyuksonmez, F.; Evans, J. Biogenic emissions from green waste and comparison to the emissions resulting from composting partII:volatile organic compounds (VOCS). *Compost Science & Utilization* 2007, *15*, 191-199.

(8) Chou, C. H.; Buyuksonmez, F. Biogenic emissions from green waste and comparison to the emissions resulting from composting (Part I:Ammonia). *Compost Science & Utilization* 2006, *14*, 16-22.

(9) CalRecycle. *Emissions testing of volatile organic compounds from greenwaste composting at the Modesto Compost Facility in the San Joaquin Valley*; San Diego State University Research Foundation: October 31, 2007 (Revised May 2008).

(10) Fukumoto, Y.; Rom, H. B. ; Dahl, P. E. Relationship between gas depth profiles in compost heap and gas emission. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development* May 2003.

(11) Hao, X.; Chang, C.; Larney, F. J.; Travis, G. R. Greenhouse gas emissions during cattle feedlot manure composting. *J. Environ. Qual.* 2001, *30*, 376-386.

(12) Hellebrand, H. J. Emission of nitrous oxide and other trace gases during composting of grass and green waste. *J. Agric. Engng Res.* 1998, *69*, 365-375.

(13) Haug, R. T. *Compost engineering, Principles and practice*; Ann Arbor Science Publishers: Michigan, 1980.

(14) Thompson, A. G.; Wagner-Riddle, C.; Fleming, R.; MacApline, M. In *2001 ASAE Annual International Meeting*; The Society of engineering in agricultural, food, and biological systems: Sacramento, California, 2001.

(15) Staley, B. F.; Xu, F.; Cowie, S. J.; Barlaz, M. A.; Hater, G. R. Release of trace organic compounds during the decomposition of municipal solid waste components. *Environ. Sci. Technol.* 2006, *40*, 5984-5991.

(16) Augenstein, D.; Yazdani, R. In *Yolo County Controlled Landfill Demonstration Project. Solid Waste Association of North America, Landfill Symposium* Sacramento, CA, 1997.

(17) US EPA *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide*: May 2005.

(18) US EPA *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide; May 2005*: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.

(19) Barlaz, M. A.; A. Bareither, C.; Hossain, A.; Saquing, J.; Messari, I.; Benson, C. H.; Tolaymat, T. M.; Yazdani, R. Performance of North American Bioreactor Landfills: II. Chemical and Biological Characteristics. **Expected to be released in March 2010**.
(20) Tchobanoglous, G.; Theisen, H. *Integrated Solid Waste Management, Engineering Principles and Management Issues*; McGrown-Hill, Inc.: New York, 1983.
(21) Maier, R. M.; Pepper, I. L.; Gerba. , C. P. *Environmental Microbiology*; Academic Press San Diego, 2000.
(22) Bohn, I.; Björnsson, L.; Mattiasson, B. The energy balance in farm scale anaerobic digestion of crop residues at 11-37 °C. *Process Biochemistry* 2007, *42*, 57-64.
(23) *Chicago Climate Exchange® Avoided Emissions from Organic Waste Disposal Offset Project Protocol*
www.theccx.com.: August 2009.
(24) *Carbon dioxide emissions from the generation of electric power in the United States*; Department of Energy Washington, D.C. 20585
Environmental Protection Agency Washington D.C. 20460: July 2000.
(25) Rapport, J.; Zhang, R.; Jenkins, B. M.; Williams, R. B. *Current anaerobic digestion technologies used for treatment of municipal organic solid waste*; California Environmental Protection Agency: California Integrated Waste Management Board (now CalRecycle): March 2008.

Appendix A: Leachate Dissolved Metals and Inorganic

Dissolved Metal or Inorganic parameter	Units	Sept 26 2007	Dec. 13 2007	Jan. 29 2008	March 52008	May 13 2008	June 13 2008	July 23 2008	Sept 23 2008	Nov. 13 2008	Dec 17 2008
Aluminum	mg/L	0.98	2.2	1.9	< 2.0	1.3	2.05	1.53	--	0.175	0.768
Barium	mg/L	--	0.069	0.075	< 0.30	0.049	0.082	0.233	0.312	0.0257	0.367
Beryllium	mg/L	--	< 0.0090	< 0.0090	< 0.045	< 0.0018	0.00227	< 0.000176	0.00109	0.000641	0.000498
Boron	mg/L	6.9	9.3	9.1	11	9.1	11.1	10.3	10	7.3	8.79
Calcium	mg/L	250	110	77	82	36	29.1	34	51.8	84.4	129
Chromium	mg/L	--	0.18	0.19	0.16	0.12	0.139	0.144	0.15	0.0113	0.0474
Iron	mg/L	2.7	5.8	4.6	4.7	5.4	5.96	7.33	15.3	9.66	4.65
Magnesium	mg/L	540	980	400	500	540	670	547	523	325	341
Manganese	mg/L	1.8	1.6	1.2	0.76	0.41	0.199	0.161	0.286	0.271	0.659
Potassium	mg/L	3900	5400	4400	5700	4700	6000	5080	5510	2320	2340
Sodium	mg/L	490	540	520	620	610	722	714	780	400	383
Tin	mg/L	--	0.81	0.53	0.75	0.1	< 0.0154	< 0.00309	< 0.00309	< 0.00309	< 0.00309
Vanadium	mg/L	--	0.046	0.05	< 0.15	0.03	0.0405	0.0347	0.0439	0.0215	0.0308
Zinc	mg/L	1.7	< 0.060	< 0.060	< 0.30	0.061	0.307	0.478	0.616	0.186	0.489
Total Kjeldahl Nitrogen (TKN)	mg/L	1100	2300	2400	2500	2400	2400	1100	2300	550	700
Alkalinity as CaCO3	mg/L	8100	13000	11000	14000	10000	12200	10800	10800	--	4150
Carbonate Alkalinity as CaCO3	mg/L	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.85	< 0.85	< 0.85	< 0.85	< 0.85
Ammonia (as N)	mg/L	990	1700	1900	2000	1500	2400	860	1500	420	26

Dissolved Metal or Inorganic parameter	Units	Sept 26 2007	Dec. 13 2007	Jan. 29 2008	March 52008	May 13 2008	June 13 2008	July 23 2008	Sept 23 2008	Nov. 13 2008	Dec 17 2008
Biochemical Oxygen Demand	mg/L	4300	460	2300	2100	1100	1300	150	1800	2000	360
Chemical Oxygen Demand	mg/L	14000	18000	17000	14000	8500	8100	12000	13000	3000	9600
Chloride	mg/L	--	3400	3400	3400	2500	3600	3300	4100	1800	1600
Nitrate (as N)	mg/L	< 3.0	4.8	< 6.0	< 3.0	< 3.0	< 0.28	< 0.55	< 0.28	< 0.28	0.95
Phosphorus, Total	mg/L	0.063	26	16	17	10	0.17	13	14	22	31
Sulfate	mg/L	51	40	25	< 4.0	180	22	51	7.3	2300	23
Sulfide, Total	mg/L	3.5	40	0.4	0.25	23	< 0.042	1.5	< 0.042	1.5	22
Total Dissolved Solids	mg/L	21000	77000	22000	25000	19000	19300	13900	17000	11400	9880
*pH	pH	--	8.11	8.08	8.05	8.32	8.46	8.18	7.91	8.37	7.68
Antimony	mg/L	--	< 0.010	--	--	--	--	--	0.00318	0.00209	0.00516
Arsenic	mg/L	--	0.18	--	--	--	--	--	0.245	0.121	0.152
Cadmium	mg/L	--	< 0.0055	--	--	--	--	--	0.00173	0.00161	0.00102
Cobalt	mg/L	--	0.051	--	--	--	--	--	0.0907	0.0598	0.0225
Copper	mg/L	0.14	0.048	--	--	--	--	--	0.0393	0.0998	0.0316
Lead	mg/L	--	0.011	--	--	--	--	0.00976	ND	< 0.00236	0.00822
Mercury	mg/L	--	< 0.00010	--	--	--	< 0.0000885	< 0.0000177	ND	< 0.000126 tr*	< 0.0000177
Nickel	mg/L	--	0.41	--	--	--	--	870	0.581	0.407	0.285
Selenium	mg/L	--	0.032	--	--	--	--	1100	0.00529	< 0.00295	< 0.00295
Silver	mg/L	--	< 0.010	--	--	--	--	1100	ND	< 0.000400	< 0.000400
Thallium	mg/L	--	< 0.0075	--	--	--	--	--	--	--	--

Dissolved Metal or Inorganic parameter	Units	Sept 26 2007	Dec. 13 2007	Jan. 29 2008	March 52008	May 13 2008	June 13 2008	July 23 2008	Sept 23 2008	Nov. 13 2008	Dec 17 2008
Total Organic Carbon		--	--	--	--	--	--	--	--	--	--
Hydroxide (as CaCO3)	mg/L	--	--	--	--	--	--	ND	--	--	--

Appendix B: Anaerobic Phase VOCs and Other Gas Emissions

Compound	Units	10/1/2007	11/8/2007	12/17/2007	12/17/2007	1/29/2008
Carbon disulfide	ppm-v	0.2	110	0	0	0
Carbonyl sulfide	ppm-v	0.53	170	210	0	120
Dimethyl disulfide	ppm-v	1.6	3400	390	0	470
Dimethyl sulfide	ppm-v	19	37000	3700	7600	2900
Hydrogen sulfide	ppm-v	0	86	690	0	0
Methyl mercaptan	ppm-v	0	0	380	0	0
Methane	ppm-c	300000	440000	470000	420000	460000
Total Non-Methane Hydrocarbons as Methane	ppm-c	8300	1600	1800	780	1500
Carbon dioxide	% (v/v)	44	49	49	53	47
Carbon monoxide	% (v/v)	0.0047	0	0	0	0
Hydrogen	% (v/v)	0.25	0.11	0.077	0	0.04
Methane	% (v/v)	30	44	47	42	46
Nitrogen	% (v/v)	27	7	6	6.7	8.4
Oxygen	% (v/v)	0.39	1.1	0	1.6	0
Acetone	ppm-v	87	33000	59000	20000	24000
Benzene	ppm-v	0.89	0	160	380	0
2-Butanone (MEK)	ppm-v	29	13000	22000	10000	6500
Chloroform	ppm-v	0.6	0	0	0	0
Dichlorodifluoromethane	ppm-v	14	0	0	0	0

Compound	Units	10/1/2007	11/8/2007	12/17/2007	12/17/2007	1/29/2008
1,1-Dichloroethane	ppm-v	0.68	0	0	0	0
1,1-Dichloroethene	ppm-v	2.9	0	0	0	0
Ethylbenzene	ppm-v	1.2	0	190	0	180
2-Hexanone	ppm-v	0	0	460	0	0
Methylene chloride	ppm-v	6.8	0	0	0	0
4-Methyl-2-pentanone (MIBK)	ppm-v	0	0	750	260	610
Tetrachloroethene	ppm-v	0.76	0	0	0	0
Toluene	ppm-v	7.7	460	550	370	540
Trichloroethene	ppm-v	2.2	0	0	0	0
Trichlorofluoromethane	ppm-v	0.54	0	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	ppm-v	11	0	0	0	0
Xylenes (total)	ppm-v	1.3	0	390	0	370

Appendix C: Aerobic Phase VOCs and Other Gas Emissions

Compound Name	units	10/2/2008 [a]		10/27/2008			11/14/2008			12/17/2008		
		Inlet [b]	BF1	Inlet	BF1	BF2	Inlet	BF1	BF2	Inlet	BF1	BF2
Aromatics												
4-Ethyltoluene	ppb (v/v)	7.7 ***	0.58 ***	1.8	0.145 *	0.16 *	0.68 ***	0.14 *	0.16 *	0.13 *	0.135 *	0.155 *
1,3,5-Trimethylbenzene	ppb (v/v)	10 ***	0.44 ***	6.9	0.63 ***	0.145 *	1.3	0.13 *	0.145 *	0.44 ***	0.125 *	0.14 *
1,2,4-Trimethylbenzene	ppb (v/v)	32	0.91 ***	12	0.86 ***	0.285 *	5	0.25 *	0.28 *	1.1 ***	0.245 *	0.275 *
Styrene	ppb (v/v)	27	0.15 *	27	0.52 ***	0.57 ***	22	0.14 *	0.45	3	0.135 *	0.15 *
1,4-Dichlorobenzene	ppb (v/v)	42	3.6	24	8.6	5.5	1.6	1.1	3.4	0.41 ***	0.1 *	0.115 *
Benzene	ppb (v/v)	33	8	40	4.1	4.2	19	4.5	5.5	7.9	1	3.7
Ethylbenzene	ppb (v/v)	120	8.1	58	12	2.5	11	0.88	1	4.1	0.085 *	0.43 ***
Xylenes (total)	ppb (v/v)	180	11	86	14	5.4	19	2.3	2.8	8.2	0.55 *	0.65 *
Toluene	ppb (v/v)	470	17	110	5.3	7.4	29	2	4.5	7.8	0.09 *	1.5
Ketones												
2-Hexanone	ppb (v/v)	23	0.44 *	28	0.41 *	0.45 *	17	0.4 *	0.45 *	3.4	0.385 *	0.435 *
4-Methyl-2-Pentanone	ppb (v/v)	1.6 *	0.13 *	52	0.12 *	0.83 ***	34	0.115 *	3.4	5.6	0.115 *	0.39 ***
2-Butanone	ppb (v/v)	5900	4.7	3100	4.3	52	790	13	72	260	1.4 ***	25
Acetone	ppb (v/v)	13,000	34	18,000	23	280	7,300	54	460	2,400	13.00	180.00
Chlorinated Compounds												
c-1,2-Dichloroethene	ppb (v/v)	1.4 *	0.115 *	1.8	0.105	0.67	0.105	0.10	0.115	0.095	0.115	0.11
Chlorobenzene	ppb (v/v)	1.15 *	0.09 *	2.6	0.085 *	0.095 *	0.085 *	0.085 *	0.095 *	0.08 *	0.08 *	0.09 *
Chloroform	ppb (v/v)	0.95 *	0.075 *	1.4	0.08 *	0.9	0.07 *	0.32	0.54	0.065 *	0.065 *	0.075 *
Trichloroethene	ppb (v/v)	1.15 *	0.92	1.3	1.1	1.1	0.085 *	0.08 *	0.09 *	0.075 *	0.08 *	0.09 *
Dichlorodifluoromethane	ppb (v/v)	42.76 **	7.4	0.13 *	0.115 *	7.76 **	0.78 ***	0.11 *	0.44 ***	2.3	2.4	3.1

Compound Name	units	10/2/2008 [a]		10/27/2008			11/14/2008			12/17/2008		
		Inlet [b]	BF1	Inlet	BF1	BF2	Inlet	BF1	BF2	Inlet	BF1	BF2
Tetrachloroethene	ppb (v/v)	200	1.8	1.6	1.4	1.3	0.085 *	0.085 *	0.095 *	0.37 ***	0.085 *	0.095 *
Chloromethane	ppb (v/v)	26.78 **	1.1	10.78 **	0.08 *	3.18 **	38	1.8	8.4	28	2.9	13
Sulfides												
Carbonyl Sulfide	ppb (v/v)	11.7 *	0.95 *	12.2 *	12.3	13.7	10.7 *	0.8 *	0.95 *	10 *	10.3 *	13.8 *
Carbon Disulfide	ppb (v/v)	150	1.9	19	3.3	14	28	15	12	4.4	1.1	2.5
Dimethyl Sulfide	ppb (v/v)	286.2	0.95 *	310.6	0.9 *	0.85 *	67.8	0.8 *	0.95 *	10 *	10.3 *	13.8 *
Dimethyl Disulfide	ppb (v/v)	398	0.95 *	1766.5	0.9 *	0.85 *	253.7	0.8 *	0.95 *	10 *	10.3 *	13.8 *
Other												
Vinyl Acetate	ppb (v/v)	4.8 *	0.385 *	160	0.36 *	0.395 *	72	0.35 *	0.395 *	19	0.34 *	0.38 *
TGNMO	ppm (v/v)	500	6.6	210	10	10	86	26	30	23.0	22	20
Methane	ppm (v/v)	15,669	5	17,222	7,475	14,629	2,946	1,302	2,377	2,383	1,356	2,542
Carbon Dioxide	ppm (v/v)	70,158	11,328	57,908	72,702	68,702	27,111	28,149	27,317	15,361	16,120	20,765
Oxygen	ppm (v/v)	152,959	193,659	161,178	144,567	164,099	211,770	208,656	203,554	203,098	196,806	233,788
Nitrogen	ppm (v/v)	785,112	816,916	810,562	596,065	624,178	726,169	729,135	708,762	821,219	729,582	755,987

a. On this sampling date, all digester exhaust gas was injected into Biofilter 1, so no gas samples were taken for Biofilter 2.

b."Inlet" refers to unfiltered gas from the digester cell; "BF1" and "BF2" refer to Biofilters 1 and 2, respectively.

* indicates that the number shown is 1/2 the Method Detection Limit (MDL) since the lab result recorded was "<MDL"

** indicates that the number shown is the lab result minus the method blank result since the compound was also detected in the method blank. According to the lab, beginning in July 2003, only compounds detected in an amount less than 5 times of the amount detected in the method blank are flagged.

*** indicates that the lab result shown was below the practical quantification limit but above the Method Detection Limit so an estimated result is provided.

Appendix D: 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.

Table 1. 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

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.
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.

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

There are two cultures that need to be maintained: one with solids and one without solids. Both cultures are grown in 125 mL serum bottles containing sulfide-reduced consortia maintenance medium. Each culture is maintained in triplicate. These cultures are only used to maintain the inoculum and are transferred on a regular basis: the culture with solids, every two weeks and the culture without solids, once a month. BMPs are inoculated using the culture with solids. The inoculum for BMP tests should be prepared two weeks prior to the initiation of a BMP test.

Inoculum Preparation for Culture with Solids

1. Cultures for transfer should be at least two weeks old.

2. Remove the overpressure from the culture by inserting a 60 mL plastic syringe into each serum bottle. Vent the gas removed from each bottle into the 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 decrimping 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 2) 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 2) in the order listed to a 2L round bottom flask, while stirring constantly.

Table 2. 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

Component	per liter
Distilled water	768 mL

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.

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.
   Cap the bottle with a rubber butyl stopper and an aluminum crimp. Cysteine is located in the cabinet area with other BMP materials.
6. 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, we have used 0.5 gm for refuse samples that are 2-5 years old and 1 gm for samples known to be well decomposed.

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.

Appendix E: Cellulose, Hemicellulose and Lignin Content-Testing Protocol

Cellulose Hydrolysis Methodology

The complete analysis of cellulose and hemicellulose involves three distinct steps: hydrolysis, sample cleanup, and HPLC analysis. Conceptually, 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 amperometric detector.

The values obtained by HPLC analysis must be corrected to account for the fact that sugars were originally in polysaccharide chains, and therefore each resulting sugar molecule is, on average, 18 mass units heavier (one H_2O molecule added for every sugar molecule in the polymer).

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. The procedure begins with samples that have been ground in a wiley mill to pass a 1mm screen. If the dryness of a ground refuse sample is suspect, then re-dry it for one day in a 65°C oven. To re-dry ground refuse samples in Mason jars, do the following: Remove the jar lid and cover the mouth of the jar with aluminum foil. Replace the threaded outer ring. Using a disposable 18-gauge needle, punch lots of holes in the aluminum foil. Put the jar into a 65°C oven for at least one day. When the refuse is dry, remove the jar from the oven. Work quickly, as the dried refuse will immediately begin to absorb moisture from the air. Unscrew the threaded outer ring and replace the aluminum foil with the metal lid. Replace the threaded outer ring, screwing it down tightly.

2. Prepare Gooch crucibles and filters by inserting a glass fiber filter (Whatman 934AH) into a crucible. Rinse the crucible with deionized water and place the crucible and filter in the furnace at 550°C for one hour. Allow crucibles to cool in a desiccator. After cooling, store the crucibles in a place where they will be protected from dust and dirt. A clean box with a secure lid, or a tray lined with paper towels and covered with aluminum foil, is ideal for this purpose. NOTE: Once crucibles have been cleaned using this process, do NOT handle them with your fingers; use tongs or a clean gloved hand only.

3. Place approximately 1 gram of sample in a Gooch crucible with the fiber filter and wash with 150 ml of a 2:1 mixture of toluene and 95 percent ethanol. Use a filter flask, with a vacuum aspirator to provide suction. This step must be performed in a fume hood and the toluene/ethanol collected and disposed of as hazardous waste.

4. Dry the refuse in the crucible at 75°C for at least 12 hours and then allow to cool two hours in a desiccator. Carefully stir the refuse approximately six hours into the drying time.

5. Remove about 0.3 gram of washed refuse from the crucible and place it in a screw-cap test tube. Record the weight of refuse removed to 4 decimal places. When weighing, work quickly and with one crucible at a time because the dried solids will immediately begin to absorb moisture from the air upon removal from the desiccator.

6. Add 3 ml of 72 percent (w/w) sulfuric acid to the sample. Using a long glass stirring rod, carefully mix the refuse and acid, trying to avoid splashing the slurry onto the walls of the tube (the objective is to have the solids in the acid and *not* clinging to the sides of the test tube). After mixing, leave the stirring rod in the test tube. Then place it in a shaking water bath at 30°C for 1 hour, agitating gently.

7. Use a graduated cylinder to measure 63ml of high purity water and pour into each test tube.

8. Prepare a fucose solution to serve as an internal standard. Weigh 1g of fucose and dilute to volume with deionized water in a 25ml volumetric flask. Record the weight to 4 decimal places. Using a calibrated automatic pipettor add 1.0 ml of the fucose solution into the tube. NOTE: Immediately proceed to the next step. Do not allow the fucose to remain in contact with the strong acid longer than necessary; otherwise the fucose recovery may be abnormally low. Analyze the fucose stock solution diluted 1/20 as a check.

9. Use a graduated cylinder to measure 20 ml of high purity water. Attach a 20 gauge disposable needle to a 20 ml syringe and draw up the 20 mL of water. Use the glass rod to thoroughly stir the mixture. Lift up the stirring rod and use about half of the water in the syringe to rinse the solids off the rod and back into the test tube. Touch the glass rod to a clean part of the test tube's inner wall to allow the excess water to drain off. While rotating the test tube, use the syringe's remaining water to rinse down the walls of the test tube. Seal the test tube with a #6 silicone stopper (Thomas Scientific P/N 8747-E65). Secure the stopper with an appropriate screw cap. Tighten it firmly but avoid overtightening.

10. Place the test tube in an autoclavable tray and autoclave for 60 minutes at 121°C and 15 psi. After the autoclave cycle is complete, do not leave the samples in the autoclave; remove samples as soon as the autoclave indicates that it is okay to remove them (but no sooner). The autoclave remains hot even when not in use, and leaving the samples in it longer than necessary causes some wood sugar destruction. Place the rack in an undisturbed place and allow the tubes to cool.

11. Filter the sample through a glass fiber filter in a Gooch crucible (as prepared in step 2). Use a filter flask, with a vacuum aspirator to provide suction. Transfer the filtrate to a plastic bottle and store it in the refrigerator. Wash the rest of the solids out of the test tube and into the crucible with a squirt bottle of deionized water while the tube is inverted over the crucible. Continue rinsing until at least 200 ml of wash water has been collected in the filter flask. Note that the water rinse serves two purposes— it facilitates transfer of the solids from the test tube to the crucible, and it washes the solids (getting rid of the sulfuric acid that would interfere with the lignin analysis).

12. Dry the remaining solids in the crucible at 75°C for at least 24 hours, then allow two hours to cool in a desiccator. Then, weigh the crucible and dried solids to 4 decimal places. When weighing, work quickly and with one crucible at a time because the dried solids will immediately begin to absorb moisture from the air upon removal from the desiccator.

13. Place the Gooch crucible containing the solids in a 105°C furnace. Increase the furnace temperature to 550°C. Allow the furnace to remain at 550°C for two hours, then reduce the

temperature to 105°C. After the oven cools to 105°C, remove the Gooch crucible and allow two hours to cool in a desiccator.

14. Weigh the crucible again. When weighing, work quickly and with one crucible at a time because the dried solids will immediately begin to absorb moisture from the air upon removal from the desiccator. The weight loss on ignition represents lignin.

Hydrolyzate Clean-Up Procedure:

1. Remove the hydrolysis sample from the refrigerator and allow it to equilibrate to room temperature. Shake the bottle gently to help ensure a homogeneous mixture. Avoid vigorous shaking, as this will tend to produce foam. NOTE: If the sample was frozen it is absolutely essential that it be shaken *very* well after thawing. Failure to do so will result in the sugars being concentrated at the bottom of the bottle, resulting in an abnormally low fucose recovery.
2. 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.
3. 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
4. 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.
5. 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.
6. 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.
7. 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.
8. 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.
9. Store leftover, undiluted hydrolyzate in the freezer. Dump unused, diluted hydrolyzate into the waste bottle.

Phosphate Solution

Component	per liter
KH_2PO_4	16.1 g
$Na_2HPO_4•7H_2O$	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.

M3 Solution

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

Store solution at 4°C.

Trace Mineral Solution

Component	1 liter
Nitrilotriacetic Acid	1.5 g
$FeSO_4•7H_2O$	0.1 g
$MnCl_2•4H_2O$	0.1 g
$CoCl_2•6H_2O$	0.17 g
$CaCl_2•2H_2O$	0.1 g
$ZnCl_2$	0.1 g
$CuCl_2•2H_2O$	0.02 g
H_3BO_3	0.01 g
Na $MoO_4•2H_2O$	0.01 g
NaCl	1.0 g
Na_2SeO_3	0.017 g
$NiSO_4•6H_2O$	0.026 g
$Na_2WO_4•2H_2O$	0.033 g

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 $Na_2WO_4•2H_2O$.

Reference:

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

Vitamin Solution

Vitamin	g per liter
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
Distilled Water	1000 mL

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 F: Acid Washing Refuse- For Total Carbon Analysis

North Carolina State University

Department of Civil, Construction, and Environmental Engineering

1. General Discussion

   1.1. Summary of Method:

   1.2. Interferences:

   1.3. Safety: Caution should be used when handling hydrochloric acid. All spills should be cleaned up immediately with water.

2. Sampling and Storage
   2.1. Ground refuse should be dried at 75ºC and stored in sealed pint mason jars. Samples should be redried if they have been exposed to the atmosphere for extended periods of time.
   2.2. The acid washing is done in 20 mL glass scintillation vials and capped after drying to prevent moisture absorption.

3. Apparatus and equipment
   3.1. 20 mL glass scintillation vials.
   3.2. Automatic pipettor with tips capable of delivering 5 mLs accurately and reproducibly.
   3.3. Analytical balance capable of weighing 0.1 mg.
   3.4. Desiccators.
   3.5. Forced air oven capable of heating to 60ºC.

4. Reagents
   4.1. 1N hydrochloric acid. Carefully add 83 mLs of concentrated hydrochloric acid to a 1L volumetric flask containing approximately 500 mLs DI water. Dilute to volume and store in a 1L glass bottle.

5. Quality control (QC).
   5.1. All samples are prepared in duplicate.
   5.2. Pipettor calibration should be checked with DI water by weighing 5 mLs of DI water. Adjust the pipettor setting until 5 mLs of DI weighs 5.0000 gms.
   5.3. Check balance calibration before using and calibrate per the specific balance instructions if necessary.

6. Procedure

6.1. Label vials and caps with lab sample numbers being sure to do all samples in duplicate.
6.2. Remove caps and place caps and vials in 60ºC oven overnight.
6.3. Remove caps and vials from oven and cap the vials.
6.4. Store vials in a desiccator until ready for use.
6.5. Remove one vial from the desiccator at a time.
6.6. Make sure balance is zeroed before starting and between each sample.
6.7. Remove the cap and place the cap and vial on the balance pan and record the total weight in a notebook.
6.8. Remove lid from the sample jar and using a spatula slowing mix the sample. Mixing too fast may generate a lot of dust.
6.9. Weigh ~1 gm (± 0.05 gms) of sample into the vial and record the weight.
6.10. Recap the vial and set aside.
6.11. After all samples have been weighed, remove caps from all vials and set the caps aside on a tray.
6.12. Slowly withdraw 5 mLs of 1N HCl into the pipet tip.
6.13. Expel HCl slowly around the inside of the vial to wash the entire sample into the bottom of the vial.
6.14. Swirl vial slowly to make sure all solids are wetted.
6.15. Watch for bubbling or effervescing.
6.16. If no bubbling is observed then set the sample aside.
6.17. Add a second 5 mLs of HCl if bubbling is observed.
6.18. Swirl the sample and set aside.
6.19. Be sure to record the amount of acid added to each sample.
6.20. Repeat the HCl addition until all samples are completed.
6.21. Separate the samples that only required 5 mLs of acid as there will be no more additional HCl added.
6.22. Put the vials and the unattached caps into a 60ºC forced air oven and dry to constant weight. This can take several days.
6.23. Remove the vials and caps from the oven and cap the vials.
6.24. Place the vials into a desiccator until they reach room temperature.
6.25. The samples that did not bubble can be weighed, with the caps on, and set aside for taking to Soil Science for total carbon analysis.
6.26. Add an additional 5 mLs of HCl to the samples that bubbled during the first addition.
6.27. Add 5 more mLs if sample bubbles again.
6.28. The samples that bubble the second time will have to be dried, weighed, and additional 5 mL amounts of HCL added until no bubbling occurs.
6.29. Once all samples are complete and dry, they are sent to Soil Science for total carbon analysis.
6.30. The sample will need to be mixed thoroughly before sending to Soil Science so they can obtain a representative sample. This will require scraping the sides and bottom of the vials using a metal spatula or some other hard sharp object. This may be difficult to do but must be done. Breaking up all particles into their smallest size will also improve their ability to obtain a representative sample.
6.31. The precise weight of sample sent to Soil Science must be recorded as this weight will reflect losses of inorganic carbon as well as the mass of Cl ions added. The percentC reported by Soil Science should be corrected back to the original sample weight.

7. Change History
7.1. 04/16/08 Added the procedure for scraping the sides and bottom and reducing particle size to help in obtaining a representative sample.

Appendix G: VFA Headspace Analysis-Testing Protocol

North Carolina State University

Department of Civil, Construction, and Environmental Engineering

VFA samples were initially preserved by freezing. After thawing, samples were filtered with a Whatman glass microfiber GF/B syringe filter (1.0µm, Whatman) and Fisher Nylon syringe filters (0.45µm, Fisher Scientific). Samples were treated with a Dionex On-Guard H cartridge. 5 mL of the solution were then added to clear 22 mL crimp top headspace vials (Tekmar, USA) with 2 grams of sodium chloride.

500 µL of 34 percent of phosphoric acid (V/V) were added into each vial and sealed vials (PTFE/silicone septa) were allowed to sit overnight and then put on a shake table at 130 rpm for an hour, all room temperature. Samples were then analyzed Teledyne Tekmar 7000 headspace autosampler and HP 5890 Gas Chromatograph equipped with a flame ionization detector and a DB-FFAP (30m X 0.45 mm X 0.85µm, Agilent, USA) column. Sample vials were equilibrated at 65ºC for 10 minutes and were mixed for five minutes. Sample vials were then stabilized for five minutes. The sample loop and transfer line temperatures were 105ºC. The temperature of injector and detector were 250ºC and 250 ºC, respectively. The initial temperature of the oven, 50ºC, was held for 30 seconds. The temperature was then increased to 100ºC at 20ºC per minute. After holding at 100ºC for five minutes, the temperature was increased to 156ºC at 8ºC per minute increment. The oven was held at temperature 156ºC for three minutes. The oven temperature was raised to 240ºC at 60 oC per minute and held for five minutes. Carrier gas was Helium.

Step-by-Step Analysis of VFA in solutions

1. Thaw the frozen samples at room temperature.
2. Homogenize samples by mixing with Vortex mixer for 10-15 seconds.
3. After 30 minutes to one-hour settlement, filter the solution with Whatman glass microfiber GF/B syringe filter (1.0µm, Whatman) and Fisher Nylon syringe filters (0.45µm, Fisher Scientific).
4. Dionex On-Guard H cartridge cleanup.
5. Condition the Dionex On-Guard H cartridge with 10 ml of DI water.
6. Use a 10 ml syringe and apply the filtered solution to the On-Guard cartridge.
7. Push the plunger so that the solutions go through the on-guard cartridge slowly.
8. Discard the first 3ml solution and collected the remaining solution.

9. Transfer 3 mL of the solution to clear 22 mL crimp top headspace vials (Tekmar, USA) with 2 grams of sodium chloride.

10. Add 500 µL of 34 percent of phosphoric acid (V/V) into each vial.

11. Cap the vials tightly with PTFE/silicone septa and crimp seal aluminum.

12. All the vials with samples and standard solutions were sitting overnight and shaking at a shake table at 130 rpm for an hour, both at room temperature.

13. Teledyne Tekmar 7000 headspace autosampler and HP 5890 Gas Chromatography –Flame Ionization Detector was used for VFA analysis. Sample vials were equilibrated in the Platen at 65^{o}C for 10 minutes and were mixed for five minutes at mixing power 7. Sample vials were then stabilized for five minutes. Other conditions : press time, 15 seconds; press equilibrated time , six seconds; loop time, six seconds; loop equilibration, six seconds and inject time, one minute. The sample loop and transfer line temperatures were 105 ^{o}C. Column DB-FFAP (30m X 0.45 mm X 0.85µm, Agilent, USA) was used to separate the VFAs. The temperature of injector and detector were 250 ^{o}C and 250 ^{o}C, respectively. The initial temperature of the oven, 50 ^{o}C, was held for 30 seconds. The temperature was then increased to 100 ^{o}C at 20 ^{o}C per minute. After holding at 100 ^{o}C for five minutes, the temperature was increased to 156 ^{o}C at 8 ^{o}C per minute increment. The oven was held at temperature 156 ^{o}C for three minutes. The oven temperature was raised to 240 ^{o}C at 60 ^{o}C per minute and held for five minutes. Carrier gas was Helium.

Materials

Of the 10 volatile fatty acids (VFAs), Acetic acid (ACS grade), 2-methylbutyric acid (98 percent) were purchased from Sigma (USA), while propionic acid (99 percent), iso-butyric acid (99+ percent), n-butyric acid (99 percent), iso-valeric acid (99 percent), Valeirc acid (99 percent), iso-caproic acid (99 percent), n-caproic acid (99+ percent), and Heptanoic acid (98 percent) were purchased from Acros Organics (N.J.). All of these chemicals were used without further purification. Stock standard solution of VFAs were made by transferring pure chemical to volumetric flask and then filled with de-ionized water to mark. The stock standard solutions of VFAs were frozen in freezer at -20 ^{o}C. VFA standard solutions were made by diluting stock standard solution with DI water.

Quality control: Two quality control solutions (one high QC and one low QC) were run about every 15 samples. The recoveries of VFAs were between 90 percent and 110 percent.

Appendix H: Aerobic Respirometry Testing Protocol

University of California at Davis

Sample Preparation:

Samples are delivered in sealed freezer bags and stored at -20 C until analysis. The evening before initiating respirometry analyses, samples are wetted with sterile distilled water to a moisture content of 60 percent wet basis and placed at 4ºC overnight to allow water and biomass equilibration.

Respirometry Analyses:

Approximately 10 dry grams (dry weight) of samples are placed into 250-ml reactors for microbial activity studies (May and VanderGheynst, 2001). Reactors are aerated continuously with humidified air at approximately 20 ml min-1 to avoid oxygen limitations. Aeration rate is monitored continuously using a mass flow meter. Samples are then incubated for eight days at 35ºC.

Oxygen concentration is measured on the influent and effluent air of the reactors using Zirconia oxide oxygen sensors (Neuwghent Technologies, LaGrangeville, N.Y.) and carbon dioxide concentration is measured using an infrared CO2 sensor (Vaisala, Suffolk, United Kingdom). Oxygen and carbon dioxide data and air flow rate is recorded every five hours using a data acquisition system (VanderGheynst et al., 2002). Carbon dioxide evolution (CER) and oxygen uptake rates (OUR) are calculated from mass balances on each reactor according to the following equations:

$$CER = F(CO_{2out} - CO_{2\,in}) \quad (1)$$

$$OUR = F(O_{2out} - O_{2in}) \quad (2)$$

where F is the air flow rate (mg air day^{-1} gdw^{-1}), $CO_{2,OUT}$ and $CO_{2,IN}$ are the concentrations of carbon dioxide in the effluent and influent air, respectively (mg CO2 mg air^{-1}), and $O_{2,IN}$ and $O_{2,OUT}$ are the concentrations of oxygen in the influent and effluent air, respectively (mg O_2 mg air^{-1}).

Data Analysis:

Logged data are imported into Excel and CER and OUR are calculated using equations (1) and (2), respectively. Numerical integration of CER and OUR results are performed using KaleidaGraph v. 4.0 (Synergy Software, Reading, Penn.). All results are plotted using KaleidaGraph.

References

MAY, B.A. and J.S. VANDERGHEYNST (2001). A predictor variable for efficacy of Lagenidium giganteum produced in solid-state cultivation. *J Ind Microbiol Biot* **27**(4): 203-207.

VANDERGHEYNST, J.S., T. M. DOOLEY, M. N. MARSHALL (2002). The influence of process management and microbial community structure on the cultivation of a biological control

agent in compost. *Proceedings of the 2002 International Symposium on Composting and Compost Utilization*. J. F.C. Michel, H.A.J. Hoitink and R. Rynk. Emmaus, PA, JG Press.

Appendix I: Comparisons With Other Composts in North America

Parameter	Units	Yolo County Green Waste Digester (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
Total Nitrogen	(%)	1.1 - 1.5	1.6 ± 0.0
Ammonia (NH4-N)	(mg/kg)	250 - 1300	902.1 ± 25.5
Nitrate (NO3-N)	(mg/kg)	0.11 - 110	311.7 ± 12.8
Org. Nitrogen (Org-N)	(%)	1.1 - 1.5	±
Phosphorus (P2O5)	(%)	0.44 - 0.57	1.3 ± 0.0
Phosphorus (P)	(mg/kg)	1900 - 2500	5930.8 ± 100.0
Potassium (K2O)	(%)	0.86 - 1.3	1.1 ± 0.0
Potassium (K)	(mg/kg)	7100 - 10000	0.9 ± 0.0
Calcium (Ca)	(%)	1.3 - 6.5	3.6 ± 0.0
Magnesium (Mg)	(%)	0.7 - 0.92	0.6 ± 0.0
Sulfate (SO4-S)	(mg/kg)	220 - 630	3999.3 ± 95.5
Boron (total B)	(mg/kg)	25 - 43	48.7 ± 1.4
Moisture	(%)	47 - 55	38.1 ± 0.2
Sodium (Na)	(%)	0.068 - 0.1	0.2 ± 0.0
Chloride (Cl)	(%)	0.24 - 0.4	2446.2 ± 46.6
pH value	(unit)	7.49 - 8.29	7.6 ± 0.0
Bulk Density (Dry wt)	(lb/cu ft)	21 - 22	26.0 ± 0.2
Carbonates (CaCO3)	(lb/ton)	23 - 200	54.1 ± 1.9
Conductivity (EC5)	(mmhos/cm)	3.2 - 6	6.4 ± 0.1
Organic matter	(%)	39.9 - 45.6	46.3 ± 0.3
Organic Carbon	(%)	17 - 22	24.3 ± 0.2
Ash	(%)	54.4 - 60.1	53.7 ± 0.3
C/N Ratio	(ratio)	13 - 15	16.5 ± 0.1
Ag Index	(ratio)	6 - 8	±
Aluminum (Al)	(mg/kg)	8600 - 13000	8121.6 ± 115.2
Arsenic (As)	(mg/kg)	4.2 - 6.2	7.3 ± 1.5
Cadmium (Cd)	(mg/kg)	1.7 - 2	2.4 ± 0.1
Chromium (Cr)	(mg/kg)	27 - 49	29.8 ± 6.8

Parameter	Units	Yolo County Green Waste Digester (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
Cobalt (Co)	(mg/kg)	6.8 - 8.8	4.7 ± 0.1
Copper (Cu)	(mg/kg)	34 - 69	123.8 ± 3.8
Iron (Fe)	(mg/kg)	15000 - 18000	13888.9 ± 227.0
Lead (Pb)	(mg/kg)	45 - 200	35.7 ± 1.2
Manganese (Mn)	(mg/kg)	290 - 440	412.1 ± 9.6
Mercury (Hg)	(mg/kg)	all < 1.0	±
Molybdenum (Mo)	(mg/kg)	1.2 - 2.2	4.3 ± 0.1
Nickel (Ni)	(mg/kg)	38 - 95	17.2 ± 0.5
Selenium (Se)	(mg/kg)	all < 1.0	2.1 ± 0.1
Zinc (Zn)	(mg/kg)	130 - 170	262.4 ± 4.8
Total Respirometry -- Organic Matter basis	(mg CO2-C/g OM/day)	1.1 - 2	3.2 ± 0.1
Total Respirometry -- Total Solids basis	(mg CO2-C/g TS/day)	0.46 - 0.81	NA
Respirometry: (based on Biologically available Carbon) -- Organic Matter basis	(mg CO2-C/g OM/day)	1.6 - 2.3	14.1 ± 0.9
Respirometry: (based on Biologically available Carbon) -- Total Solids basis	(mg CO2-C/g TS/day)	0.69 - 0.95	NA
Stability rating		all Very Stable	±
Emergence	(%)	all 100	83.3 ± 0.6
Seedling vigor	(%)	all 100	83.9 ± 0.7
Description of plants		all Healthy	0.0 ± 0.0
Fecal Coliform	(MPN/g)	>1500 - 1800 [c]	314.6 ± 16.2
Rating		all Fail (see note above) [c]	
Salmonella	(MPN/4g)	all < 3	< 3 ± 0.0
Rating		all Pass	±
Plastic	(% by weight)	all < 0.5	0.2 ± 0.1
Glass	(% by weight)	all < 0.5	0.1 ± 0.0
Metal	(% by weight)	Four samples < 0.5 One sample 0.55	0.0 ± 0.0
Sharps	(% by weight)	all Non Detected	0.0 ± 0.0
Size Distribution (by weight)			

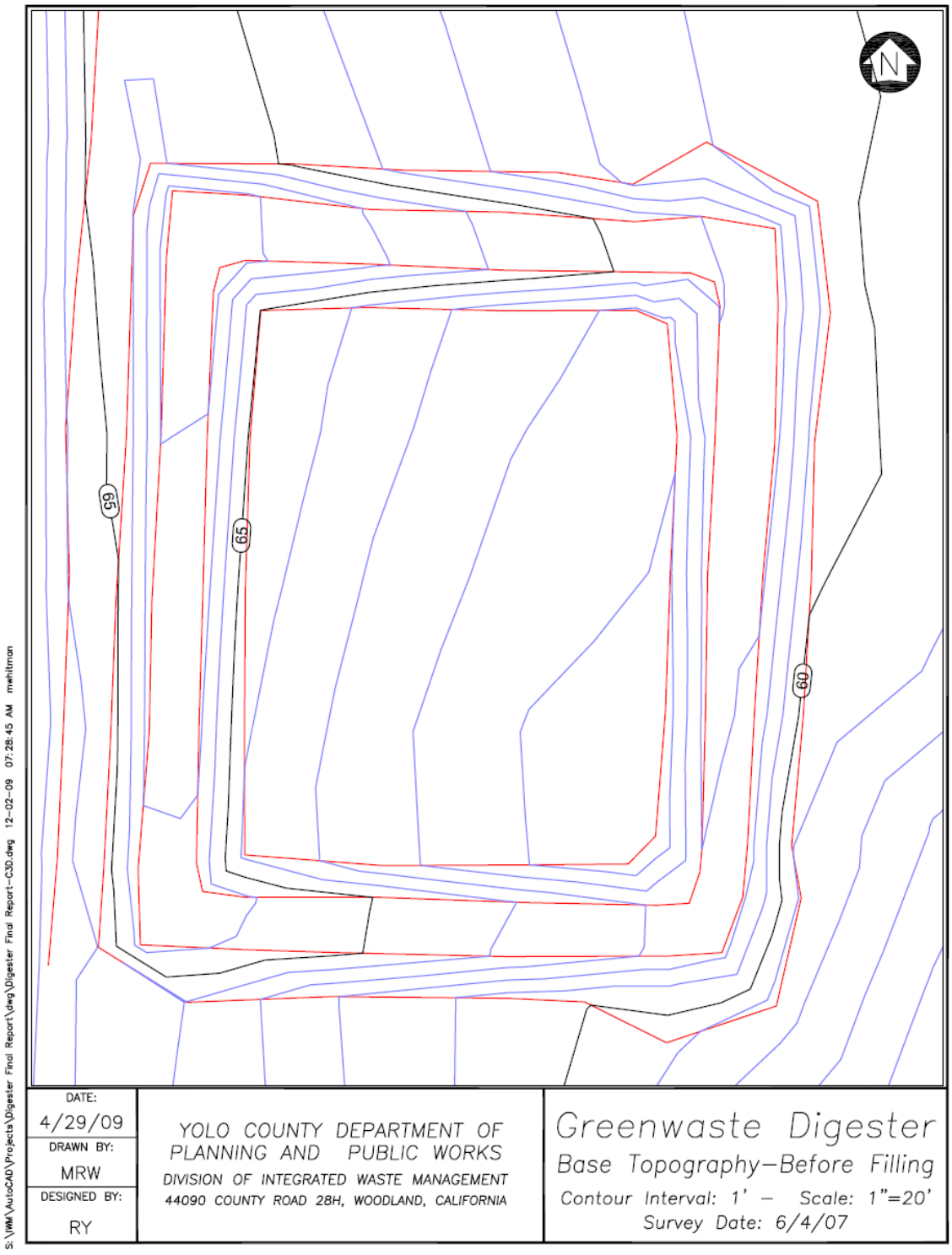
Parameter	Units	Yolo County Green Waste Digester (range of values for compost samples) [a]	Other North American Composts (Average ± Standard Error) [b]
<2.0 mm	(% by weight)	53.5 - 61.3	59.8 ± 0.3
2.0-4.0 mm	(% by weight)	14.5 - 22.6	18.6 ± 0.1
4.0-6.3 mm	(% by weight)	6.9 - 10.7	10.1 ± 0.1
6.3-9.5 mm	(% by weight)	2.9 - 5.6	7.3 ± 0.1
9.5-16 mm	(% by weight)	4.1 - 6.2	3.2 ± 0.1
16 to 25 mm	(% by weight)	0 - 11.7	0.7 ± 0.1
25-50 mm	(% by weight)	0 - 9.9	0.1 ± 0.0
>50 mm	(% by weight)	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).

c. After another 84 days of curing, the windrow whose sample had 1800 MPN/g for fecal coliform (the worst result of all samples), was sampled again, and fecal coliform had reduced to < 2.0, a passing rating.

Appendix J: Topographic Survey



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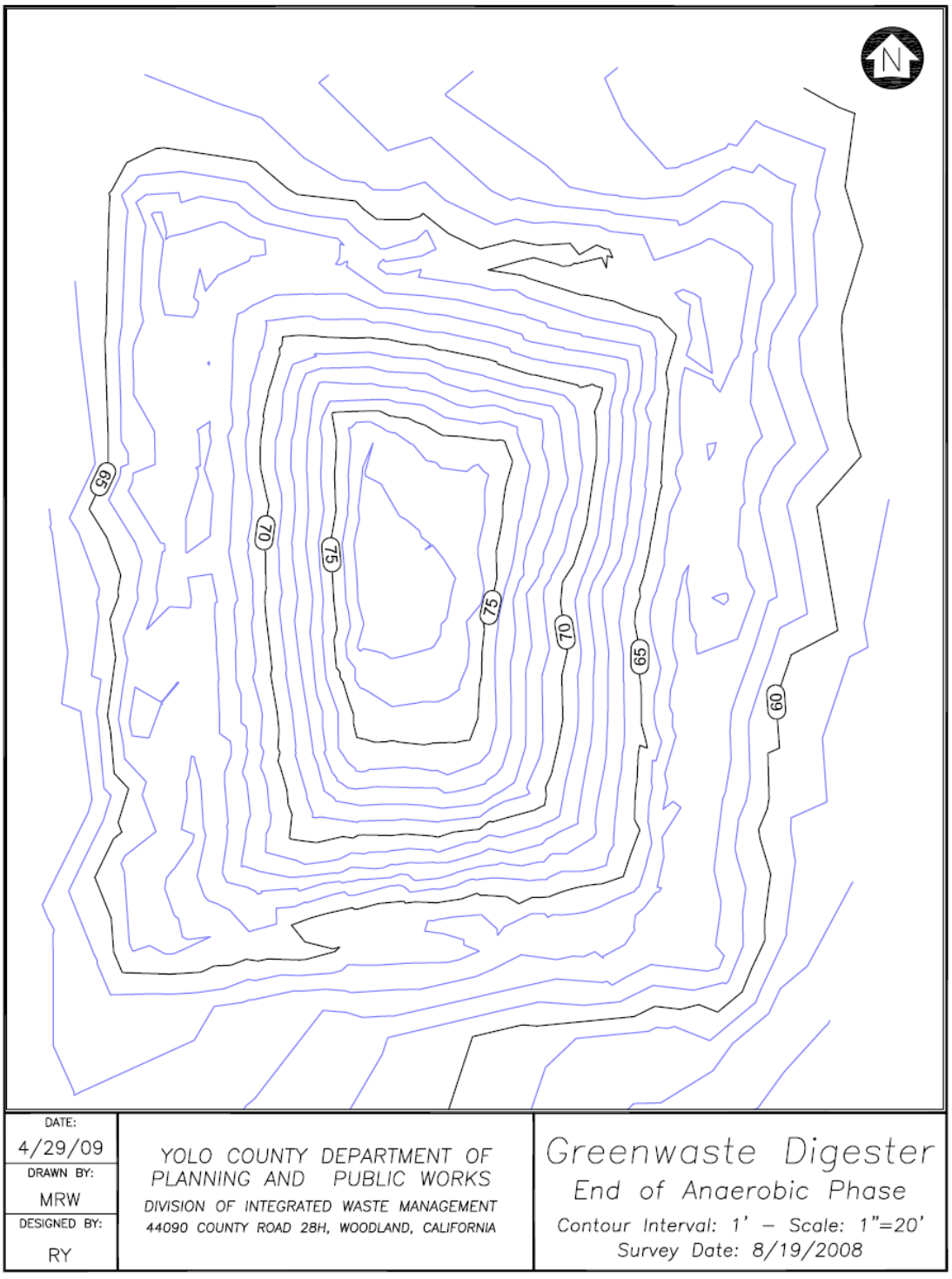
DESIGNED BY: RY	44090 COUNTY ROAD 28H, WOODLAND, CALIFORNIA	Contour Interval: 1' – Scale: 1"=20'
		Survey Date: 9/13/07



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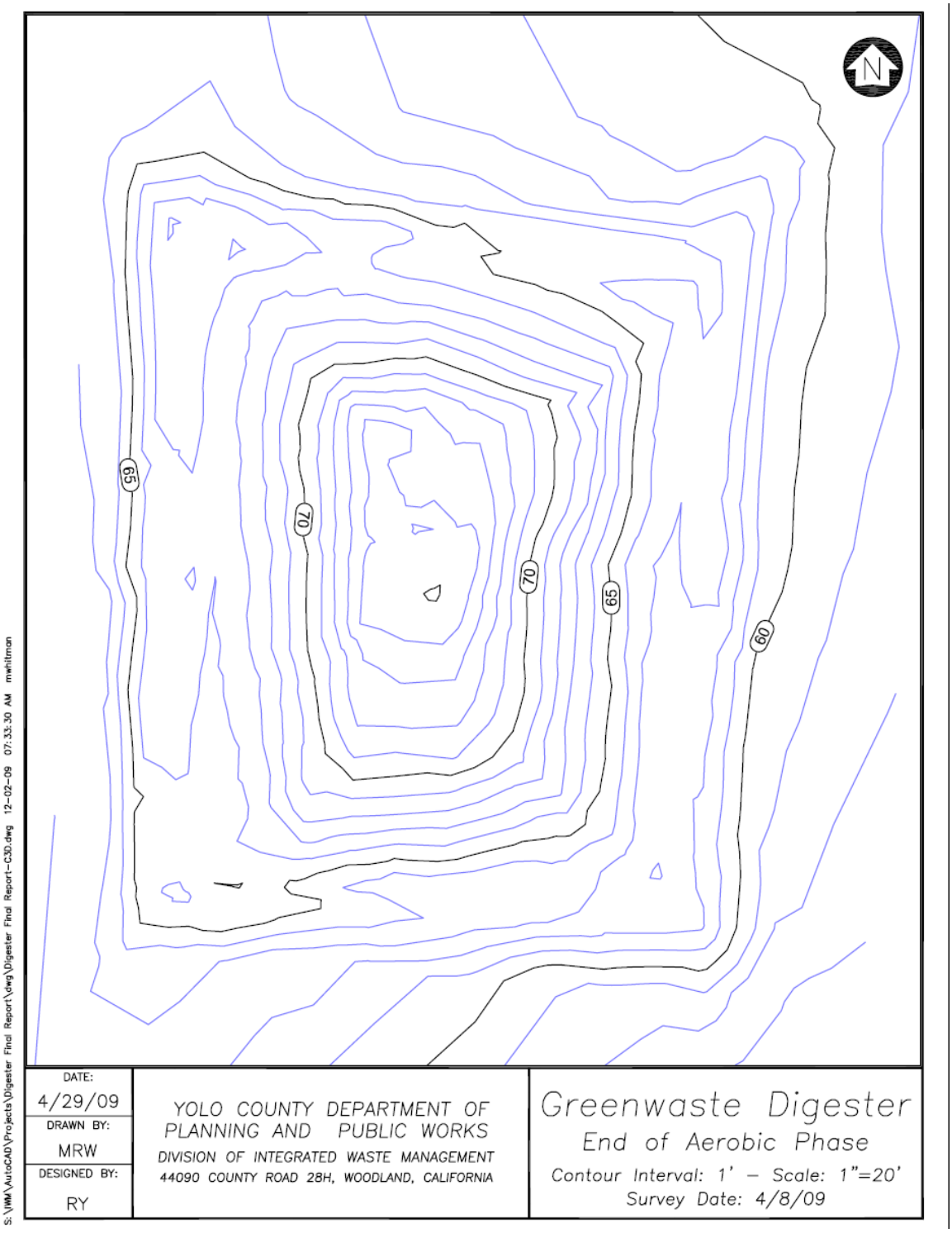
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4/29/09
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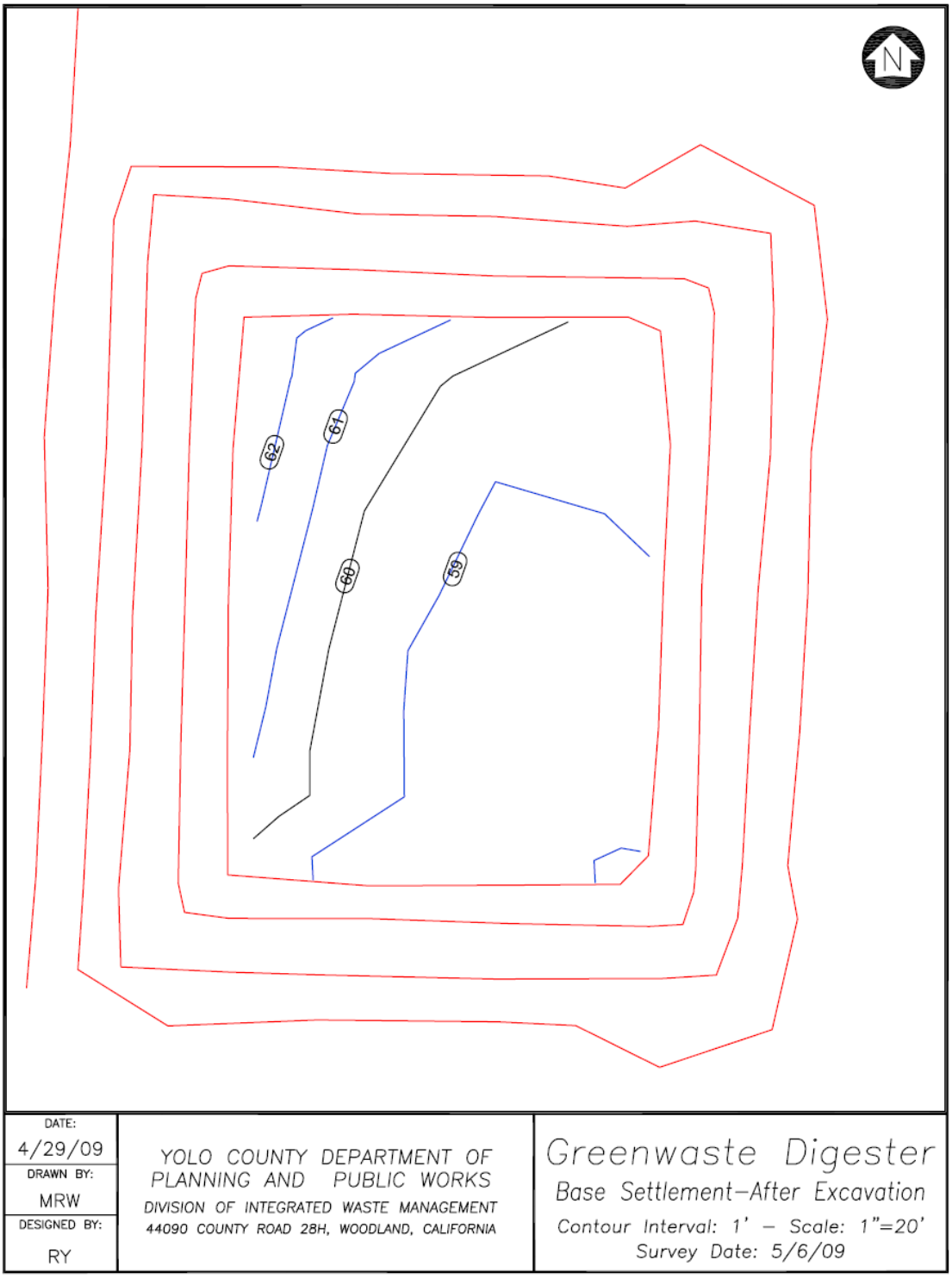
MRW
DESIGNED BY:
RY
YOLO COUNTY DEPARTMENT OF PLANNING AND PUBLIC WORKS
DIVISION OF INTEGRATED WASTE MANAGEMENT
44090 COUNTY ROAD 28H, WOODLAND, CALIFORNIA
Greenwaste Digester
End of Aerobic Phase
Contour Interval: 1' – Scale: 1"=20'
Survey Date: 4/8/09



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DATE:	YOLO COUNTY DEPARTMENT OF PLANNING AND PUBLIC WORKS	Greenwaste Digester
4/29/09	DIVISION OF INTEGRATED WASTE MANAGEMENT	Base Settlement–After Excavation
DRAWN BY: MRW	44090 COUNTY ROAD 28H, WOODLAND, CALIFORNIA	Contour Interval: 1' – Scale: 1"=20'
DESIGNED BY: RY		Survey Date: 5/6/09