Final Technical Report

Project Title: West Village Energy Initiative: Community Renewable Energy Deployment Project

Award Number: DE-EE0003072

Recipient: University of California, Davis

Project Location: University of California, Davis

SECTION 1

The Feasibility Study for the Renewable Energy Anaerobic Digester Project, University of California, Davis, prepared by HDR, Folsom, California includes the analyses that were used to determine the initial feasibility of UC Davis READ project. The goals of this study were to:

- Evaluate the quantity and suitability of organic feedstocks at UC Davis including the Davis and Sacramento campuses.
- Compare the operational suitability and economic consideration of various digester technologies including:
  - High-solids Anaerobic Digestion
  - Low-solids Anaerobic Digestion

    - Dry Fermentation

- Evaluate alternative uses for biogas produced at the biodigester
- Evaluate siting considerations
- Evaluate environmental consideration
- Evaluate economic considerations

SECTION 2

The Renewable Energy Anaerobic Digester Facility Design and Operations Summary, prepared by CleanWorld reports on the design and components of the biodigester project that was constructed and is operating through collaboration between the University of California, Davis, and CleanWorld, LLC.

SECTION 3

The Research Progress Report is a preliminary performance assessment of the UC Davis READ facility. This analysis was led by Dr. Ruihong Zhang, Professor in Biological and Agricultural Engineering at UC Davis. This preliminary report was prepared for the California Energy Commission under an ARRA Cost Share Grant to UC Davis.

SECTION 1

September 28, 2011

Feasibility Study

For Renewable Energy Anaerobic Digester Project

University of California, Davis

Prepared by HDR Egineering, Inc.

HDR

UNIVERSITY OF CALIFORNIA, DAVIS

RENEWABLE ENERGY ANAEROBIC DIGESTER FEASIBILITY STUDY

Issue Date: April 4, 2011

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Abbreviations

AD	Anaerobic Digestion
Annammox	Anaerobic Ammonium Oxidation
APS	Anaerobic Phased Solids
ARPA-E	Advanced Research Projects-Energy
ARRA	American Reinvestment and Recovery Act
Btu	British Thermal Unit
CH4	Methane
CO2	Carbon Dioxide
^{o}C	Celsius
cf/lb	Cubic Feet per Pound
DOE	Department of Energy
FML	Flexible Membrane Liner
FRP	Feedstock Receiving and Preparation
GHG	Greenhouse Gas
gVS/L	Grams per Volatile Solids per Liter
HDR	HDR Engineering, Inc.
HDPE	High Density Polyethylene
HHW	Household Hazardous Waste
H^2S	Hydrogen Sulfide
HR	Hydrolysis Reactors
HRT’s	Hydraulic Retention Times
IC	Internal combustion
KW	Kilowatt
lb/d	Pounds per Day
LF	Lineal Foot
LFG	Landfill Gas
LS	Lump Sum
MMBTU	Million Metric British Thermal Units
Mg/L	Milligrams per Liter
mL	Milliters
$MTCO^2E$	Metric Tons of Carbon Dioxide Equivalent
MR	Methogenic Reactor
MSW	Municipal Solid Waste
MW	Megawatt
NDN	Nitrification-Denitrification
NH3	Ammonia
NOx	Nitrogen Oxide
NPC	Net Present Cost
PH	Acidity
POTW	Publicly Owned Treatment
psi	Pounds per Square Inch
READ	Renewable Energy Anaerobic Digester
ROI	Return on Investment
Scfd	Standard Cubic Feet per Day
SPRR	Southern Pacific Rail Road
SS	Sewer System
tpd	Tons per Day
TS	Total Solids
UC Davis	University of California, Davis
UF-RO	Ultrafiltration-Reverse Osmosis
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
VS	Volatile Solids
WARM	Waste Reduction Model
WWTP	Wastewater Treatment Plant

1.0 Executive Summary

This Feasibility Study of the Renewable Energy Anaerobic Digester (READ) project has been prepared for the University of California, Davis (UC Davis) by HDR Engineering Inc. (HDR) and describes the analysis of the feasibility of employing an anaerobic digestion process to convert various sources of organic wastes into a renewable form of energy.

The READ facility is envisioned to treat organic wastes from the UC Davis agricultural campus facilities as well as food waste from the various campus dining facilities. As an option to explore the possibility of increasing the tributary feedstock quantity to the facility, other possible feedstock materials were considered as well and include waste paper towels from the campus restrooms, municipal solid waste (MSW) from the campus community, and possibly biosolids from the campus wastewater treatment plant (WWTP).

If implemented, the READ facility would be equipped to receive these various feedstock materials, pre-treat them to remove undesirable materials, and prepare the feedstock for insertion into the anaerobic digestion process. The receiving area and pre-treatment facility would be enclosed to contain objectionable odors and would be equipped with an air collection and treatment system. For planning purposes we have assumed a biofilter would be used to treat the air from various possible odor causing sources.

The digestion process would facilitate the conversion of the organic matter into biogas, using any one of the possible treatment technologies. In general, the digestion process would convert the complex organics in the feedstock to volatile organic acids. The acids would then be converted to biogas primarily consisting of methane and carbon dioxide.

Biogas would be extracted from the digester tanks or bunkers and could be used in a variety of energy production systems. Possible biogas uses include the production of electricity using a fuel cell, microturbine, or internal combustion engine, supplementation of natural gas boiler fuel at the Primate Center, or cleaning the gas for injection into the University's local natural gas distribution system or other uses. The use of an internal combustion engine appears to be the most financially attractive alternative among the viable biogas recovery alternatives. The use of biogas to supplement natural gas as a boiler fuel at the Primate Center is the next most financially attractive. The use of a fuel cell is the most expensive alternative but could become financially attractive if grant funding can be secured. The recovery of biogas generated at the READ facility would also benefit UC Davis by reducing the campus' greenhouse gas emissions.

By-products in the form of solids (also called digestate) could be used as alternative daily cover at a landfill, or be incorporated into a compost feedstock and made into a useful soil amendment product. Liquid effluent by-products from the facility could be used in a variety of ways, including as dilution water for the digestion or composting processes, or could potentially be converted to a liquid fertilizer. Alternatively, liquid effluent could be treated and discharged to the WWTP. The study assumes at this stage of the planning of the READ project that liquid effluent will be biologically treated to remove nitrogen and utilized at the READ facility.

The overall feasibility of the READ facility considers several technical aspects of the project. UC Davis controls the collection and management of campus wastes either by UC Davis performing the collection services or remotely through contracts with others. This applies to all wastes associated with the various functions of the University as well as student housing and agricultural facilities. Consequently, the focus of the study is limited to the technical aspects of the facility's processes and does not evaluate the effects of upstream waste collection, flow control or related impacts. However, the project is also anticipated to include non-technical beneficial aspects. For example, the proposed READ facility is envisioned to augment the research and development efforts of UC Davis. The facility would ideally be equipped with a public education and community outreach element that would accommodate the public for tours or other educational uses.

Three possible sites were considered as a part of this feasibility level study for the READ facility. They include a 20 acre site north of the landfill, a portion of the existing Avian facility on Hopkins Road consisting of approximately 19 acres and an approximate 14 acre site north of the WWTP. From the perspective of off-site improvements required, the sites appear generally equivalent in terms of the availability of utilities and related improvements necessary. The variance in off-site cost is minimal when compared to the development cost, particularly insomuch as the value of land has not been incorporated into this comparison. The primary differences between the sites appear to be somewhat subjective in nature and reflect issues such as the benefit of proximity of feedstock materials to the site, the use of by-products, thermal efficiencies, possible cost of relocation or replacement of existing utilities, and possible downwind receptors in consideration of potential odors. The preferred site would ideally be selected pending refinement of key issues identified in this feasibility study.

The READ facility may have an extended return-on-investment due to several key aspects; 1) the relatively low cost of the current disposal of the tributary feedstock materials, 2) the relatively low cost of power, 3) the relatively small quantity of feedstock materials and 4) the fact this project would be an 'alpha-project' or the first of its kind in the nation. However, we anticipate that the development of project enhancements that may improve the financial aspects of the future 'beta-project'. Further, we would anticipate if UC Davis elects to proceed with the project, a variety of benefits in the form of grants, etc. could be obtained thereby improving the financial terms discussed in this report. In an effort to improve the financial viability of the facility, HDR initiated an exploration of possible grant funding opportunities. Most grants that would be applicable to the READ facility are issued from state or federal government agencies. For the most part, grant opportunities are funded or authorized annually. Consequently, if UC Davis elects to pursue the project, a focused effort to seek appropriate grant opportunities at that time would be appropriate. While the focus of the funding programs is to reduce United States dependence on foreign oil, there are also several programs that fund projects that convert organic feedstock from the waste stream for the generation of energy as well as Biofuels.

The study considered a variety of industrial anaerobic digestion technologies which for planning purposes are represented in three categories of technology described as follows:

- Low-Solids Digestion
- High-Solids Digestion
- Dry Fermentation

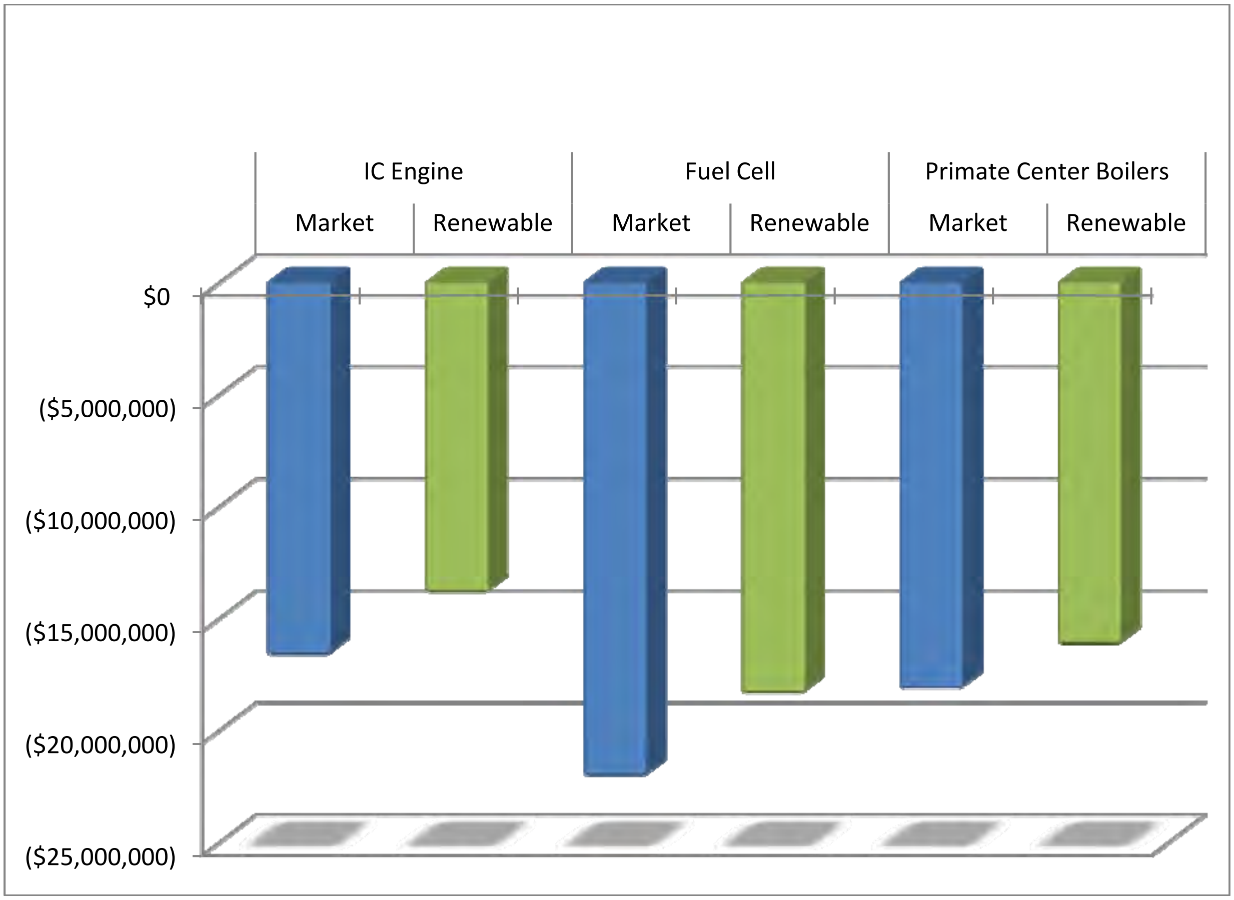
A comparison of the technologies concluded the High-Solids Digestion to be the most preferable due primarily to the characteristics of the incoming feedstock, system performance and relative overall system cost.

The study further evaluated the configuration of three High-Solids Digestion facilities using the anaerobic phased solids (APS) technology patented by Dr. Ruihong Zhang of UC Davis. The study compared three scenarios using the APS technology, each scenario reflecting a unique set of parameters as follows:

- Scenario A – processing the available manure and food waste feedstock materials but relying on land application of the dewatered digestate.
- Scenario B – also processing the available manure and food waste feedstock materials but further stabilizing the dewatered digestate using a composting process to produce a saleable compost by-product.
- Scenario C – processing UC Davis' municipal solid waste to extract the digestable organics from the MSW and blending with the available manure and food waste feedstock materials. This scenario also includes the stabilization of the digestate using a composting process to produce a saleable compost by-product.

The study summarizes the benefits and limitations of the three scenarios in terms of by-products, performance, cost and related issues. The study evaluates various opportunities for the beneficial use of biogas recovery ranging from natural gas supplementation at the Primate Center boilers to the use of Fuel Cells to efficiently produce electricity and recoverable heat. The study explores high and low revenues from each of these uses by modeling revenue rates for electricity and natural gas at market rates (currently paid by UC Davis) and renewable energy portfolio rates. The study also concludes the sale of power as either electricity or biogas is approximately fifteen percent (15%) higher if the power is sold as a renewable energy. The following figure illustrates this finding for Scenario B:

Figure ES1. Present Value of READ facility (configured as Scenario B) for Various Biogas Recovery Alternatives at Various Energy Revenue Rates



Note: The Present Value is a cost, so the least costly value as illustrated is the IC Engine using Renewable values for the sale if electricity generated by the facility.

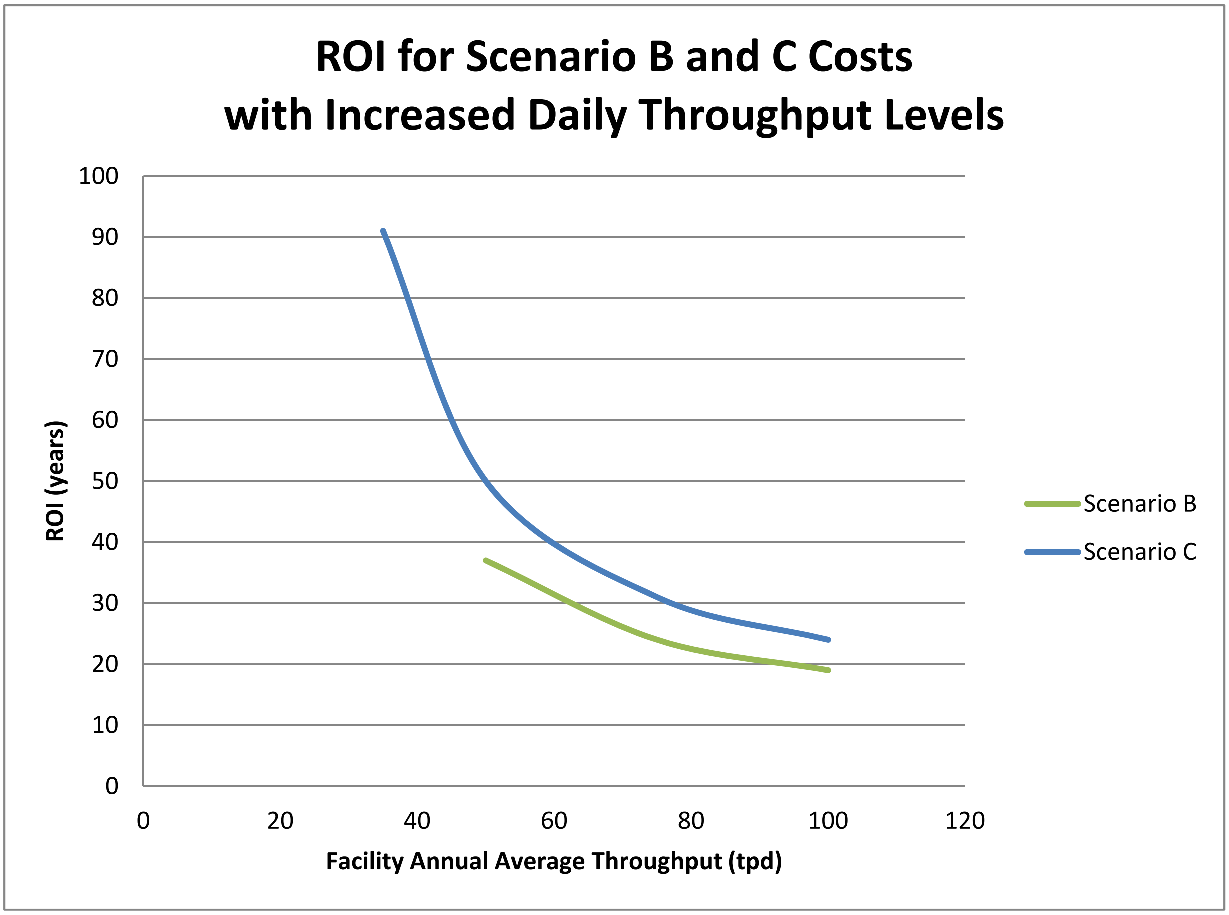
The study also models likely financial terms if the quantity of feedstock could be increased to levels where the facility scale would be more efficient. Although not currently within the scope of this study, there may be an opportunity to incorporate organics from surrounding areas including the City of Davis or other jurisdictions. The READ facility economics would follow conventional economies of scale where the facility unit capital cost ($ per ton feedstock processed) would decrease as the size of the facility increased. Using return-on-investment (ROI) as the indicator for increased financial attractiveness, the study concludes the READ facility would be more attractive if the tributary tonnages were increased to near or above 100 tons per day. The following table illustrates this finding by showing the ROI for Scenario B at increasing daily tonnage levels.

Table ES1. Return on Investment of READ Facility for Scenario B Modeled at Increasing Tonnages

	Facility Annual Average Throughput			
	22 tpd	50 tpd	75 tpd	100 tpd
Capital Cost	$14,400,000	$23,570,000	$30,060,000	$35,720,000
O&M Cost	$730,000	$1,100,000	$1,350,000	$1,560,000
Revenue	$760,000	$1,740,000	$2,610,000	$3,480,000
Net Present Value	$13,900,000	$14,800,000	$12,800,000	$9,300,000
ROI (yrs)	480	37	24	19

To further illustrate this point for both Scenario B and C, the following chart shows the ROI for these two facility configurations in correlation to increasing daily tonnage levels.

Figure ES2. Return on Investment of READ Facility for Scenarios B and C Modeled at Increasing Tonnages



The study also describes other ways of improving the financial attractiveness of the project would be to secure grant funds to reduce the capital cost of the project. In order to benefit from many of the grant opportunities, it may be necessary to alter the project in the future to fit grant opportunity criteria. For example, some grant opportunities focus on transportation fuels as a replacement of fossil fuels and the project could be altered to produce compressed natural gas for vehicle use to meet the criteria for this type of opportunity.

In addition, there are project developers who have already secured grant funding approvals that are exploring the possibility of applying their grants to the project. The READ facility could be revised or rearranged if needed to more closely align to these types of potential partners. The study closes with a section describing findings, conclusions, and recommended next steps.

2.0 Introduction

The University of California**,** Davis (UC Davis) retained HDR Engineering Inc. (HDR) to prepare this evaluation of the feasibility of developing a commercial-scale Renewable Energy Anaerobic Digester (READ) project to convert various sources of organic wastes into a renewable form of energy. This Feasibility Report is our initial analysis of the technical aspects of this project and was developed utilizing prior and on-going research that are continuing as this report was being prepared.

The READ facility, when constructed, could facilitate the conversion of waste materials from the campus agricultural departments and dining commons, converting them into a renewable energy source, thereby fulfilling three of the University Regents Policies on Sustainable Practices: 1) the development of local renewable energy, 2) the reduction of greenhouse gases on behalf of University operations, and 3) the minimization of University-generated waste sent to landfills.

Ideally, the READ facility would be located in or very near to the other campus utilities so as to provide heat and power efficiencies and to provide public exposure for educational benefits. Such a facility has potential challenges that need to be considered, particularly if the facility is to be located in close proximity to sensitive receptors such as residences and related educational facilities. Organic feedstock wastes, and digestion and digestate management processes inherently produce odors which, if not properly managed, could be offensive. Consequently, this feasibility study includes a variety of odor containment and treatment functions to mitigate these issues.

The READ facility would process organic wastes from the campus agricultural farm operations and food waste from the various campus dining facilities into biogas which could then be used as a renewable energy source for a variety of energy production systems. These include, but are not limited to, internal combustion engines, turbines, or fuel cells. Other possible uses include using the biogas as a fuel source for heating the Primate Center, located on the western edge of the campus.

In addition to an assortment of agricultural manures and bedding from a variety of campus animal containment facilities and food waste from the dining commons, this feasibility study also explores the possible use of municipal solid waste (MSW) from the various on-campus sources, such as single family residential units, as well as wastes from academic sources. For planning purposes, we have assumed the existing household hazardous waste (HHW) education and materials collection program that UC Davis employs would mitigate the potential of contaminants such as heavy metals from entering the tributary feedstock to the facility if MSW is selected as a favorable feedstock.

Essentially all of the feedstock sources are within the control of the University. The majority of the feedstock consists of campus manures. All manure sources are controlled by UC Davis and are collected by University waste collection services. A small quantity of the feedstock is cafeteria wastes. Cafeteria wastes are managed by the dining commons service providers

(Sudexo). However, the cafeteria operators have expressed interest in the READ project and willingness to direct their wastes to the READ facility. Consequently, for planning purposes all feedstock sources are assumed to be controlled by the University and can be directed to the READ facility.

The type and extent of collection services are anticipated to remain essentially the same for the READ facility. Consequently, the cost of collection services was not included in this feasibility study.

This study considered a variety of industrial anaerobic digestion technologies, condensing the various technologies into three broad categories:

- Low-Solids Digestion – with solids less than approximately ten percent (10%)
- High-Solids Digestion – with solids above approximately ten percent (10%) and as high as forty percent (40%) but processed in a tank type reactor.
- Dry Fermentation – with solids above forty percent and processed in a bunker type reactor where materials are placed in a stacked condition and remain throughout the digestion phase.

HDR considered these technologies in conjunction with the possible use of the Anaerobic Phased Solids (APS) digestion technology patented by Dr. Ruihong Zhang of UC Davis and considered the APS technology as a representative of the High-Solids Digestion category. The comparison of Low-Solids, High-Solids digestion and dry fermentation technologies was limited to a qualitative comparison due to time and budget constraints. The comparison relied on data gathered by HDR for a variety of other projects and does not necessarily purport to represent all of the possible permeations of anaerobic digestion treatment technologies available worldwide.

If the READ facility employs the APS technology patented by UC Davis as the preferable technology for this use, development to a commercial scale could have secondary benefits. The first demonstration sized version of this technology was developed by UC Davis in conjunction with Onsite Power Systems, and is located adjacent to the existing WWTP east of Old Davis Road and south of Interstate 80. The demonstration facility was constructed in 2004 and began testing various feedstock sources in 2006. If developed as the READ project technology to a commercial scale, the replication of the APS to other communities or industry may be possible.

One reason the APS technology was considered is that the APS technology has been developed at UC Davis by Dr. Zhang through years of evaluation and refinement. Through this effort Dr. Zhang has evaluated the performance of the APS technology by testing a wide variety of feedstock materials. Her research initiated with laboratory bench scale testing which led to the construction of the demonstration plant where additional pilot-testing was performed. The feedstock materials tested using the demonstration facility have been extensive and include restaurant kitchen wastes, food processing wastes, agricultural crops, agricultural processing wastes and a wide variety of manures. Some of Dr. Zhang's publications on this technology and its applications are included in the reference summary at the end of this report.

3.0 Project Goals and Objectives

Project goals and objectives of the READ facility include but are not limited to the following:

Primary Objective

- The creation of a renewable energy source and improved greenhouse gas conditions by utilizing biogas generated at the READ facility

Secondary Goals and Objectives

- Elevated diversion of waste from landfilling
- Reduced landfill operations and regulatory obligation due to increased diversion
- The creation of either a soil amendment or land-applied digestate as a useful agricultural by-product
- Potentially convert liquid effluent to a recoverable fertilizer product
- Evaluation and consideration of grants, loans, and renewable energy credits to assist in defraying the cost associated with the READ facility
- A showcase facility able to accommodate additional research projects in similar or related fields

These are described in more detail in the various technical sections of this report.

An important additional consideration is that the facility is intended to produce a renewable energy source as a part of the renewable energy goals set by the University Regents. This renewable energy source would address three of the University Regents Policies on Sustainable Practices: 1) the development of local renewable energy, 2) the reduction of greenhouse gases on behalf of University operations, and 3) the minimization of University-generated waste sent to landfills. The READ facility provides an educational opportunity and communicates UC Davis' commitment to sustainability to the public.

4.0 Feedstock Issues and Considerations

HDR initiated the feasibility study with an investigation into the quantity and quality of feedstock potentially tributary to the READ. The initial goal was to confirm the quantity and composition of the feedstock sources originally identified by Dr. Ruihong Zhang and various postgraduate students in prior planning efforts.

To confirm the feedstock quantity and composition, HDR consulted with operations staff at UC Davis facilities generating waste streams that were considered potential feedstocks, and helped coordinate a sampling and laboratory analysis effort performed by UC Davis staff. HDR coordinated with the UC Davis Design Services group and other UC Davis staff, including Dr. Zhang and her research students, to visit many of these key campus facilities. Visits involved meeting with appropriate site management staff and discussing current waste quantities, waste compositions, waste management practices and concerns, flexibility of operations to accommodate changes, and interest level in diverting waste streams to the READ facility. These visits generally included touring waste management operations and sampling waste streams. In order to understand how these various college campus waste sources fit into the overall campus waste management plans, HDR also researched current practices of the campus landfill, composting, and diversion management The purpose of our approach was to facilitate an understanding of the feedstock in the following categories:

- the quality of the material in terms of biochemical methane potential (the laboratory testing and results which were performed by Dr. Zhang),
- the quality of the material in terms of contamination, or quantity of undesirable materials,
- the quantity in terms of tons,
- insights as to the unique issues associated with the generation and consolidation of the feedstock materials at the source of generation, and
- the logistics of its availability in terms of collection frequency, method, by whom, etc.

Appendix A contains a Feedstock Matrix that summarizes the waste streams considered as feedstocks and the information gathered from site visits and phone calls with staff at the facility generating the waste. **Figure 1** shows the location of facilities that were identified as generating key waste streams that would be appropriate for the READ facility in terms of quantity and/or quality. Other waste streams were evaluated but not considered to be key to the feasibility of the READ facility because their quantities were not significant or are not generated consistently enough throughout the year. HDR and participating UC Davis representatives visited the following facilities in person over the course of evaluating potential feedstocks:

- Segundo Dining Commons (as representative of the three dining commons on campus run by Sodexho)
- The Coffee House and the Memorial Union

- UC Davis Medical Center
- Animal Science Facilities
  - Dairy
  - Feed Lot
  - Sheep
  - Beef Barn
  - Cole Facility
  - Goat
  - Swine
- Center for Equine Health
- Equestrian Center
- Veterinary Medicine Teaching Hospital

Samples were taken from several feedstocks to use in laboratory testing. Some feedstocks were chosen to confirm older test results on similar materials. Others were chosen because they had not been tested in past APS technology research. Because these tests were performed concurrently with the analysis that HDR has provided in this feasibility study, some assumptions had to be made based on prior APS demonstrations, laboratory research, available literature, and industry knowledge. **Tables 1 and 2** shows the assumptions that were made regarding the quantity and quality of digester feedstocks to be used in the READ scenarios presented in this report. The total solids (TS) data is based on information provided by UC Davis staff. The percent solids and potential for methane production were estimated by HDR. **Table 1** shows the organic feedstock assumptions used in developing the facility scenarios. **Table 2** shows the MSW feedstock assumptions.

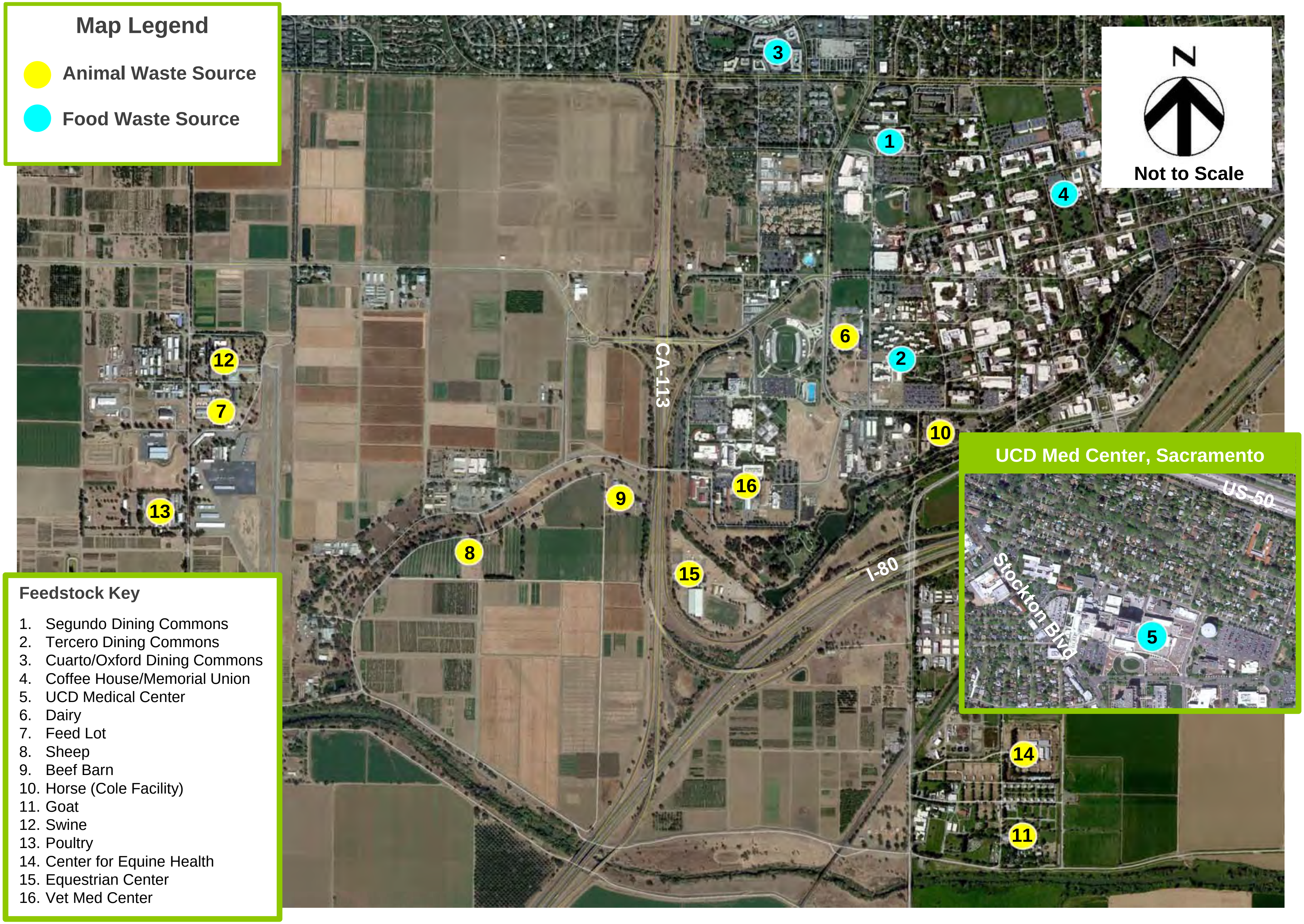


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Figure 4: Key Feedstock Location Map

Draft Feasibility Study for Renewable Energy Anaerobic Digester Project

Table 1. Organic Feedstock Assumptions

Department	Facility	Waste Stream	TS to Digesters (tpy)	TS (wet tpd)	TS (wet lb/d)	% Solids	Methane Production (scfd)
Sodexho (Food Waste)	Segundo	Compactor - Other	170	0.47	932	18%	1,539
		Compactor - Food Pulper	80	0.22	438	18%	724
		Waste Oil	3.12	0.01	17	18%	28
	Tercero and Cuarto/Oxford Combined	Compactor	170	0.47	932	18%	1,539
		Waste Oil	2.26	0.01	12	18%	38
Olive Center	Olive Press	Olive Pomace	10	0.03	55	29%	81
Animal Science	Dairy	Manure	2600	7.12	14,247	48%	32,483
	Feed Lot	Manure + Straw Bedding	1440	1.97	3,945	16%	6,014
	Sheep	Manure + Straw Bedding	300	0.82	1,644	16%	1,253
	Beef Barn	Manure + Straw Bedding	100	0.27	548	16%	414
	Horse (Cole Facility)	Manure + Straw Bedding	460	1.26	2,521	16%	2,356
	Goat	Manure + Straw Bedding	150	0.41	822	19%	811
Center for Equine Health	Center for Equine Health	Straw bedding	371	1.02	2,033	32%	2,370
		Dry Lots	35	0.10	192	32%	213
Campus Recreation	Equestrian Center	Barn	1530	4.19	8,384	19%	6,209
		Pasture	510	1.40	2,795	43%	1,403
ASUCD	Coffee House/MU	Pre-Consumer Food Waste	50	0.14	274	38%	635
Med Center	New Facility	Canola Shortening	11	0.03	60	18%	100
Robert Mondavi Institute for Wine and Food Science	Winery	Pomace	5	0.01	27	29%	40
Food Service	Cafeterias	Grease Trap Waste	104	0.29	571	15%	1,465
Total[1]			8,102	22.2	44,392		59,520

Table 2. MSW Feedstock Assumptions

Department	Facility	Waste Stream	TS to Digesters (tpy)	TS (wet tpd)	TS (wet lb/d)	% Solids	CH_4 Production (scfd)
Source Separated Organics as listed in Table 2			8,102	22.2	44,392		59,520
MSW Collection	Campus wide	MSW from Rotary Drum	4,794	13.1	26,268	47%	49,075
Total[1]			12,895	35.3	70,660		108,594

[1] Data presented in the table are annual averages.

Laboratory testing of select feedstocks was completed by Dr. Zhang's research team just prior to the completion of this report. The tests performed determined the biogas yield, methane yield, and volatile solids reduction of these waste streams under thermophilic conditions. The initial stage of testing was performed as laboratory scale batch tests. The results of these tests will be used to determine the operating conditions (e.g., temperature, hydraulic retention time, and loading rate) and feedstock mixtures of different types of wastes for future tests at the pilot plant.

Samples were collected by hand and placed into 1-gallon plastic bags. All samples were tested in the state in which they were collected, with the exception of the cardboard and paper towel samples, which were mixed with 10 parts water for 24 hours and blended. Because samples were collected as part of site visits to the waste generators on various occasions from December 2010 and February 2011, samples were kept frozen at -20 ºC until the day before they were tested. At that time, samples were moved to a refrigerator kept at 4 ºC to thaw. Cardboard and paper towel samples were left to thaw at room temperature. The batch reactor tests were performed in two different rounds. Table 4 shows which waste stream samples (substrate) were tested in each round. All samples were measured for their solid contents, and the samples tested in Round 1 were also measured for pH.

Batch tests were inoculated with sludge samples that were collected from East Bay Municipal Utility District's thermophilic digesters in Oakland, California on January 14, 2010. The inoculants as kept in an incubator maintained at 50 ºC ± 2ºC for an initial sludge stabilization period, allowing for gas pressure relief through a water seal. This inoculant was used for both rounds of tests that were performed. The inoculum used for Round 1 was incubated for 4 days, while the inoculum used for Round 2 was incubated for 4 weeks.

All batch reactor tests were performed under anaerobic and thermophilic (50 ºC ± 2 ºC) conditions, using a food to microorganism ratio (F/M) of 1.0. Food waste tests (olive pomace and food waste from Segundo dish room) used an organic loading of 3 grams of volatile solids per liter (g VS/L). Tests on all other samples used an organic loading of 6 g VS/L. Each batch reactor had a total volume of 1130 milliliters (mL) and an effective volume of 500 mL. Tap water was used to bring the working volume to 500 mL after substrate (waste sample) and inoculum (sludge) were added. Each waste stream was tested in duplicates. Two blank batch reactor tests, containing only water and inoculum, were performed with each round of testing. Results were used to reference the amount of biogas produced from the inoculum.

Biogas production was calculated daily from the measurement of pressure in the head space of each reactor. Biogas composition (CH_4, CO_2, H_2S) was measured using gas chromatography as follows:

For Round 1:

- Once after the first 24 hours of digestion,
- Daily for 5 days, then

- 2 to 3 times per week for 2 weeks.

For Round 2:

- Once after the first 24 hours of digestion,
- Daily for 2 days, then
- 2 times a week for 3 weeks.

At the conclusion of the batch testing, all batch reactors were measured for their solid contents and pH in duplicate.

4.1 Feedstock Laboratory Test Findings

The results indicate that the quantity of biogas from the various feedstock materials varied from a low of 1.5 to 13.8 cf CH_4/lb VS. The analysis was performed in two rounds. **Table 3** summarizes the results of the laboratory testing. Results are shown in more detail in the laboratory report, which is included in this feasibility study as **Appendix B**. Results from the laboratory testing were used to develop the final version of the feasibility study.

Table 3. Summary of Results from Laboratory Tests

Round 1:			
Substrate	Source	Biogas Yield (cf/lb VS)	Methane Yield (cf/lb VS)
Thin Cardboard	Outside Vendor	8.5	4.9
Thick Cardboard	Outside Vendor	9.7	5.7
White Cardboard	Outside Vendor	7.5	4.2
White Paper Towel	Restrooms/Custodial	8.1	5.3
Brown Paper Towel	Restrooms/Custodial	8.8	5.2
Olive Pomace	Olive to Bottle Olive mill	8.2	5.6
Food Waste	Segundo Dining Commons dish room	13.8	9.8
Inoculum, 1 week old	East Bay Municipal Utility District (EBMUD)		
Round 2:			
Substrate	Source	Biogas Yield (cf/lb VS)	Methane Yield (cf/lb VS)
Coffee Grounds	ASUCD Coffee House	8.6	6.2
Horse Manure from barns	Equestrian Center	6.0	4.2
Horse Bedding - Wood Shavings	Center for Equine Health	1.5	1.3
Cow Bedding - Rice Hulls	Dairy	3.6	2.5
Horse Manure from pasture	Equestrian Center	5.1	3.5
Straw Bedding, clean	Vet Med Center Large Animal Clinic	9.3	5.9
Cow Bedding - Straw	Feedlot	7.7	5.4
Cow Manure - from cow on antibiotics	Vet Med Center Large Animal Clinic	5.4	3.8
Inoculum, 4 weeks old	East Bay Municipal Utility District (EBMUD)	2.7	

4.2 Consideration of MSW as a Feedstock

Based on the results of the feedstock analysis performed as a part of this study, an average of 22 tons per day would be available for the READ facility. In anticipation that the quantity would be too little for the READ and as the feedstock confirmation study was underway, Dr. Zhang requested that HDR expand the consideration of feedstock sources potentially tributary to the facility to include waste hand towels (paper hand towels) from restrooms throughout the campus. Dr. Zhang's recommendation was to employ the use of a rotating drum pre-treatment system to pre-treat the paper materials for the digestion process. One of the reasons to expand the exploration of feedstock sources is to consider feedstock streams that would be typical of other city, county or related waste management jurisdictions. If employed, the use of a rotating drum pre-treatment device combined with the anaerobic digester could demonstrate the potential of this technology for treatment of more common waste stream compositions.

Working with the UC Davis staff, HDR determined that the quantity of used paper towels on campus would be relatively minor and would likely not be enough to justify the use of the smallest commercially available pre-treatment device. In subsequent discussions regarding the use of the rotating drum device, it became evident that it could be an appropriate system to process MSW in addition to paper towels. One of the key values of expanding this feasibility study to consider MSW as a possible feedstock is that MSW and potentially biosolids are common waste materials throughout the United States. Although we recognize the possibility that contaminants are present in the MSW, for this phase of READ feasibility study, we assume the contaminants can be removed or otherwise not deleteriously affect the facility performance of the digestion process or degrade the quality of the finished by-products such as compost. Consequently, demonstrating the viability of these feedstock materials using the combined rotating drum and digester could make the technology more universally applicable and therefore more attractive commercially.

Based on conversations with the landfill operations management[1], the campus typically disposes of approximately thirty-one (31) tons per day of mixed MSW on annual average basis[2]. Of this quantity, approximately six (6) tons per day consists of gravel mixed with manure from the Primate Center which would not be suitable for the READ facility. According to UC Davis landfill operations management, the remaining twenty-five (25) tons per day reportedly consists of typical MSW, which is reportedly similar to the MSW materials studied by Dr. Zhang and reported in the paper entitled Integration of Rotary Drum Reactor and Anaerobic Digestion Technologies for Treatment of Municipal Solid Waste, dated June 2010 and published by the California Department of Resources Recycling and Recovery. As a result, further consideration of MSW was explored. Rotating Drum representatives Keppel Seghers were invited to present the performance of their technologies to the UC Davis Design Services staff and Dr. Zhang[3].

Subsequent to the presentation by Keppel Seghers, conversations with Dr. Zhang regarding available data for use of the rotating drum device in addition to conversations with UC Davis

[1] Conversations with Michael Fan, March 10, 2011.
[2] Feedstock tonnages presented in report hereinafter are based on annual averages.
[3] Rafael Salazar, Keppel Seghers-Dano Drum, February 21, 2011.

regarding the limited time to produce this feasibility study, HDR concluded it would be necessary to rely on readily available information to approximate the performance of the rotating drum. Our analysis regarding the rotating drum relied on both Dr. Zhang's paper mentioned above and information provided by Keppel Seghers regarding the performance of their Dano Drum currently operating in Rapid City, Iowa.

4.3 Feedstock Conclusions

In general, the ideal feedstock from campus sources consists of manures, food waste and similar organic matter. Unacceptable materials need to be removed, either by selecting feedstock sources where the sources' quality can be controlled at its source location, or by implementing a method of removing the impurities if they are present in the feedstock. One of the reasons we explored a variety of feedstock compositions was to differentiate between the opposing views of a relatively clean source separated stream which, for the most part would not require extensive pretreatment, and a mixed waste stream which would possess the capacity for feedstock pretreatment, thereby being more accepting of feedstock sources that could contain contaminants. Our conclusions regarding the two feedstock sources are provided below:

Manure and Food Waste Feedstock

The manure and food waste sources that were laboratory tested provided some useful insights into the appropriateness of the various feedstock sources. The results indicate that horse bedding with wood shavings and rice bedding with dairy manure was too low in biochemical methane potential to be useful in the digester. These materials have the potential to be useful for the digestate stabilization process which employs an aerobic composting technology. However, the laboratory results reveal that the remainder of the materials tested appears to be suitable for the digester. In general, bench-scale testing indicates that these materials provide ample biochemical methane potential within the relatively short hydraulic retention time of 14 days tested to be useful as feedstock materials at the commercial scale.

Municipal Solid Waste Combined with Manure and Food Waste Feedstock

In contrast to manure and food waste feedstock sources, the MSW feedstock materials were not laboratory tested as a part of this feasibility study. However, understanding that MSW typically contains significant portions of cardboard, paper, paper towels, etc., it is anticipated that the organic fraction of MSW will behave similar to the biochemical methane potential laboratory test results above. Also, relying on the prior studies of Dr. Zhang, we estimated the performance of the rotating drum facility to retain approximately 50 to 55% of the raw MSW[4]. As a result, the 25 tons per day of MSW sent to the READ facility would result in approximately 13 additional tons per day of organic feedstock for digestion. Further, we assumed the rotating drum and subsequent screening phase would facilitate the removal of contaminants from the MSW materials to a level acceptable for insertion to the digesters.

[4] *Integration of Rotary Drum Reactor and Anaerobic Digestion Technologies for Treatment of Municipal Solids Waste* (California Department of Resources Recycling and Recovery, 2010).

5.0 Comparison of Various Digester Technologies

Anaerobic digestion is a process where organic matter is consumed by bacteria in the absence of oxygen and converted to methane and carbon dioxide. Potential waste-derived organic feedstock materials evaluated above include but are not necessarily limited to MSW-derived organics, wastewater treatment plant biosolids, manure, farm wastes, and food waste. Three general types of anaerobic digestion were considered in this review: High-Solids, Low-Solids, and dry fermentation as follows:

- High-Solids anaerobic digestion is generally characterized by the treatment of waste streams with 10 to 40% total solids and often in the range 20 to 30% solids.
- Low-Solids anaerobic digestion, typical of biological sludge digestion operations at large municipal wastewater treatment plants, commonly operate with a feedstock total solids concentration of less than 10%[5].
- Dry fermentation is similar to High-Solids digestion and processes wastes typically greater than 40% and as high as 70% solids.

AD system reactors are commonly constructed as covered earthen lagoons, or concrete, steel or stainless steel tanks. Tanks are more common because solids are difficult to remove from a lagoon at an elevated TS concentration. Lagoons also typically require a larger footprint than tank reactors and are commonly used for agricultural applications and liquid organic waste treatment.

Furthermore, both High-Solids and Low-Solids systems can be designed as single-stage and multi-stage (phased) processes, batch or continuous operation, and mesophilic or thermophilic operation. These process design features are discussed below.

Phase Separation

There are two phases to anaerobic digestion known as the "acid phase" and the "methane-producing phase," or, "methanogenic phase." In the first phase, complex organic matter is hydrolyzed and converted to simpler organic acids. In the second phase, organic acids are converted to methane, carbon dioxide, water and simpler end-products. Acid and methane production can occur in a single containment vessel or be separated into two vessels, one for each phase. Generally, in a digester that is working on a continuous basis, both the "acid phase" and "methanogenic phase" occur simultaneously through the action of different types of bacteria. However, some designs of High-Solids and Low-Solids systems purposely and physically segregate the acid phase process from that of the methane-producing phase as discussed below. The objective of separating the phases is to provide favorable environmental conditions to both the acid-forming and methane-forming bacteria.

AD systems are designed as single-stage and two-stage (e.g. phased, some phased systems are designed with more than two stages). The advantage of operating a two-stage system is that the first stage allows for hydrolysis and partial acidification of complex particulate organic matter.

[5] *Typical digesters at municipal wastewater treatment facilities operate in the range of 3% to 5% solids.*

After the hydrolysis and partial acidification occur in the first-stage, digester contents are transferred to a second-stage reactor where most of the methane is produced and collected for recovery. Much of the biogas produced in the first stage is carbon dioxide. The noted advantage of a phased AD arrangement is that the hydrolysis/acidification step and methane production step are physically separate which allows the two classes of bacteria associated with each phase to thrive under their respective favored environmental conditions. For a single-stage continuously fed system, hydrolysis, acidification, and methane formation occur in the same reactor. Phasing has shown more efficient volatile solids destruction compared to single stage systems when considering an equivalent total volume of the two systems. However, the cost of constructing two reactors rather than one adds capital cost to an AD system. The improved efficiency and subsequent reduced total AD reactor volume is somewhat offset by the added cost associated with two tanks when compared to one for a single stage system.

Batch versus Continuous Operation

AD systems are either operated as a batch or continuous process. A batch system is fed raw feedstock, left to react over a prescribed period and followed by removal of the reactor contents from the system. A continuous system is fed continuously with raw untreated organics and material is also removed from the AD reactor continuously. For a single stage batch process, hydrolysis, acidification, and methane formation occur sequentially within the reactor during the prescribed reaction period of the system. It has been noted in some cases that batch feeding is more efficient than continuous feeding as hydrolysis and acidification are allowed to occur in the early stages of the detention period, followed by methane formation in the latter stages. For a single-stage continuously fed system, hydrolysis, acidification, and methane formation occur simultaneously within the reactor; because of this localized acid-forming and methane-forming bacteria populations must co-exist under sometimes less than ideal environmental conditions.

Batch systems are unique in that there must be multiple tanks available for feeding raw feedstock. While one AD reactor is in batch operation it cannot be fed additional feedstock, and so, additional reactor(s) must be available for feeding. Continuous systems do not have this limitation. However, batch systems can be expanded to provide an increase facility throughput capacity relatively easily by adding additional hydrolysis/acidification tanks, assuming the methane formation tank has adequate capacity.

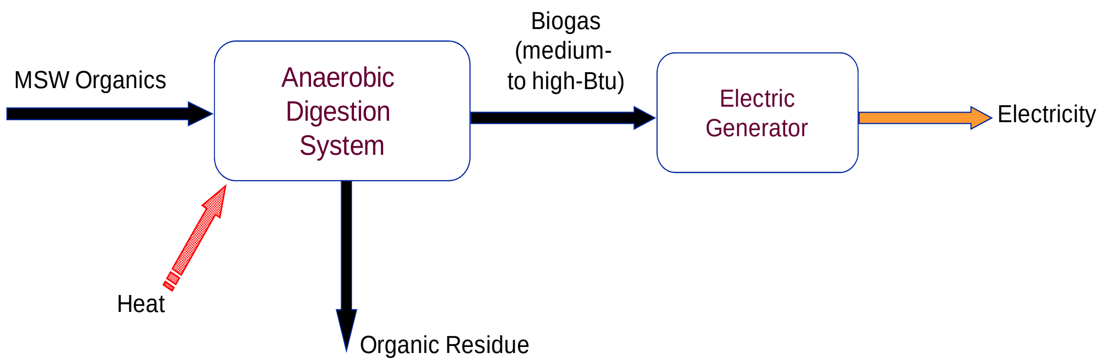
Digester Temperature

AD systems commonly operate either in the mesophilic (32 to 40 ^{o}C) or thermophilic (48 to 58 ^{o}C) temperature ranges. These above-ambient temperatures are required for healthy, functioning methanogenic bacteria. Mesophilic operation has been more widely practiced than thermophilic primarily due to historical problems with process stability of thermophilic systems and the energy needed to raise the digester temperature to more than 48 ^{o}C. However, thermophilic operation has become more common particularly with digestion of organic wastes and MSW. In the last ten years, approximately one-third of the digesters installed in Europe for organic wastes and MSW were thermophilic systems.

The advantage of thermophilic systems is that the bacteria metabolize organic substrate at a higher rate compared to mesophilic systems. A second advantage is that the hydrolysis of particulate organic matter occurs more rapidly at higher temperatures. As a result of these factors, the volume of thermophilic systems is less than mesophilic systems. As noted above, the disadvantage of thermophilic systems is reduced process stability and additional energy demand. A second disadvantage is that free ammonia (which is toxic to methanogenic bacteria at elevated levels) is present in higher concentrations in thermophilic systems compared to mesophilic systems due to its higher solubility at elevated temperatures. Depending on the nitrogen content of the feedstock, the feedstock may require dilution to lower the nitrogen concentration to be acceptable to methanogenic bacteria under thermophilic operation.

There are several factors that influence the design and performance: the concentration and composition of the organic content of the material to be digested, feedstock biodegradability, nutrient contents in the feed, solids content, and temperature of the digesting mass, retention time of the material in the reactor, pH, acid concentration, and oxygen level. These factors are used to size AD facilities. An idealized typical diagram of an anaerobic digestion system diagram is provided in **Figure 2.**

Figure 2. Typical **Anaerobic Digestion System**



5.1 High-Solids Anaerobic Digestion

High-Solids AD systems typically operate at a minimum TS content of 10% and often in the range of 20 to 30%. High-Solids AD systems have grown in popularity over the past 20 years outside of the United States as more experience has been gained with their operation. A key differentiator of High-Solids systems is that the waste that is digested must be handled as a solid rather than a liquid normally requiring the use of augers and conveyors rather than conventional pumping equipment. Solids are more challenging to handle and convey compared to liquids which is a disadvantage of High-Solids systems. However, High-Solids systems are more robust with regard to feedstock physical impurities as they are able to pass larger inert objects such as glass, metal and similar objects. Such materials can damage pumps, valves and associated pumping and conveyance equipment in Low-Solids systems.

High-Solids AD systems employ mixing however such systems serve to agitate digester contents rather than completely mix digester contents. Due to the viscous nature of High-Solids AD reactor contents, complete mixing is difficult to achieve and so gas-mixing or paddle mixing devices are used to agitate AD reactor contents and allow the material to be conveyed from the reactor.

An advantage of High-Solids systems is that the digestate from the AD system may not require dewatering as it can be managed and utilized more as a solid rather than a liquid. Costs associated with dewatering and the need to manage and potentially treat dewatering centrate is eliminated.

A key concern during anaerobic treatment of organic wastes (particularly manure) is free ammonia and its toxic effect on methanogenic bacteria. Organic nitrogen contained in raw feedstock is converted to ammonia during anaerobic digestion. Methanogenic bacteria activity is reduced or inhibited at high unionized ammonia levels greater than approximately 350 mg/L[6] (NH_3 expressed as N) particularly during system start-up. If the raw feedstock contains significant nitrogen, it may require dilution to reduce ammonia concentration in the digester to levels acceptable to the methanogenic bacteria. In some cases, the feedstock is diluted to the point that the AD system would be considered a Low-Solids system rather than a High-Solids system. As a result, a disadvantage of High-Solids systems is that they may have difficulty processing high nitrogen feedstocks. **Figure 3** illustrates a typical High-Solids system.

5.2 Low-Solids Anaerobic Digestion

Low-Solids digestion treats organic wastes at a low TS content on the order of 10 to 15% or less. This process is known as wet or Low-Solids digestion. Low-Solids digestion is most commonly used at municipal wastewater treatment plants where biosolids from aerobic treatment are digested. As a result, Low-Solids digestion has been extensively practiced and has an extensive operating history. Digested solids are then dewatered and processed further for disposal, land application, composting, or beneficially used in some other way. Water from the process is recovered from the dewatering process and recycled internally to the head of aerobic treatment. Organic waste feedstocks often have TS content greater than 15% and in such cases Low-Solids digestion systems require dilution water to lower TS content of the AD feedstock.

One advantage of Low-Solids digestion is that the material being digested has a higher moisture content making it simpler to pump and convey. Materials with higher solids content are less amenable to pumping and conveying systems therefore equipment such as augers are necessary. A second advantage of Low-Solids digestion is that the liquid serves as a medium to promote contact between the organic substrate and biomass. High-Solids systems are less homogenous and more difficult to mix and as a result, provide less contact between the organic substrate and biomass.

A disadvantage to wet systems is that the liquid and solids fractions stratify more easily. Particulate material can settle to the bottom of a reactor leaving more liquid material at the upper portions of the reactor. This separation can yield two distinct materials within the reactor

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[6] Higher levels have been noted typically after a system has been in operation for a long time and methanogenic bacteria have acclimated to the elevated ammonia concentration.

that may need to be managed separately. However, adequate mixing can promote a homogenous mixture of liquid and solids within the reactor.

A second disadvantage of Low-Solids systems is that the digestate from the AD system is commonly too wet to be handled as-is and it must be dewatered before the digestate solids are further managed and recovered. Dewatering yields a liquid centrate stream that must be managed and possibly further treated prior to being land applied, reused at the AD facility, or discharged to a local municipal wastewater treatment facility.

5.2.1 High and Low-Solids Systems Suppliers

Single-stage Systems

High-Solids, continuously fed digesters commonly process 20 to 40% total solids feedstock sometimes using a mixing pulper for the raw feedstock, a top fed vertical tank, and a conical section at the bottom of the tank for digestate removal. Low-Solids systems are more varied with reactor feed and withdrawal methods since the materials are wetter and easier to handle and convey. Some High-Solids single-stage vendors include DRANCO, Ros Roca, Kompogas, and Valorga, all of which are based in Europe. There are more than 50 installations outside of the United States utilizing these types of AD systems. Single-stage systems have been the prominent technology installed for organic waste digestion.

Two-stage Systems

Two-stage systems vary in design and are used more commonly for Low-Solids applications. Some designs operate the first stage at longer hydraulic retention times (HRTs) such as the UC Davis technology while others design the HRT of the first stage much less than the second stage. While two-stage systems are recognized as being more efficient than single-stage and grew in popularity during the 1990's, it appears that installations for organic wastes in Europe are trending to single-stage systems. It has been speculated that the added complication of an extra digester tank and associated component costs may not outweigh the higher efficiency benefits. At the same time, phased Low-Solids digestion installations for municipal biosolids are gaining popularity and growing in the United States. Few technology vendors offer two-stage systems for High-Solids; these include Linde and BTA. Many more technology providers offer Low-Solids two-stage AD systems including UTS Bioenergy, BTA, and Entec Biogas GMBH.

Anaerobic Phased Solids (UC Davis patented technology)

The UC Davis Anaerobic Phased Solids (APS) technology is a two-phase process. The first phase are multiple anaerobic High-Solids hydrolysis tanks operated in batch mode, in the thermophilic temperature range and with a hydraulic retention time (HRT) of about 12 days. The second phase includes a continuous Low-Solids methanogenic reactor with an HRT of approximately 3 days. The UC Davis technology has been successfully tested at the bench-scale level and the pilot-scale AD system at the UC Davis campus utilizes similar technology. UC Davis researchers are planning pilot testing during 2011of the feedstocks presented in Section 4.0 of this study.

While minor differences exist between technology suppliers with regard to design features and modes of operation, overall performance of phased anaerobic systems is similar from supplier to supplier when using similar design criteria such as hydraulic retention time. As such, it is expected that the APS system would perform similarly to other available phased anaerobic systems from other suppliers. One unique benefit of the UC Davis system is that it utilizes multiple hydrolysis reactors. A secondary goal of the READ facility is to promote research of the APS technology for different feedstocks. Multiple reactors allow delivering a single type of feedstock to a single reactor for evaluating treatment performance for a given feedstock. In this way, the APS technology has a slight competitive advantage over other technology suppliers. **Figure 4** is a photo of the UC Davis APS system.

Figure 3. High-Solids Anaerobic In-Vessel Digestion, Barcelona Spain

Figure 4. APS Demonstration Plant

5.3 Dry Fermentation

The use of organics derived from MSW as a feedstock for AD is an evolving industry and includes the advancement of new technologies. One such advancement has been particularly achieved in Europe in response to the need to meet current strict regulations limiting quantities of biodegradable waste that can be disposed in landfills. The cost of traditional Low-Solids AD systems for MSW derived feedstock materials has been too high to be financially attractive. As a consequence, several companies have developed "dry fermentation" digestion technologies primarily for the treatment of mixtures of biosolids, green waste and food waste. Dry fermentation AD systems are being considered in the United States as a method to efficiently utilize and manage non-liquid organic wastes. Dry systems can use input organic material that has much higher total solids content of up to 60% (i.e., if the material is stackable).

Bunker Type Dry Fermentation

For dry fermentation AD processes, the organic material is maintained in bunker-type reactors at solids concentrations of up to 50 to 60%. There are a several variations on the use of this technology where a different method of liquid circulation through the solids is employed. Bunker-type dry fermentation facilities consist of a series of concrete bunkers equipped with air tight ceilings and doors. The materials are typically loaded using a front-end loader; hence require a stackable feedstock composition. If the feedstock contains high water content to the extent it is not stackable, bulking materials such as chipped wood are used to increase porosity as well as improve the ability to stack the material in the bunker. The bunkers are filled and the door sealed closed to initiate the anaerobic phase. The bunkers are equipped with a liquids circulation system and a biogas collection system. Depending upon the manufacturer's recommendations, the feedstock is moisture conditioned and biogas is extracted from the closed bunker. After the digestion process the bunker is purged with fresh air to cease the anaerobic phase. The purged air is collected and treated in a biofilter to remove odorous and problematic air. The material is removed from the bunker using a front-end loader. The digestate is typically stabilized in a brief aerobic composting phase.

Typically these systems do not employ a method of mixing due to the solid nature of the feedstock; rather, a method of liquid recirculation is used. Unlike Low-Solids and High-Solids systems, dry fermentation plants are designed around the principle that microorganisms are more easily moved than a large amount of material. To facilitate digestion, water is recycled through the system and percolated through the mass of waste by the forces of gravity. This allows the organic input to remain stationary for the digestion retention time while the needed biochemical interactions still occur. Because the mass stays stationary, the overall structure of a dry fermentation plant is very different than a wet plant. There are no moving parts inside the fermentation bunker.

Digestate material from a dry digestion process is solid in character so it does not require dewatering prior to the further processing that is required to biologically stabilize the mass (e.g., composting) prior to use. Dry fermentation is operated in a batch mode. Once gas generation peaks and declines, the partially stabilized organic matter can be aerobically cured and used as compost.

Dry fermentation offers many advantages for the processing of the organic fraction of the waste stream. Because material does not require movement or pumping in a dry AD plant, pre-processing of the input materials to remove plastic bags and other inert materials is significantly reduced. Input material does not need to be ground, diluted with water, nor even have the contaminants removed. These systems do not require dilution of the feedstock. As a result, centrate from a digestate dewatering process found in Low-Solids and some High-Solids systems is eliminated and does not impact a local municipal WWTP that may need to accept and treat a centrate stream.

The operation and maintenance of dry digesters include some complexities not seen with other technologies. The feedstock handling is complex as the waste is no longer a liquid stream and like High-Solids systems, conveyance of the feedstock can be challenging and is typically done with front-end loaders or similar manually operated equipment.

Using a dry fermentation system minimizes processing costs, both prior to and after digestion, and the use of water and other resources within the system itself. This allows for the most efficient and productive recovery of resources within the organic material. One disadvantage of a dry fermentation system is that it produces less biogas compared to Low-Solids and High-Solids systems which must be considered when evaluating the economics of these systems. **Figure 5** is a typical bunker-type dry fermentation facility.

Figure 5. Dry Fermentation Bunker-Type Facility, Europe

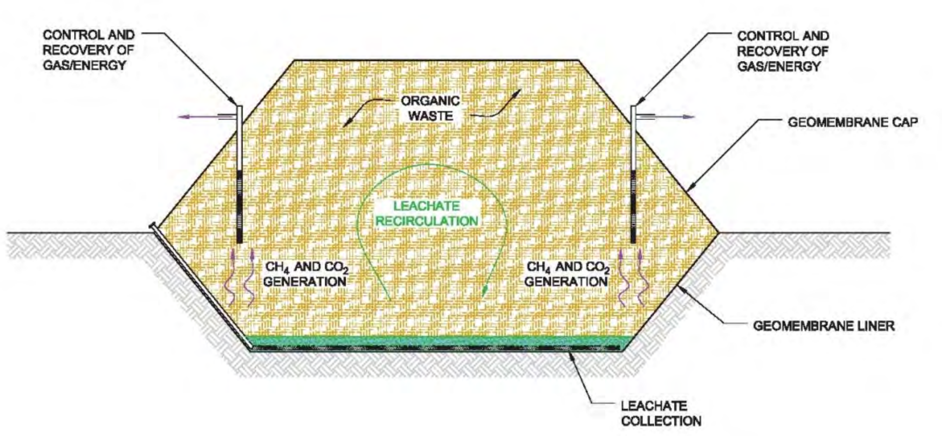
Flexible Membrane Type Dry Fermentation

The use of a flexible membrane liner (FML) to enclose the dry fermentation process is also possible. The use of an FML is growing in popularity in the US for several solid waste management organizations who own/operate landfills. The FML type system is a low cost alternative method of using a bunker-type dry fermentation process described above. The FML type process employs an HDPE (high-density polyethylene) membrane type containment system, typically on a landfill rather than in a concrete bunker or tank reactor system. The FML type dry fermentation process employs a technique to efficiently process large quantities of organic waste without constructing the concrete bunker enclosure described above. The FML-type dry fermentation process is in essence a combination of existing organic waste processing technologies including anaerobic digestion and composting but it requires less capital as it takes place within a landfill cell.

Anaerobic digesters produce a stabilized material in a matter of days or weeks; composting systems stabilize materials in a matter of months; but the FML-type residence time depends on a number of factors such as organic waste mixture, initial moisture content, leachate recirculation efficiency, and temperature. The time required can range from six months to a few years to complete the entire stabilization process. The benefit of the FML-type system is that it does not require the organic waste to undergo extensive pre-processing and/or handling during the process, and has a lower capital cost than other techniques used to process and recycle organic waste because it can utilize an existing landfill cell and does not require new infrastructure to be constructed.

The FML-type system involves the sequential application of anaerobic degradation, aerobic decomposition and residuals mining in a single module. Once the module is filled it is capped and sealed with an impermeable geomembrane liner. After the module is sealed it is operated as an anaerobic digester to recover biogas generated as the organic waste degrades. Once the anaerobic phase is completed, the biogas is extracted to produce energy. After the digestion phase is essentially complete, air is pushed into the module to create an aerobic condition to finish the composting process. The finished compost is then exhumed from the module. Once the material has been removed, a final curing step is conducted prior to the use of the stabilized material. Once the material has been exhumed, the empty module is then ready to accept new organic material to begin the process once again. The FML-type system anaerobic digestion phase is designed to treat many biodegradable wastes, such as biosolids, and other organic wastes generally not considered for conventional composting, such as animal by-products, meat and cooked food. **Figure 6** illustrates an FLM-type system.

Figure 6. Illustration of Flexible Membrane type dry fermentation module



5.4 Economic Considerations of Various Digester Technologies

HDR prepared a preliminary economic comparison of the three digester technologies to aid UC Davis in selecting a digester technology for the READ facility.

As described earlier, Low-Solids systems typically require larger reactors compared to High-Solids and dry fermentation systems. In addition, Low-Solids systems yield a wet digestate that must be dewatered and a centrate stream from dewatering that must be treated. For these reasons, Low-Solids digestion is typically more costly than High-Solids and dry fermentation technologies. At the same time, Low-Solids digestion is more effective at digesting organic material and therefore produces slightly greater biogas for recovery.

Order-of-magnitude cost opinions were developed for the three technologies sized to digest UC Davis campus food waste and animal waste (without MSW). The resulting economic comparison is presented in **Table 4.** This analysis indicates a Low-Solids technology is the most capital intensive and that dry fermentation yields the lowest revenue due to reduced unit biogas production. On a present value (or, present cost) basis, a High-Solids system appears to be most economically favorable.

Table 4. Economic Comparison of Digester Technologies

Digestion Technology	Capital Cost ($M)	Annual O&M Costs	Annual Revenue	Present Cost ($M)
Low-Solids	$16.6	$750,000	$720,000	$17.1
High-Solids	$14.4	$730,000	$760,000	$14.0
Dry Fermentation	$14.6	$660,000	$550,000	$16.1

5.5 Summary of Various Digester Technologies

HDR prepared the following summary of digester technologies. In terms of appropriate feedstock material, by-products produced and advantages and disadvantages, the three digester technologies are summarized in **Tables 5, 6 and 7** below:

Table 5. Digester Technology Preferable Feedstock and Dilution Rate Summary

Digestion Technology	Preferable Feedstock Type	Dilution rate
Low-Solids	Highly soluble organics such as manures, food waste	Feedstock diluted with 8 to 10 times the feedstock quantity with water (to approximately 95% water, 5% solids)
High-Solids	Moderately soluble organics such as manures, food waste	Feedstock in some cases diluted with 2 to 4 times the feedstock quantity with water (to approximately 80% water, 20% solids)
Dry Fermentation	Stackable organics such as green waste mixed with food waste	Feedstock not diluted. Feedstock saturated with water (to 50% water, 50% solids)

Table 6. Digestion Technology Effluent, Digestate and Biogas Summary

Digestion Technology	Liquids (Effluent)	Solids (Digestate)	Gas (biogas)
Low-Solids	Highest quantity of liquid effluent which would likely require treatment.	Digestate pumped from digesters as a slurry and requires dewatering. Digestate requires bulking and stabilization, typically using composting.	Greatest biogas production.
High-Solids	Moderate quantity of liquid effluent which would likely require treatment.	Digestate pumped or augured from digesters as a pulp often requires dewatering. Digestate requires bulking and stabilization, typically using composting.	Moderate biogas production.
Dry Fermentation	Likely no liquid effluent to be managed.	Digestate extracted from digesters using front-end loaders as a compost-like material, does not require dewatering. Digestate requires stabilization but not necessarily bulking. Stabilization typically using composting.	Lowest biogas production.

Table 7. Summary of AD Technology Advantages and Disadvantages

Technology	Advantages	Disadvantages
Low-Solids Technology	Is a common technology employed throughout the US for the treatment of waste water. Relatively simple material conveying. Efficient destruction of organic volatile solids. Is an appropriate technology to treat the UC Davis feedstock materials evaluated. Potentially less material handling equipment in digesters.	Larger reactors (tanks) required consequently more capital expense required to construct. Often requires supplemental dilution water. Requires robust pre-processing necessary to remove inerts to facilitate use of mixing systems. Also potential for lost of volatile solids with removal of inert fraction in pre-treatment process. Requires digestate dewatering and centrate management. Potential for liquid/solids separation in reactor.
High-Solids Technology	May eliminate or reduce the need for dewatering and centrate management. Less pre-processing required than dry fermentation. Also less likely for volatile solids loss in pre-treatment Is an appropriate technology to treat the UC Davis feedstock materials evaluated Requires relatively smaller tank capacity than Low-Solids and therefore has lower	Difficult to convey material. Requires robust material handling equipment. Little to no operating experience in US. Limited ability to digest high nitrogen feedstocks particularly for thermophilic operation. May require dilution water to maintain proper inhibitor levels.

Technology	Advantages	Disadvantages
	capital and operating cost. Supplemental water source for feedstock dilution typically not required.	
Dry Fermentation Technology	Pre-processing is not required. Consequently, no loss of volatile solids in pre-treatment. Dewatering and centrate management not required. Supplemental water not needed for dilution. Relatively low capital cost. Relatively low operational requirements. No pumping or mixing required (liquids are circulated through media as opposed to circulating the media as a liquid).	Requires a stackable feedstock (i.e. green waste, yard trimmings, chipped wood, etc.) Little to no operating experience in US. Less efficient at organic solids destruction, consequently less biogas produced per ton of feedstock. Is likely not an appropriate technology to treat the UC Davis feedstock materials alone (would require augmentation of additional green waste feedstock).

5.6 Recommended AD Technology

The use of anaerobic digestion for food waste or similar types of organic wastes typically managed as solid wastes has developed in Europe primarily in response to public policies that banned the disposal of organics in landfills and promote renewable energy sources. The use of anaerobic digestion to treat organic wastes typically managed as solid waste is largely undeveloped in the United States. [7] Although there is a growing desire to explore the use of digestion to treat solid waste derived organics using all three types of technologies discussed above, there is not a clear preference established at this time. Consequently, the specifics of key issues such as feedstock, site constraints and potentially beneficial use of by-products are preferred factors for determining the preferred type of treatment technology.

Based on the feedstock analysis and further discussions with UC Davis staff, there is little green waste available at the campus for use as a feedstock to the READ facility. For a dry fermentation process to be viable, supplemental green waste would need to be hauled to the READ facility from off-campus which is unnecessarily costly. Furthermore, there is little operating experience with this technology in the United States. As a result, dry fermentation does not appear to be the appropriate AD technology for UC Davis.

While a Low-Solids AD system appears technically viable, this technology appears to be marginally more expensive than High-Solids technology (as presented earlier in **Table 4**). This is due to a variety of factors such as tank size and additional liquid effluent treatment. Also, dilution of the feedstock for Low-Solids AD systems are likely to create additional liquid effluent treatment processes adding to operational costs. UC Davis staff has indicated that the existing WWTP has limited capacity to accept and treat liquid effluent. Low-Solids AD would

[7] *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, March 2008, California Integrated Waste Management Board*

produce the highest quantity of liquid effluent, which is an additional deterrent to using this technology. Further, the feedstocks available at UC Davis appear to be more suitable for High-Solids digestion as opposed to dry fermentation due to the lack of adequate quantities of green waste feedstock material.

Because there is no clear advantage of using Low-Solids AD over a High-Solids technology, High-Solids technology appears to be the most suitable digestion technology for the READ facility based on this cursory review. Process details including the implementation of phasing rather than single stage operation, mesophilic versus thermophilic operation, and continuous versus batch operation will be completed during preliminary design of the system. There are a variety of High-Solids AD technologies available which could be employed, one of which is the APS technology developed by Dr. Ruihong Zhang. Other potentially viable tank type High-Solids AD technologies include Continuous Plug flow AD or similarly, low cost High-Solids AD technologies include lagoon type AD.

At this feasibility planning level of analysis, there are no clear advantages to the other High-Solids type AD technologies when compared to the APS technology by Dr. Zhang. Consequently, for purposes of the feasibility study, it is assumed the UC Davis APS (High-Solids) AD technology will be utilized. The APS technology has the ability to accept and test various organic feedstocks which fits with UC Davis' objective of providing additional AD research using the READ facility. Other systems don't necessarily provide this flexibility. Section 7.0 below provides a discussion of the UC Davis APS patented digesters. Other high-solids digestion technologies can and may be considered as the READ facility enters the preliminary engineering phase and more detailed design is developed. During preliminary engineering design, detailed mass, water, and energy balances will be developed.

6.0 Biogas Uses

Biogas generated during anaerobic treatment can be recovered in a variety of ways at the READ facility to generate electricity or to provide an additional heat source at the UC Davis campus. A summary of select technologies to utilize biogas from the READ AD system is provided below.

6.1 Condition of Biogas

Biogas generated from the AD facility may contain approximately 60 to 70% methane, 30 to 40% carbon dioxide, hydrogen sulfide, and other trace gases. The biogas from the AD reactors will also be saturated with moisture. As the biogas cools during handling, water will condense in biogas piping and therefore provisions for condensate removal must be considered.

Depending on how biogas is recovered and utilized as described below, extraneous biogas constituents including water, sulfur, carbon dioxide, and siloxanes, may need to be removed from the gas before it is utilized. Furthermore, air emission restrictions may require additional biogas treatment upstream of utilization beyond what may be required by the biogas utilization equipment. Therefore careful consideration of biogas quality is important to properly account for biogas treatment requirements needed for a particular facility.

The following sections describe the extent of biogas cleanup required for each of the uses stated**. Table 8** below provides a range of biogas cleanup required for each of these uses.

6.2 Electricity Generation

6.2.1 Internal Combustion Engines

Internal Combustion (IC) Engines are the most widely used technology for generating electricity from biogas. IC Engines sizes range from approximately 300 kW to 3 MW and larger. Electrical efficiency for IC Engines may range between approximately 32 and 38%. Heat is recovered from IC Engines providing there is a location the heat can be utilized, otherwise the heat must be wasted. For the READ facility, heat would be recovered from the IC Engine for heating the digester tanks. If heat is recovered, the combined electrical and thermal efficiency when using an IC Engine is approximately 60%. A disadvantage of IC Engines is that they characteristically produce higher air emissions compared to other electrical generation technologies for biogas. However, IC Engine capital cost is competitive when comparing this engine to other methods for generating electricity.

For IC Engines, it is generally recommended that moisture be substantially removed (to less than 80% relative humidity) from the biogas prior to sending it to an IC engine. Sulfur should also be removed (to less than 250 parts per million by volume) from the biogas to reduce sulfur air emissions from the IC engine. To achieve these gas quality requirements, it is assumed a chiller system and iron sponge would be used for moisture and sulfur removal. For budgetary purposes the chiller and iron sponge would consist of a pre-manufactured skid mounted system similar to those used for landfill gas type cleanup systems.

6.2.2 Micro-turbines

Microturbine technology is gaining in popularity over the past decade for smaller applications with sizes ranging from about 30 to 250 kW electrical output. Microturbines require that moisture be removed from the biogas and the biogas must be pressurized to approximately 75 psi, much higher than internal combustion engines. An advantage of microturbines is that they produce low emissions compared to IC Engines. A disadvantage of microturbines is their electrical efficiency which ranges between approximately 24 and 30%. Heat can be recovered from microturbines (albeit a relatively small amount considering the quantity of biogas consumed) and have a combined electrical and thermal efficiency of up to approximately 50%.

Similar to IC Engines, moisture must be removed from biogas prior to combustion in the microturbines but to an even greater extent than that of IC Engines (less than 40% relative humidity). Sulfur should also be removed from the biogas to reduce sulfur air emissions from the IC engine. Microturbine manufacturers commonly require less than 25 parts per million by volume. Due to the increased level of biogas cleanup necessary for the microturbine a corresponding increased cost would be appropriate for biogas conditioning prior to use in a microturbine.

6.2.3 Fuel Cell

Fuel cell technology is an emerging method for generating electricity in the waste treatment industry. Fuel cells are different from other electricity generation technologies in that they employ a non-combustion technology, specifically, an electro-chemical process using hydrogen (contained in the methane) and oxygen from supplemental air addition to produce electricity and heat. As such, the fuel cell offers the lowest emissions profile when compared to the combustion-type technologies. The process utilizes an anode and cathode including an electrolyte between them and functions similar to a battery. A reforming process within the fuel cell creates hydrogen gas from methane. The hydrogen gas is consumed electrochemically along with carbonate from the cathode to produce water and electrons. The electrons flow through an external circuit which produces power.

The fuel cell process is approximately 45 to 50% electrically efficient and more efficient than combustion processes used to generate power. Like combustion technologies, waste heat is generated using fuel cells which can be recovered to supplement facility heating demands. The combined electrical and thermal efficiency of a fuel cell can be 70% or greater. In addition, fuel cells produce ultra-low emissions which are an advantage where facilities may be limited by air quality standards.

A disadvantage of fuel cells is that they require scrubbing of biogas to remove essentially all sulfur as well as moisture and particulates. More so than the microturbines discussed above, fuel cells require pipeline quality natural gas. Consequently, moisture and sulfur must be removed to or below detection levels, much more so than IC Engines and micro-turbines. The moisture (relative humidity) level for the fuel cell is stipulated by the dew point at the pressure level delivered to the fuel cell at the lowest possible temperature at the site over the life of the fuel cell. Sulfur should also be removed from the biogas to the range of less than 10 parts per million by volume. Due to the increased level of biogas cleanup necessary for the fuel cell a corresponding increased cost would be appropriate for biogas conditioning prior to use in a fuel cell.

The second disadvantage of fuel cells is their cost. Fuel cells can cost up to twice that of other electricity generation methods. However, grants and other incentives may be available particularly in California to partially offset the fuel cell's higher cost.

6.3 Beneficial Use as a Boiler Fuel Source

An efficient means to capture energy contained in biogas is to burn it in steam or hot-water boilers. Steam boilers are approximately 80% efficient in producing energy in the form of steam. Many industrial facilities that use AD to treat waste and utilize boiler systems choose to capture and return biogas to existing facility boilers to supplement natural gas use. Typically, minor improvements and modifications are necessary to allow biogas to either be blended with natural gas boiler feed or burned directly in boilers. As a result, using biogas in existing boilers is an attractive option providing boiler facilities are in close proximity to AD facilities. Emissions from boilers are moderately high and as a result boilers are typically fitted with special burners to reduce air pollutants, particularly, NO_x emissions. Gas treatment is expected to be required prior to utilizing biogas especially if a facility is trying to limit its sulfur emissions. If sulfur emissions are not a critical concern, gas treatment may not be required prior to utilization.

The Primate Center requires a large amount of energy to support facility heating requirements. Two large boilers (#1 and #2 boilers) serve the Primate Center area of the campus and are sized at 10 MM Btu/hr and 7.5 MM Btu/hr, respectively. Both boilers utilize natural gas as the fuel source, however, the #2 boiler also blends landfill gas with natural gas as its fuel source. It appears the capacity of these boilers would allow biogas generated from the READ facility to supplement natural gas use in Boilers #1 and/or #2. Since landfill gas is already blended with natural gas, it appears biogas could feasibly be combined with natural gas as boiler feed fuel. The use of biogas at the Primate Center would be possible for two of the possible sites (Landfill site and Hopkins Road site) but would not be feasible for the WWTP site due to the length of the pipeline required to deliver biogas to the Primate Center boilers. Also, we have been informed the existing use of landfill gas has been consistent and that the heating requirements of the Primate Center are projected to be high enough to use the estimate quantity of biogas generated by the READ facility, should the biogas be directed to the Primate Center.

Similar to IC Engines and microturbines above, moisture must be removed from biogas prior to being compressed and conveyed to the Primate Center to avoid condensate formation in the biogas transmission pipe. Similarly, sulfur is also assumed to be removed from the biogas to reduce sulfur air emissions from the boiler. To achieve these gas quality requirements, it is assumed a chiller system and iron sponge similar to the IC Engines above would be used for moisture and sulfur removal. For budgetary purposes the chiller and iron sponge would consist of a pre-manufactured skid mounted system similar to those used for landfill gas type cleanup systems. Also this use of biogas would require a larger compressor than the IC Engine assumptions. For budgetary purposes, the use of biogas is assumed to require a new dedicated pipe to convey the biogas to the Primate Center at an approximate cost of $400,000.

6.4 Bio-methane

Bio-methane is biogas that has been cleaned to a quality standard typical of natural gas. Under such cases, moisture, particulates, carbon dioxide, and sulfur are removed from biogas to leave essentially pure methane, or bio-methane. The bio-methane can then be injected into a natural gas utility's pipeline or be used as a compressed natural gas (CNG) fuel for vehicles or other equipment. The disadvantage of producing bio-methane is that relatively extensive gas treatment is required specifically for removal of carbon dioxide. Depending on the point-of-use of the bio-methane (vehicle fueling, natural gas pipeline), bio-methane can be an attractive alternative.

6.5 Biogas Generation and Recovery at UC Davis

The average quantity of methane projected from the READ facility using the APS technology is estimated to be approximately 59,000 scfd to 109,000 scfd (depending on the scenario chosen), which has a raw energy value of about 2.6 million Btu/hr. to 5.0 million BTU/hr. Several uses of the methane are potentially available, including supplementation of existing natural gas use in boilers at UC Davis facilities (such as the Primate Center), electricity generation using fuel cells, internal combustion engines or mictroturbines, cleaning of the biogas for injection into the natural gas pipeline or use in vehicles that use compressed natural gas. Of these alternatives, utilizing the biogas in existing boilers is typically the most cost effective and efficient means for utilizing the methane unless the cost to convey the gas to the boiler facility or there is a large demand for waste heat generated with the use of fuel cells, internal combustion engines or mictroturbines. A portion of this waste heat from electrical power generating devices could be used for digester heating yet excess heat would still be available. We understand the Primate Center management may be making modifications to its existing boiler system that could include continued use of the existing landfill gas and use of biogas from the READ facility.

Alternatively, the biogas could be cleaned to pipeline quality or converted to electricity using an IC Engine, microturbine or fuel cells. Any one of these means for recovering biogas could be employed for each digester technology presented earlier. That is, the biogas quantity or quality from each digester technology will be similar and does not dictate which biogas recovery option should be used for the READ facility. Any biogas recovery alternative could be used for any one of the digester technologies presented above. A summary of the biogas alternatives including advantages and disadvantages is provided in **Table 9** below.

Some of the biogas recovery alternatives described above requires unique feed gas composition or qualities and therefore the extent of gas cleaning varies between biogas recovery alternatives. UC Davis expressed interest in understanding relative cleaning costs for the different recovery technologies. **Table 8** summarizes equipment and their costs for biogas treatment technologies associated with each alternative. Costs are based on Scenario A biogas flows. **Table 8** indicates that the cleaning requirements are the most robust for bio-methane production since CO_2 removal is required for this alternative. Among the remaining options, gas cleaning for fuel cells is the next most extensive. The requirements for cleaning biogas for recovery as a supplemental fuel in existing boilers or use in an IC Engine are similar and reflect the lowest cost option.

Table 8. Summary of Various Biogas Cleaning Costs-Comparison for Various Recovery Alternatives

Biogas Recovery Alternative	Technology Approach to Biogas Cleaning	Range of Potential Biogas Cleaning Equipment Costs (20%/+40%)
Recovery in Existing Boilers	• Chiller system (moisture removal) • Single stage iron sponge (sulfur removal)[1]	\$180,000 - \$320,000
IC Engine	• Chiller system (moisture removal) • Single stage iron sponge (sulfur removal)	\$180,000 - \$320,000
Microturbine	• Chiller system (moisture removal) • Two-stage iron sponge (sulfur removal) • Media filter (particulate removal)	\$230,000 - \$410,000
Compressed Natural Gas (biomethane)	• Water scrubber (CO2 and H2S removal) • Biofilter (air stripper off-gas)	\$520,000 - \$920,000
Fuel Cell	• Chiller system for (moisture removal) • Two-stage iron sponge (sulfur removal) • Activated Carbon Filter (organic sulfur removal) • Media filter (particulate removal)	\$290,000 - \$520,000

[1]could be eliminated depending on air emission permitting limits.

Table 9. Summary of Biogas Recovery Alternatives

Biogas Recovery Alternative	Advantages	Disadvantages
Recovery in Existing Boilers	• Moderately low cost. • Would expand upon the current practice of using landfill gas as a supplement to the natural gas boilers at the Primate Center.	• Adds complexity to boiler operation. • Would be limited to use for sites within close proximity to the Primate Center.
IC Engine	• Well established technology. • Moderately low cost.	• Potentially higher NOx could result in higher permitting costs.
Microturbine	• Available in small sizes compatible to UC Davis biogas generation. • Less NOx is generated so potentially less permitting.	• Low efficiency (~25-30% overall efficiency). • Moderately high cost. • Less established use.
Compressed Natural Gas	• Available pipelines nearby candidate READ facility sites. • Efficient use of gas.	• Significant biogas cleaning needed. • Moderately high cost.
Fuel Cell	• Highest efficiency (~47% electrical efficiency). • Less NOx is generated, so potentially less permitting.	• Highest cost. • Significant biogas cleaning needed.

Preliminary cost estimates for using fuel cells indicate it will be approximately two to three times the capital cost of the other alternatives. If grant monies can be obtained for the use of fuel cells that make the fuel cell attractive, use of the fuel cell should be considered. Otherwise, fuel cells do not appear to be an economically attractive alternative for the READ facility. These grant opportunities will be monitored as this feasibility study and the preliminary design of the READ facility continues. If such funding is significant enough, fuel cells will be considered, however, at this stage they are not considered for use at the READ facility.

IC Engines have successfully been utilized for converting biogas to electricity and are the lowest cost compared to other viable electricity generating technologies at the READ facility. It is assumed IC Engines would be used for generating electricity at the READ facility. As this project develops into preliminary design, the finer details of using a microturbine or creating CNG or use of the biogas as a supplement to natural gas for boiler fuel at the Primate Center could be compared to an IC Engine.

7.0 Consideration of READ Facility Scenarios

To analyze a range of costs and associated site development issues of the READ facility reflecting the High-Solids digestion technology, HDR prepared three scenarios utilizing the UC Davis APS patented technology as a representative High-Solids digestion system as follows:

- Scenario A: Scenario A represents the lowest cost alternative, consisting of the minimum components needed for a functional READ facility. This facility would receive only source separated manure and bedding, along with food waste which is assumed to be relatively free of contaminants and therefore require a minimal pretreatment effort. By limiting the feedstock to source separated sources, the facility would not be equipped with the pre-processing elements described in Scenarios B and C below. The facility would function with the digestion, biogas treatment, digestate dewatering and liquid effluent treatment systems, but would rely on land spreading of the digestate on agricultural lands in an effort to save costs. The liquid centrate would be treated using a conventional biological nitrogen removal process. Insomuch as the feedstock materials are primarily manures which would be stabilized by the digestion process, it is assumed that land application of the digestate would be viable. HDR recognizes further study would be needed to evaluate the affect on surface water, groundwater and nutrient loading rates for this scenario to be employed. However, for planning purposes, this scenario offers the lowest cost alternative for implementing a digestion technology, albeit with limitations. This scenario would lack the ability to store and stage feedstock materials and would not include the digestate dewatering and composting components. However, the facility would be equipped with an air collection and treatment system (using a biofilter) to contain and treat potentially objectionable odors, particularly at the waste receiving building.
- Scenario B: This scenario would process the same source separated material as Scenario A, but would also include the materials storage components digestate dewatering components and a digestate stabilization/composting system. The unique variations of this scenario include an enclosed unloading and manure storage facility to allow blending of the feedstock materials prior to blending and pumping into the digester tanks. This scenario would employ a composting process to stabilize the undigested solids (digestate), producing a useful soil amendment. The liquid centrate would be treated using a conventional biological nitrogen removal process. Potentially objectionable odors would also be contained and treated using a biofilter system, similar to Scenario A, but enlarged to accommodate the treatment of air collected during the active composting phase of the digestate stabilization process.
- Scenario C: Scenario C reflects a facility that would receive municipal solid waste (MSW) in addition to the source separated organic material described in Scenarios A and B. In order to extract the organic fraction of the MSW, a robust pre-processing system would be required to remove undesirable materials from the feedstock. To contain the odors from the larger pre-processing facility, a larger building enclosure would be included. Following pre-processing and separation, the organic fraction of the MSW would be blended with the source separated organic material and digested using an array of digesters, biogas treatment and effluent treatment systems similar but larger than those in Scenarios A and B. With the

higher volume of organics being treated in the facility, the resulting digestate composting, curing and related facilities would also be larger than Scenario B. The digestate for Scenario C is envisioned to require stabilization using a composting process prior to being ready for commercial use. The liquid centrate would be treated using a conventional biological nitrogen removal process. Again, potentially objectionable odors would also be contained and treated using a biofilter system, similar to Scenario B, but enlarged to accommodate the treatment of air from the increased tonnage and associated expanded facilities.

A comparison of key factors for three scenarios is provided in **Table 10** below:

Table 10. Comparison of Scenarios

	Scenario A	Scenario B	Scenario C
Feedstock (type)	Manures, Bedding, Food Waste	Manures, Bedding, Food Waste	Manures, Bedding, Food Waste, MSW
Feedstock delivered to the facility (annual average wet tons per day)	22.3	22.3	47.1
Feedstock Available for Digestion (annual average wet tons per day)	22.3	22.3	35.3
Expected Methane Generation (scfd)	59,500	59,500	109,000
Energy Contained (Million Btu/year) in Biogas	23,200	23,200	41,100
Capital Cost	$8.3M	$14.4M	$23.7M
Annual O&M Cost	$700,000	$731,000	$1,040,000
Annual Revenue	$663,000	$763,000	$1,300,000
Net Present Cost (6%, 30 years)	$8.8M	$14.0M	$20.1M

HDR prepared this study with the understanding that the READ facility has the option of processing one of the following compositions of feedstock:

- Animal manure and bedding from a wide variety of campus agricultural facilities, combined with source separated food waste from the campus dining commons.
- Municipal solid waste combined with animal manures, bedding, and food wastes.

The facility requirements and economics of these two feedstock sources were evaluated and three concept-level configurations were chosen to represent the wide range of possibilities for the READ facility. These three different scenarios are not site specific and can be modified to accommodate specific potential sites, feedstocks, and technologies.

Scenario A would process approximately 22 tons per day of various campus manure and bedding sources as well as source separated food wastes from the campus food preparation facilities. **Figure 7** shows a conceptual layout for the Scenario A READ facility. This scenario would consist of the following features:

- a small feedstock receiving and storage building equipped with grinding, screening and dilution of the arriving materials,
- a series of above ground anaerobic digestion tanks,
- pumping systems, buffer tanks, etc.,
- a gas clean-up compression system,
- an IC engine system,
- a digestate removal and dewatering system and truck transport facility for land application of the dewatered digestate,
- a conventional biological nitrogen removal system for liquid effluent, and
- an air collection and control system including biofilters or scrubbers.

Scenario B would process approximately 22 tons per day of various campus manure and bedding sources as well as source separated food wastes from the campus food preparation facilities (the same feedstock as Scenario A). This composition of feedstock is the same as the one for Scenario A, but uses a larger feedstock receiving and processing building and has a complete composting system for managing digestate. **Figure 8** shows a conceptual layout for the Scenario B READ facility. This scenario would consist of the following features:

- a feedstock receiving and storage building equipped with grinding, screening and dilution of the arriving materials,
- a series of above ground anaerobic digestion tanks,
- pumping systems, buffer tanks, etc.,
- a gas clean-up compression system,
- an IC engine system,
- a digestate removal and dewatering system,
- a conventional biological nitrogen removal system for liquid effluent,
- a composting system consisting of windrows (for digestate stabilization), and
- an air collection and control system including biofilters or scrubbers.

Scenario C would receive and pre-process approximately 25 tons per day of municipal solid waste (MSW) which would result in an organics recovery rate[8] of approximately 13 tons per day of organics which would then be combined with the approximately 22 tons of feedstock materials in Scenarios A and B above (various campus manure, bedding, and food waste

[8] *Integration of Rotary Drum Reactor and Anaerobic Digestion Technologies for Treatment of Municipal Solid Wastes, Ibid*

sources). The overall combined processing capacity of 47 tons per day would reflect the quantity of material arriving at the site per day. The digesters would receive approximately 35 tons per day of organic material. **Figure 9** shows a conceptual layout for the Scenario C READ facility. This scenario would consist of the following features:

- a feedstock receiving/storage and preparation building for grinding and screening of the arriving materials,
- a feedstock preparation phase consisting of a rotating drum pretreatment system, followed by a screening and feedstock quality confirmation function,
- a recovered materials shipping and off-site transfer function,
- a series of above ground anaerobic digestion tanks,
- pumping systems, buffer tanks, etc.,
- a gas clean-up compression system,
- an IC engine system,
- a digestate removal and dewatering system,
- a conventional biological nitrogen removal system for liquid effluent,
- a composting system consisting of windrows (for digestate stabilization) and
- an air collection and control system including biofilters or scrubbers.

In general, the READ facility will consist of a receiving/pretreatment facility, above ground anaerobic digestion tanks, a biogas to electricity facility, a composting system consisting of windrows (for digestate stabilization), and an air collection and control system to limit and contain problematic odors. The specific sizes of the various elements at the facility could vary depending upon the feedstock.

The project would function as follows:

- Collection vehicles carrying waste materials would arrive at the site and enter the scale-house facility, where the weight of the vehicle would be measured. The vehicle would then proceed to the unloading/receiving facility, enter the facility and unload its contents. After unloading, the vehicle will depart from the facility, weighing out at the scale before leaving the site.
- For Scenario A, the contents of the collection vehicle would be discharged directly into a container where the wastes would be blended, diluted and pumped into the digesters. No staging, storage or preprocessing function would be included. Consequently, the materials arriving for this scenario would need to be free of contaminants and appropriate for direct insertion into the digesters.
- For Scenario B, the contents of the collection vehicle would be discharged directly onto the floor of the receiving facility. Manures would be staged for blending into the digesters depending upon the availability of various other materials, so as to prepare an optimal

mixture of feedstock for blending and subsequent insertion into a digester. The unloaded waste materials will be managed using a front-end loader to deliver the materials into an appropriate storage or preprocessing area, depending upon the character of the material. The receipt, storage and pre-processing of wastes will occur within an enclosed building where the air within the building will be extracted and treated prior to being discharged to the atmosphere.

- For Scenario C, the MSW will be pre-processed to remove undesirable materials. The MSW will be visually screened to determine the level of pre-processing necessary. Based on the feedstock evaluation efforts, it appears manures will require only minor screening to remove rocks and other inert materials, while food waste from the cafeteria may require additional manual sorting. Depending upon the type of feedstock material and its contamination level, the waste materials will be screened. The screening pre-processing will remove materials which are not digestable such as sand, stones, broken glass and other inert materials. The residual organic materials will be ground, blended with the manure and food waste materials as described in Scenario B above, then mixed with water into a slurry and pumped into a hydrolysis tank to begin the digestion process.
- Once in the hydrolysis tank, the slurry will be mixed using a gas mixing system. The material will remain in the hydrolysis tank for between ten and fourteen days, depending upon the character of the material.
- Organic acids and reduced organics will be pumped or augered from the hydrolysis tank to a mixing tank. Here hydrolyzed fluids from several tanks will be blended and pumped into the methanogenic tank. Once in the methanogenic tank, the organic acids and reduced organics will be digested in a methanogenic bacteria rich environment.
- The biogas will be extracted from the top of the AD tanks and pumped to the gas processing facility, where a clean-up system will remove water and related undesirable components (depending on the end use of the biogas). Depending on the chosen configuration, the required infrastructure could include either a pipeline for delivery of the biogas to an internal combustion engine, a micro turbine or fuel cell for production of electrical power. Electrical power would be conveyed using the campus grid to power energy needs at the campus. The biogas management system would include a back-up flare to properly manage the biogas in the event the processing facility is not operational.
- Residual materials from digestion will be extracted from the digesters and incorporated into a composting system for stabilization to produce soil amendments.

Figure 7: Scenario A Conceptual Layout

Figure 8: Scenario B Conceptual Layout


Administration &
Public Education
Building
Feedstock Receiving
& Processing Building
5
Digester
Tanks
Blend
Tank
Biogas Conditioning
& Cogeneration
Methane
Digester Tank
Effluent
Treatment
R&D
Digester
Digestate
Dewatering
Biofilter
Compost Operations
Curing &
Sales Pad
Stormwater
Retention Pond

8.0 READ Facility Processing Elements and By-Products

Associated with the siting of this project are issues with regard to environmental impacts, political concerns and facility operational efficiency. There are several factors that influence the design of anaerobic digestion. Some of these factors include: the organic content of the material to be digested, feedstock biodegradability, nutrient content, solids content, and temperature. These factors are used to size AD facilities.

The end products of anaerobic digestion are: biogas, compost, and a solid or liquid residue. The biogas consists primarily of methane (60 to 70% by volume), carbon dioxide (30 to 40%), and trace amounts of hydrogen, hydrogen sulfide, and other gases. The key considerations in determining the most desirable configuration for the project elements include but aren't necessarily limited to the following:

- technical viability for processing the available feedstock,
- mitigation of odor impacts,
- thermal efficiency,
- costs,
- public acceptability,
- usefulness of the facility as an educational and public outreach tool,
- minimization of required infrastructure,
- risks to public safety from potential gas explosions, and
- planning and permitting logistics.

Operational efficiency considerations in choosing a configuration include: proximity of the power generation facility to the digesters, potential recovery of excess heat, liquid effluent management, potential separation of the pre-sorting system from the digesters, and possible isolation of the biogas management components.

The preferred configuration of processing elements will either enhance or diminish the public outreach and educational component of the project. Assuming the odor issues could be properly managed, the close proximity of the facility in its entirety to the public/educational elements would be preferable.

Other key concerns are making sure that the feedstock is appropriately managed and in sufficient supply, managing the gap between the production of biogas and the production of power, and sizing the elements for optimum efficiency.

8.1 Facility Processing Elements

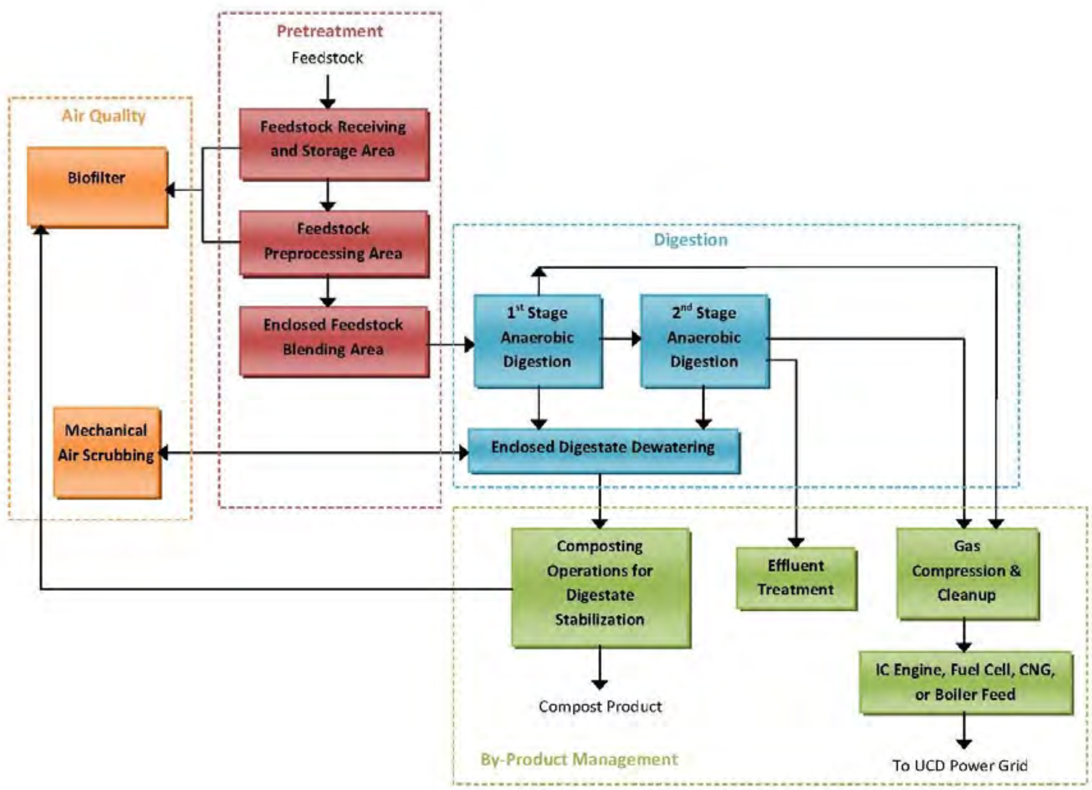
Facility processing elements broadly include:

1. Feedstock receiving and preparation

2. Anaerobic Digestion Components
3. Digestate Handling and Composting
4. Biogas Recovery

The attached **Figure 10** illustrates the typical facility configuration in a Process Flow Diagram.

Figure 10. Process Flow Diagram



8.2 Feedstock Receiving and Preparation (FRP)

The purpose of the FRP system is to allow for the receipt and unloading of the feedstock materials delivered to the READ facility and prepare the feedstock for the AD reactors in a form that can be adequately and easily conveyed and suitable for digestion. The FRP will provide appropriate phasing, pretreatment and preparation of the feedstock materials for insertion to the AD reactors depending upon the feedstock assumed to be tributary to the facility.

For Scenarios A and B, incoming feedstock is assumed to be source separated and therefore relatively free of contaminants. Consequently, these scenarios are believed to require minimal pre-processing for the removal of contaminants. The feedstock materials arriving at the facility would however be relatively high in solids. High-Solids feedstock materials cannot be easily be pumped and would require auger-type conveyance systems or special solids handling pumps for delivery to the AD system. The average TS content of the raw feedstock materials for the READ facility is approximately 44% solids. The proposed AD reactors are planned to operate at a feed TS content of approximately 15% solids. Treated liquid effluent from the READ facility could be recycled to the feedstock receiving area to dilute the feedstock to achieve this TS content. The diluted feedstock will allow simpler conveyance of the feedstock using pumps rather than augers. The second purpose of feedstock dilution is to reduce the nitrogen concentration of the feedstock in an effort to reduce the concentration of unionized ammonia in the downstream AD reactors and help prevent toxicity to the methanogenic bacteria. Dilution water will be added to the receiving pit which will include two submersible grinder/mixing pumps to help homogenize the AD feed and provide additional particle size reduction through grinding. Discharge from the digester feed pumps (or, augurs) will pass through two grinder units (one duty, one standby) to further reduce feedstock particle size and help protect downstream pumping equipment.

Scenario C is envisioned to utilize additional feedstock preparation and pre-processing equipment in comparison to Scenarios A and B. It is envisioned Scenario C will employ a rotating drum to pre-process the MSW feedstock. The purpose of the rotating drum is to allow the mechanical size classification of the organic contents of the MSW, separating the organic materials from the larger materials. This is accomplished by moisture conditioning the MSW from the approximate 35% arriving moisture content to approximately 55% to 60% moisture, followed by allowing the material to tumble in the rotating motion, converting the fiber content (paper, cardboard, etc.) into a paper-mâché type consistency. This material can be screened from the other contents of the MSW by passing through a relatively small screen size (approximately 3/8 inch to ½ inch). There are a variety of rotating drum designs with differing retention times, diameters, lengths and rotating speeds. The type of drum under consideration for this feasibility study is a drum that operates with a relatively high rotating speed (approximately 5 rotations per hour as opposed to 1 rotation per hour in others) with a correspondingly short retention time (approximately six hours as opposed to two to three days in others). The drum would be approximately ten feet in diameter and approximately 125 feet long and set a gradual declining slope to allow the contents of the drum to proceed slowly as the drum rotates. At this conceptual level of the feasibility analysis, we anticipate the MSW feedstock will be blended with decanted water from the methane reactor (described below) to reach the optimal moisture content when inserted in the rotating drum. Following the six hour retention time in the drum, the contents of the drum will be emptied and screened using a trommel screen with several screen sizes. The organic fraction of the MSW will pass through the fine screen size. This material will be blended with the manure and food waste described in Scenarios A and B above. A de-stoner will remove gravel and grit before being pumped into the digesters. We anticipate the 25 tons of MSW will require the addition of approximately 14 tons of water to reach the optimal moisture content for the rotating drum device. Following the rotating drum and screening, we anticipate 13 tons of organic material will be screened out for blending with the approximate 22 tons per day of manure and food waste.

8.3 Anaerobic Digestion Components

For purposes of the feasibility study, a phased AD system is proposed for Scenarios A and B which will include two to three hydrolysis/acidification reactors (HRs) and one methanogenic reactor (MR) with a total volume of approximately 225,000 gallons. Scenario C will include four to five hydrolysis/acidification reactors (HRs) and one methanogenic reactor (MR) with a total volume of approximately 420,000 gallons. The exact number of AD tanks and process design for the READ facility will be determined during preliminary design; however, the volumes presented here represent the required total volume to treat the incoming feedstock loads for each scenario.

Phasing of the AD reactors promotes hydrolysis of the organic material to a soluble, more digestable form and separates the acidification step from the methanogenic step of the digestion process. Separation of these two steps has proven to be a more efficient means of digestion compared to single-stage systems. Feed to the HRs will alternate and likewise feed from the HRs to the MR will alternate. Consequently, the HRs will operate in batch mode and the MR will operate continuously with regard to reactor feeding. The AD tank reactors will be circular, coated, bolted steel with the top section of the tank walls in the gas headspace constructed of stainless steel to protect against corrosion. The tanks would include rigid covers with connections for biogas withdrawal.

The AD reactors will include mixing systems and it is assumed for purposes of the feasibility study that unconfined gas mixing systems will be used. Gas mixing is preferred since it is better suited to digesters operating at higher TS content. Other mixing alternatives such as pumped mixing, or mechanical mixing are potentially viable and can be considered during the preliminary design phase of the facility. An unconfined gas mixing system utilizes gas compressors to compress and recirculate biogas from the headspace of the digester through lances located near the bottom of the digester. The biogas ejected from the lances creates turbulence and a defined mixing pattern within the digester tanks.

The AD process will result in the conversion of VS to liquid constituents and biogas. As a result, the TS content within the reactors is less than the diluted raw feedstock with a 15% TS content.

8.4 Digestate Handling and Composting

The digestate from the AD reactors is approximately 90% water and should be mechanically dewatered prior to use in producing compost, so as to reduce the quantity of bulking agent required. A dewatering system will be employed to reduce the requirement for bulking agents in the composting process. Common dewatering devices for digestate from AD reactors treating feedstocks of this nature include screw presses and centrifuges. For this feasibility study, it is assumed a centrifuge will be used to dewater the digestate before composting. The conceptual design of the facility assumes approximately 85% of the digestate TS will be captured by the centrifuge for use in making compost and this centrifuge cake will contain 20% TS. The remaining 15% of TS will be contained in the centrate. The centrifuge, ancillary digester mixing equipment, and digestate pumps will be located in a Digestate Management Building adjacent to the AD reactors.

The Centrifuge cake will be stored in an enclosed building in a container until it is ready to be mixed. The centrifuge cake will be blended with enough of a bulking agent (which for is assumed to be purchased from offsite the campus) and transported to the composting area for placement into windrows. Blended centrifuge cake/bulking material will be blended with other bulking materials to reach an optimal moisture content for composting (typically 55 to 65%). The facility will employ an aerated static pile (ASP) method of composting to control odors and accelerate the composting process. ASP composting employs a negative aeration process whereby blowers will draw air through the windrow to maintain oxygen content. The windrow will be placed over an air collection manifold that will collect the compost air mixture. Fresh air will be drawn down through the windrow to the air manifold where it will capture gases from the compost process. The compost gases and air mixture will be directed to a biofilter where the air is treated prior to being discharged into the atmosphere. The ASP composting process will require temperature and moisture monitoring to assure the compost process occurs correctly. The materials are envisioned to remain in the 'active compost' phase for approximately seven weeks where they will be turned periodically. After the active compost phase is complete, the materials will be 'cured' for an additional four weeks. Following curing, the materials will be ready for market and sale, or possibly for use by the campus grounds staff for various soil applications. The total quantity of compost available is projected to be approximately 5,000 tons per year for Scenario B, and 7,500 tons per year for Scenario C.

As described previously, Scenario A represents a possible cost reduction alternative. It does not have the digestate dewatering/composting elements that Scenario B does, even though the two scenarios are designed to receive the same feedstock. In order to remove the dewatering and composting elements, the digestate from the Scenario A tanks would be extracted as a slurry into pump trucks where the digestate would be land applied to agricultural crop lands similar to the practice of managing biosolids. Insomuch as the feedstock sources for Scenario A are mostly manure, the possibility of land applying the digestate appears to be plausible, particularly from a regulatory standpoint. Consequently, we include an analysis for Scenario A where the digestate would be pumped as slurry into tanker trucks and land applied on agricultural fields in accordance with land application rates to maintain a nutrient balance between application and crop uptake.

8.5 Liquid Effluent Management

Organic wastes including manures and food wastes characteristically contain high concentrations of organic nitrogen. During the digestion process, particulate organic nitrogen, which constitutes most of the total nitrogen in the READ facility feedstock, is converted to ammonia which is soluble. Ammonia is not removed in the digesters and when the digestate is dewatered, the ammonia concentrates in the centrate sidestream from the dewatering process. This centrate sidestream is low-flow yet high in nitrogen and total solids and if discharged to the campus WWTP would exceed its nitrogen removal treatment capacity. As a result, the centrate must be managed to remove nitrogen if it is discharged to the POTW. As noted earlier, the READ facility feedstock must be diluted to enable simpler pumping of the material and reduce its nitrogen concentration to prevent ammonia toxicity in the digesters. If nitrogen is substantially removed from the dewatering centrate, the centrate could be recycled to the facility pre-processing area to serve as feedstock dilution water.

Conventional wastewater treatment methods for nitrogen removal could be employed at the READ facility to treat dewatering centrate. Such conventional nitrification-denitrification (NDN) systems biologically convert ammonia to nitrate during nitrification and subsequently convert nitrate to nitrogen gas during denitrification. The nitrogen gas is stripped to the atmosphere and as such is removed during the treatment process. A NDN system for the READ facility would include aeration tank(s) for nitrification, anoxic (i.e. oxygen free) tank(s) for denitrification, and a clarifier for settling bacteria. The anoxic phase of NDN requires adequate soluble carbon for bacteria to convert nitrate to nitrogen gas. Because most of the soluble organic carbon is removed during digestion, a supplemental soluble carbon source (such as methanol) would be required to provide denitrification. NDN is a well established process that would reliably remove nitrogen from the centrate prior to discharge to the POTW or being recycled to dilute the feedstock.

Another developing method for nitrogen removal is the Anaerobic Ammonium Oxidation (Anammox) process which utilizes a specialized family of bacteria to convert ammonia to nitrite and nitrogen gas. Nitrite is then also converted to nitrogen gas. The benefits of this process compared to conventional NDN is that it does not require blowers (and associated energy), does not require an external carbon source, produces less carbon dioxide, and requires a small footprint. The key disadvantage is that it is a developing technology with only five installations worldwide, none of which are located in the United States.

An alternative to implementing ammonia recovery is to implement a process that recovers ammonia as a by-product that can be sold to generate revenue. Research of possible alternatives to recover ammonia suggests a flash vacuum distillation system coupled with sulfuric acid addition may be feasible to produce ammonium sulfate fertilizer. This type of process has been used significantly in other industries outside the waste treatment field however is gaining attention and developing. The process recovers about 80% of the incoming nitrogen in the centrate. The City of New York will be building such a system (CASTion system from ThermalEnergy) at its 26th Ward plant to recover ammonia from 1.2 million gallons per day of its anaerobic digester dewatering centrate stream. This is understood to be the first installation in the United States. Installation of such a large system by a large long-established wastewater utility provides some confidence that the technology may work for UC Davis.

A second recovery alternative is to concentrate the ammonia through a combined ultrafiltration-reverse osmosis (UF-RO) process. The purified liquid permeate from this process could be recycled for diluting feedstock while the concentrated nitrogen RO reject could be sold as a liquid fertilizer similar to a vacuum distillation system. These ammonia recovery technologies are in their infancy stage and require further evaluation and development. It is understood that UC Davis is planning to pilot test the UF-RO process during 2011.

Costs for these three liquid effluent alternatives were preliminarily considered to aid in considering liquid effluent management alternatives. It appears conventional NDN and the Anammox process will have similar capital costs while the Ammonium Sulfate Production system could be approximately 30% cheaper than these two options. Ammonium Sulfate production would also potentially be the most economically attractive in terms of operating cost and product revenue since the system yields a saleable product. Operating costs of the Anammox system will be less than an NDN system due to its lower energy requirement and that it does not require a supplemental carbon source. From an economic perspective, nitrogen recovery appears to be the most economically attractive alternative, yet, risky from a technical feasibility perspective.

At this stage of the feasibility study, it is assumed an NDN system would be included with the READ facility to manage nitrogen in the liquid effluent. While the cost of this alternative is higher than the two other alternatives presented here, it is the lowest risk alternative for removing nitrogen from the liquid effluent. Anammox or Ammonium Sulfate alternatives could be implemented as well and should be scrutinized as the design concepts for the READ facility are further developed.

8.6 Foul Air Collection and Management

Potentially odorous sources of air are envisioned to be treated using a variety of methods. Typically solid waste processing performed in enclosed buildings do not treat the air before exhausting the air to the atmosphere. For planning purposes, we have assumed the waste receiving/pre-processing building will be equipped with an odor mitigation system similar to that of other solid waste processing facilities. These air management systems typically consist of deodorants or enzymatic additives to a misting system combined with a negative air pressure system where potentially foul air will be treated in place and then extracted from the building and exhausted to the atmosphere. Also, we have assumed the more significant foul air sources would be the digestate removal from the digester function. For this feasibility study level of analysis, we have assumed capturing air from the digestate removal area for all three scenarios and treating the air through a biofilter media before discharging the air to the atmosphere. Also, for Scenario's B and C, the biofilter is sized to collect air from the active compost phase of the digestate stabilization process and treat the air through the biofilter media.

9.0 Potential Site Considerations

The UC Davis staff has offered three possible sites as candidates for the READ facility. They are:

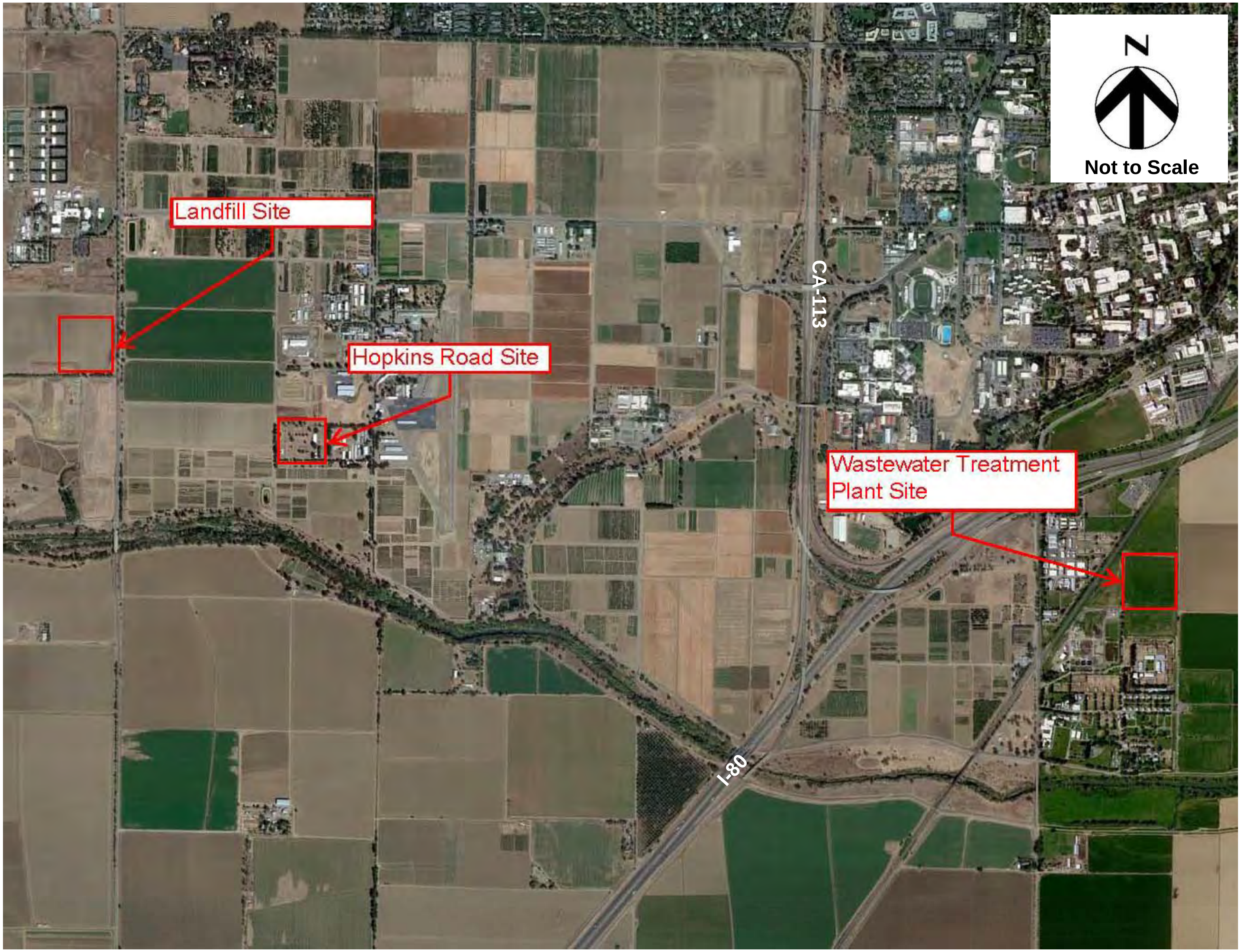
- An approximate 20 acre vacant parcel adjacent to and north of the campus landfill,
- The approximate 19 acre parcel currently occupied by the Avian facility on Hopkins Road, and
- An approximate 14 acre vacant but row-crop parcel north and east of the existing campus WWTP.

Each of these sites appears to have enough available property which would provide ample room for the READ facility. The attached **Figure 11** shows the location of the three potential sites.

As background, in a prior planning effort, HDR was requested to evaluate the possibility of gaining the maximum educational benefit and maximum facility performance while incurring the least environmental risk at the lowest possible cost. HDR was requested to explore a variety of site configurations and to evaluate the benefits and drawbacks from each configuration to better inform UC Davis of the preferred facility configuration. This process began in July, 2010 at which time HDR made a presentation to the University's West Village engineering group at a planning meeting. The presentation outlined the options, key issues, potential energy output of the campus feedstock, sizing considerations, environmental concerns, infrastructure requirements and costs. The presentation also provided four potential development configurations of the facility as follows:

1. The entire facility at the West Village, equipped with robust odor minimization features including enclosed preprocessing and post processing facilities
2. The highly odorous elements (feedstock preparation and digestate stabilization processes) at the UC Davis landfill and the less risky odorous elements (digester, gas clean-up compression and fuel cell) at the West Village
3. The fuel cell at the West Village and the remainder of the facility at the landfill, plus a gas pipeline connecting the two facilities
4. The entire facility at the landfill using less costly processes (i.e.: open air composting facilities, etc.)

The study explored mechanical and thermal benefits in the form of overall facility efficiencies which can vary depending upon how the project elements are configured and their proximity to the various end-users of the products. Given these divergent sets of goals and risks, the objective of this initial planning phase was to explore these issues so as to facilitate a decision by UC Davis as to the preferred site configuration for the development of the facility. This prior planning effort concluded with UC Davis preferring a single site configuration where all necessary functions could occur, thereby promulgating symbiotic benefits due to proximity. Also, due to timing concerns, the concept of the digester facility was removed from the West Village for further consideration.


N
Not to Scale
Landfill Site
Hopkins Road Site
CA-113
Wastewater Treatment Plant Site
I-80

In order to explore the differences between the top sites, HDR met with campus planning[9] staff on March 24, 2011 to discuss the benefits and limitations of the three sites. **Table 11** provides an overview of the three sites with respect to the availability of utilities, access, sensitive receptors and related possible site criterion.

Table 11. Suitability of Sites

Criterion	1	2	3
	Landfill	Hopkins Road	WWTP
Sewer	Requires 1650 LF new SS or new Lift Station, or Septic system	Requires 2750 LF new SS to discharge to LFT #11, or Septic system	Requires 1600 LF new SS or Septic system
Water	Existing 10" main in street	Existing 8" main in Street	Requires 1600 LF new water main to connect to Equestrian facility to south and possibly another 1400 LF water main to connect to existing 6" main north of SPRR line, if looped system is required
Storm Drain	No Storm Drain in area. Requires storm water retention	Existing 48" Storm Drain in Hopkins Road is reportedly at capacity. Is likely to require storm water detention to mitigate peak runoff	Existing open drain canal south of site adjacent to Equestrian facility. Is likely to require storm water detention to mitigate peak runoff
Power	Campus power is overhead in street. Conduits consist of 336 lines. Appears adequate as is.	Campus power is overhead in street. Conduits consist of 336 lines. Appears adequate as is.	Campus power is overhead crossing through west edge of site. Conduits consist of 336 lines. Appears adequate as is.
Gas	Requires 1925 LF new service to site. Existing PG&E service in street appears to be a supply line from a natural gas well. Existing 6" plastic LFG pipe from landfill to Primate Center could have beneficial uses.	Requires 1400 gas service extension to connect to existing 3" line, north on Hopkins Road.	Requires 2200 gas service extension to connect to existing 3" line at Equestrian Center.
Communications	Requires 2200 LF service extension to site or possible wireless base to line-of-site base at Primate Center	Existing underground line in street	Requires 1600 LF to Communications manhole adjacent to SPRR
Street access	County Road 98 is adequate as is	Hopkins Road is adequate as is	Requires 800 LF new roadway to connect to existing campus roadway at east end of WWTP
Environmental	Site is agricultural field requiring analysis. However, site is Pre-mitigated for presence of Swainson's Hawk	Site is developed (Avian facility). Also site is pre-mitigated for presence of Swainson's Hawk	Site is agricultural field requiring analysis. However, site is Pre-mitigated for presence of Swainson's Hawk
Relocation of Existing facilities	No relocation required	Would require relocation of a portion of or all of existing Avian facility	Would require acquisition of row crop lands, east of Equestrian Center.

[9] *Meeting attendees Kurt Wengler, Ardie Dehghani, Sid England, Bob Segar and Ernesto Signey*

Criterion	1	2	3
	Landfill	Hopkins Road	WWTP
Odor	Downwind receptors include the Primate Center	Downwind receptors include Beef and Swine facilities, West Village	Downwind receptors include UC Davis entrance and Mondavi Center

Using only off-site costs development as a differentiator between the sites, we prepared the following summary table. **Table 12** illustrates the approximate development of off-site improvements for each of the sites. Please note due to variability of in the three site locations and differing off-site costs, we have not included the off-site improvement cost or land cost in the three Scenario's capital cost estimates above.

Table 12. Cost Comparison for Off-Site Improvements

Description	Landfill Site	Hopkins Site	WWTP Site
Sanitary Sewer	$ 198,000	$ 330,000	$ 192,000
Water Main	$ -	$ -	$ 320,000
Storm Drain Retention Pond	$ 60,000	$ 60,000	$ 60,000
Power	$ -	$ -	$ -
Gas	$ 288,750	$ 210,000	$ 330,000
Communications	$ 220,000	$ -	$ 160,000
Street Improvement	$ -	$ -	$ 288,000
Total	$ 766,750	$ 600,000	$ 1,350,000

Summarizing from an off-site development viewpoint, the sites appear generally equivalent in terms of the availability of utilities and environmental issues. The variance in off-site cost is minimal when compared to the development cost, particularly insomuch as the value of land has not been incorporated into this comparison. The primary differences between the sites appear to be somewhat subjective in nature and reflect issues such as the cost of relocation or replacement of existing croplands, and possible downwind receptors.

However, there are other issues that should be considered in the selection of the preferred site, namely the proximity of the proposed facility to other facilities that could use the READ's by-products or which could provide feedstock materials. An example of this is the use of biogas as boiler fuel at the Primate Center. Both the Landfill site and the Hopkins Road site are within close proximity of the Primate Center and could conceivably provide biogas to the Primate Center central boiler plant. The appropriateness of using biogas for this purpose would require some additional research. We understand landfill gas is currently piped from the landfill to the Primate Center for this use. An existing 6 inch diameter plastic pipe provides low pressure, untreated landfill gas from the landfill blower to the Primate Center. However, we also understand the Primate Center is exploring an upgrade to the boiler facility which may remove their desire for this gas source. The biogas from the READ would be of similar low BTU value consisting of approximately half to sixty percent methane. Although both the Landfill site and the Hopkins Road site have the possibility of providing biogas to the Primate Center, our analysis relied on the generation of electricity, which could occur at any of the three potential sites.

Another example of beneficial uses due to proximity is the possibility of using WWTP biosolids as a feedstock to the rotating drum. If desired, the WWTP site would pose some benefits due to its proximity. Untreated (non-dried) biosolids could be pumped from the WWTP to the READ for injection to the rotating drum. The rotating drum will require approximately 6,000 gallons of moisture per day. Untreated biosolids could provide the necessary make-up water needed. However, we assume the liquid effluent from the digesters can be used for this purpose. Also, we understand the current practice of WWTP biosolids is to dry the biosolids and have them beneficially used as an alternative daily cover at the Yolo County landfill. We also understand the cost of drying, transportation and the landfill tip fee is very economical from the perspective of the WWTP staff. Finally, we understand the use of biosolids in the READ facility would revise the classification (according to EPA 503 regulations) of the finished compost product to a derivative of biosolids which could have a deleterious affect on the marketability of the compost product. Consequently, we do not foresee a distinct benefit of the WWTP site due to this issue.

Yet another example of potential beneficial use is the Hopkins Road site. A significant benefit of the Hopkins Road site is the possibility of using the site to replace the existing dairy, which is reportedly under consideration to increase on-campus housing needs. If selected as the dairy site, the Hopkins Road site would have a variety of possible unique benefits including but not necessarily to the following:

- Proximity of the dairy waste which is the largest manure feedstock
- Beneficial use of dairy rinse water for rotating drum or digester make-up water
- Possible biogas shared uses from a dairy lagoon-type anaerobic digester, if one would be included in the new dairy facility
- Possible cogeneration opportunities of excess heat or power

Until such time as the relocation of the dairy is determined, this study remains open to the possible use of any of the three sites considered above.

10.0 Environmental Considerations of APS Technology Scenarios

Sustainability and environmental stewardship are important aspects of the UC Davis culture, and a driving force for making the READ project a reality. Although the main focus of this report is to evaluate the READ project on a technical and economic level, some environmental implications have been considered in accordance with the UC Davis commitment to sustainability and the environment.

10.1 Greenhouse Gas Emissions

A conceptual comparison of greenhouse gas (GHG) emissions from the current waste practices and the proposed alternatives was prepared in order to illustrate the potential for GHG reductions. The United States Environmental Protection Agency (USEPA) WAste Reduction Model (WARM) was used to illustrate GHG emissions from landfill and compost operations. There are many limitations to the model, and results should be seen as illustrative of overall GHG reduction potential. One such limitation is that the model does not offer anaerobic digestion as an alternative to disposal. Separate calculations were done to estimate the GHG reduction that would result using the biogas from the READ as an alternative energy source. Specific transportation distances were not taken into account for any of the emission evaluations, since haul routes are not part of this feasibility study.

10.2 WARM

WARM was created as a tool to help managers and policy makers understand and compare the emissions and offsets resulting from different materials management options (e.g., landfilling, composting) for materials commonly found in the waste stream. Only anthropogenic emissions are considered as GHG emissions in WARM. Biogenic emissions are considered to be carbon that was originally removed from the atmosphere through natural processes, like photosynthesis, and would eventually return to the atmosphere through a natural degradation process. Anthropogenic emissions are emissions resulting from human activities and subject to human control, which are considered disruptive to the naturally occurring carbon cycles and balance. The emissions resulting from burning fossil fuels are considered to be anthropogenic because the emissions would not have been released without human intervention.[10]

Landfill scenarios create an anaerobic environment that generates methane (CH_4) which would not have been generated without human intervention, and so WARM counts this emission. However, capturing this landfill gas (LFG) can reduce these emissions, either by flaring or being burned to produce energy. Carbon dioxide (CO_2) produced by these activities is not counted as it is considered biogenic. If a scenario entered in WARM includes using LFG to produce energy, the model takes into account the emissions from fossil fuel derived electricity that is avoided. Landfilling scenarios also assume a level of biogenic carbon storage and emissions produced by landfill operating equipment.

[10] http://www.epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf

For the READ WARM scenarios, the landfill is assumed to be "dry" (receiving fewer than 25 inches of precipitation annually). The model assumes that 75% of the LFG is collected and flared. The percentage collected is a default value representing typical collection efficiency over the life of an active phased landfill. LFG from the UC Davis landfill is mostly used in boilers at the Primate Center. For the purposes of this modeling, the emissions from flaring and the emissions from using the LFG as fuel for the boiler are considered to be approximately equal. The current practice of using LFG does offset the burning of natural gas at the Primate Center. For the annual MSW tonnage modeled, however, the amount of anthropogenic emissions offset by this practice is not considered significant enough to affect the scope of this model.

Composting scenarios assume a windrow composting operation of yard trimmings and food discards, and that the finished compost is applied to soils. WARM assumes that well-managed composting operations are completely aerobic and biogenic. The only emissions that WARM assumes will be generated from composting operations are those associated with equipment operation and transportation.

Odors

During anaerobic digestion, organic acids are formed and sulfate is reduced to various sulfur forms. Some organic acids and reduced sulfur are odorous compounds and if not managed properly during treatment, odors from an AD plant can be a concern. Although public perception of AD is generally positive, odor episodes from a working AD plant can turn local public opinion against the plant. A plant that is designed and operated to minimize odor releases should not have extensive odor problems, but it is an issue that must be considered in the planning and siting of a plant. Please refer to Section 8.6 Foul Air Collection and Management above for further discussion regarding odors.

10.2.1 Scenarios A and B

Currently, all organic waste streams on campus are composted or land applied as part of an agricultural practice. For GHG modeling purposes, HDR used WARM to estimate the emissions produced from composting mixed organics and considered this the baseline for Scenarios A and B. This baseline was compared to emissions from using these mixed organics as feedstock for the READ facility. This assumes that the anaerobic digester will yield approximately 8,100 MMBTU (2,370,000 kWh) per year by processing these organics and using the resulting biogas to power an internal combustion engine operating at 35% overall electrical efficiency. Using this power will avoid the GHG emissions that would have been created using an equivalent amount of power from delivered electricity. Power that is generated but needed for operation of the READ facility is not counted in the power generation number. The modeling also takes into account that the anaerobic digestion process produces digestate that will be composted. For Scenario A, the emissions from using digestate for land application are assumed to be the same as those for composting the digestate. This is a reasonable assumption because WARM assumes all composting emissions are biogenic except for those generated by operating equipment. WARM also assumes that the finished compost is land applied, just as the digestate would be in Scenario A. This model assumes that the emissions from composting digestate are similar to those produced by composting the same amount of mixed organics in WARM. The amount of digestate produced is assumed to be half of the tonnage used as feedstock for the digester.

10.2.2 Scenario C

For Scenario C, the same assumptions and methods were used to estimate GHG emissions from the organic waste stream. Since Scenario C also includes processing a MSW stream through the READ facility, the baseline for this scenario also uses WARM to estimate the emissions from landfilling that MSW. The total baseline emissions are a combination of landfilling the MSW stream and composting the organic waste stream. The emissions estimated for Scenario C assumes that half of the MSW put through the rotating drum pretreatment system will be useful for digester feedstock, and the other half will be landfilled. Like Scenarios A and B, Scenario C estimates that the digestion process will produce an amount of digestate equal to half the tonnage used for feedstock for the digester, and that it will be composted. Emissions are estimated based on the assumption that the biogas is used to power an internal combustion engine operating at 35% overall electrical efficiency, and offsetting 14,400 MMBTU (4,220,000 kWh) of power from delivered electricity. Power that is generated but needed for operation of the READ facility is not counted in the power generation number.

10.2.3 GHG Emission Results

Analysis using WARM and the estimated GHG offset from reducing the need for delivered electricity shows that the proposed READ facility has the potential to lower the emissions produced by the campus. Power from the anaerobic digestion process, as an alternative to power from delivered electricity, offsets more GHG emissions than current landfilling and composting practices. Scenarios A and B each have the potential to reduce GHG emissions by 0.24 metric tons of carbon dioxide equivalent ($MTCO_2E$) per ton processed by the READ facility. Scenario C has the potential to reduce GHG emissions by 0.27 $MTCO_2E$ per ton processed by the READ facility. **Table 13** shows more detailed results of the GHG modeling. WARM results and related GHG calculations are provided in **Appendix C.**

Table 13. GHG Emissions Model Results

Description of Waste Management Scenario		GHG Impact of Scenario				
Alternative Scenarios	Annual Throughput (tons/year)[1]	Yearly GHG Emissions BASELINE SCENARIO ($MTCO_2E$)[2]	Yearly GHG Emissions ALTERNATIVE SCENARIO ($MTCO_2E$)[3]	Yearly GHG Emissions Reduction ($MTCO_2E$)[4]	GHG Emissions Impact per Ton Managed ($MTCO_2E$/ton)[5]	Equivalent # of Cars Removed from the Road for the Year[6]
Scenarios A and B - Organics only	8,102	-1,624	-3,547	1,923	0.24	352
Scenario C - Organics + MSW through Drum	17,147	168	-4,391	4,559	0.27	835

1 - Assumes that 8,102 tons of organic feedstock is processed per year in both alternatives. Scenario C also contains 9,045 tons of MSW per year to be processed through the rotating drum equipment.

2 - EPA WARM model assumes that for Scenarios A and B, composting mixed organics is the baseline management strategy. Composting is the current practice for most organic waste streams on campus. EPA WARM model assumes that for Scenario C, composting mixed organics and landfilling MSW is the baseline management strategy. Assumes 75% landfill gas capture and that it is flared; transportation distances related to collection are assumed to be zero for all scenarios.

3 - For Scenarios A and B, this value includes EPA WARM modeling for composting digestate. For Scenario C, this value includes EPA WARM modeling for composting digestate and landfilling over's from the rotating drum. Values for all scenarios also include avoided grid GHG emissions from anaerobic digestion biogas net electrical generation using an internal combustion engine with 35% overall electrical efficiency. Emissions are recorded as metric tones carbon dioxide equivalents ($MTCO_2E$); negative emissions indicate that a management scenario represents a net CO_2 sink relative to no management based on the U.S. EPA WARM model.

4 - Positive values indicate a GHG reduction from the Baseline scenario, with larger positive values indicating larger GHG reductions. Negative values indicate a GHG increase from the Baseline scenario.

5 - This value is reported in $MTCO_2E$ per ton of waste managed. Positive values indicate a GHG reduction from the Baseline scenario, with larger positive values indicating larger GHG reductions. Negative values indicate a GHG increase from the Baseline scenario.

6 - Based on average 5.46 $MTCO_2E$ of emissions per car per year from the EPA WARM model. A negative value indicates the number of cars that would be added to the road when compared to the Baseline scenario.

11.0 Economic Considerations of APS Technology Scenarios

The capital and operating costs of the project will be dependent on the project configuration that is chosen, because the type of equipment required for the control of potential impacts and infrastructure will vary with the configuration. In the event that residual heat or electricity is generated by the project, the potential exists for the facility to generate revenue as an additional benefit.

For this planning phase, HDR prepared a feasibility level cost analysis that provides the basic costs of the project as well as a cost comparison between the three site development Scenarios. We have included capital costs and operating costs as well as revenues for each of the Scenarios. This study does not include an evaluation of financing alternatives which will be evaluated by UC Davis at the conclusion of this study. Each of the financial categories (capital, operations and revenues) varies depending on the Scenario chosen. Summary tables (**Tables 14 thru 23** below) are provided in this report, but full details of the cost estimates can be found in **Appendix D**.

Our analysis took into consideration the potential revenues that can be generated by the project for each Scenario. Detailed market assessments were not conducted as part of this study however cursory evaluation of current pricing for marketable products such as soil amendments and biogas generated energy were completed. The potential revenues that can be generated by the project appear to offset costs. Revenue generation is possible from the electricity output, biogas production, tipping fees and sale of the soil amendments from the composting of the residual digestates.

In the analysis of Scenarios, power output and operating efficiency were taken into consideration. One consideration is the opportunity to generate additional power with the excess heat generated by the digesters (cogeneration). Another efficiency consideration is the ability to recover the wastewater from the digesters and apply it to the composting windrows. Operational efficiency considerations include minimizing the handling and transporting of feedstock, residuals, digestate and wastewater.

We conclude the READ return-on-investment is low or negative due to several key aspects such as:

- the relatively low cost of the current disposal of the tributary feedstock materials,
- the relatively low cost of power,
- the relatively small quantity of feedstock materials and
- the fact that this project would be the first of its kind and therefore relatively high compared to 'one-off' or the second generation facility.

We also anticipate that if UC Davis elects to proceed with the project, a variety of benefits in the form of grants, etc. and value engineering efforts during design could be obtained thereby improving the financial terms discussed in this report.

11.1 Costs and Revenues for Each of the Project Scenarios

The following section provides an overview of the capital and operating costs and potential revenues associated with each of the three scenarios.

11.1.1 Scenario A

We developed Scenario A as the Base Case facility cost that reflects the fundamental elements of the facility. The Scenario A cost includes the following categories:

Scenario A Capital Costs include:

- Site improvements
- Feedstock receipt and blending equipment
- Digester tanks
- APS Digester components
- Gas clean-up and conditioning system
- Internal Combustion engine
- Electrical system
- Digestate removal, dewatering and connections for tanker truck extraction for land application
- Liquid effluent treatment
- Odor reduction biofilter system
- General construction

Scenario A Operating Costs include:

- Labor
- Power
- Digestate hauling
- Effluent treatment

Our estimate of the total cost for the project Base Case is as follows:

Table 14. Capital Cost for Scenario A

Description	Total Cost
General Items Subtotal	$1,466,000
Pre-Treatment Items Subtotal	$320,000
Digester Items Subtotal	$880,000
Digestate Management Items Subtotal	$140,000
Biogas Items Subtotal	$970,000
Effluent Items Subtotal	$0
Electrical & Mechanical Subtotal	$1,133,000
Contingency Subtotal	$1,718,000
Construction Subtotal	$6,627,000
Engineering, Permitting, & Construction Management Subtotal	$1,643,000
Total Estimated Cost	$8,270,000

Table 15. Operations and Maintenance Costs for Scenario A

Cost Description	Qty.	Qty. Units	Cost &	Cost Units	Total Annual Cost
Operator Labor	120	hr/week	$50	$/hr	$312,000
Power	100	Hp	$0.080	$/kw-hr	$52,000
Parts and Maintenance	1	Ls	$50,000	$/yr	$50,000
Liquid Effluent O&M Cost					
Conventional Nit-Denit	1	Ls	$84,175	$/yr	$84,000
Biogas to Energy System					
IC Engine	2,255,295	kw-hr	$0.015	$/kw-hr	$33,000
IC Engine Rebuild Fund	1	Ls	$25,000	$/yr	$25,000
Digestate pumped and land applied	14,309	gal/yr	$6	$/gal	$93,000
Misc Chemicals	1	Ls	$50,000	$/yr	$50,000
Total Estimated O&M Costs					$700,000

Table 16. Expected Revenues for Scenario A

Revenue Description	Qty.	Qty. Units	Revenue $	Revenue Units	Total Annual Revenue
Avoided Disposal Costs from Organics	8,102	ton	$30	$/ton	$244,000
Beneficial use of Biogas					
IC Engine	2,255,295	kw-hr	$0.169	$/kw-hr	$381,000
Carbon Credits for IC Engine	1,923	MTCO2E	$20	$/MTCO2E	$38,000
Total Estimated Annual Revenue					$663,000

11.1.2 Scenario B

We developed Scenario B as the facility cost that reflects the fundamental elements of the facility, including composting of digestate. The Scenario B cost includes the following categories:

Scenario B Base Case Capital (construction and project development) Costs include:

- Site improvements
- Feedstock Receiving and Processing Building, including area for recovered materials and off-site transfer
- Digester tanks
- APS Digester components
- Gas clean-up and conditioning system
- Internal Combustion Engine
- Electrical system
- Digestate dewatering
- Composting system for digestate stabilization
- Liquid effluent treatment system
- Odor reducing biofilter system
- General construction

Scenario B Operating Costs include:

- Labor
- Power
- Digestate hauling
- Effluent treatment
- Composting operations

Our estimate of the total cost for the project Base Case is as follows:

Table 17. Capital Cost for Scenario B

Description	Total Cost
General Items Subtotal	$1,507,000
Pre-Treatment Items Subtotal	$1,314,000
Digester Items Subtotal	$1,896,000
Digestate Management Items Subtotal	$520,000
Biogas Items Subtotal	$965,000
Effluent Items Subtotal	$473,000
Electrical/Mechanical	$2,003,000
Contingency Subtotal	$3,038,000
Construction Subtotal	$11,716,000
Engineering, Permitting, & Construction Management Subtotal	$2,676,000
Total Estimated Cost	$14,392,000

Table 18. Operations and Maintenance Costs for Scenario B

Cost Description	Qty.	Qty. Units	Cost $	Cost Units	Total Annual Costs
Operator Labor	120	hr/week	$50	$/hr	$312,000
Power	100	Hp	$0.080	$/kw-hr	$52,000
Parts and Maintenance	1	Ls	$50,000	$/yr	$50,000
Liquid Effluent O&M Cost					
Conventional Nit-Denit	1	Ls	$84,175	$/yr	$84,000
Biogas to Energy System					
IC Engine	2,255,295	kw-hr	$0.015	$/kw-hr	$34,000
IC Engine Rebuild Fund	1	Ls	$25,000	$/yr	$25,000
Compost Equipment and Ops	16,060	ton	$5	$/ton	$80,300
Bulking Materials	5,475	ton	$8	$/ton	$44,000
Misc Chemicals	1	Ls	$50,000	$/yr	$50,000
Total Estimated O&M Costs					$731,000

Table 19. Expected Revenues for Scenario B

Revenue Description	Qty.	Qty. Units	Revenue $	Revenue Units	Total Annual Revenue
Avoided Disposal Costs from Organics	8,102	ton	$30	$/ton	$243,000
Beneficial use of Biogas					
IC Engine	2,255,295	kw-hr	$0.169	$/kw-hr	$381,000
Sale of Compost	4,997	cy	$20	$/cy	$100,000
Carbon Credits for IC Engine	1,923	MTCO2E	$20	$/MTCO2E	$38,000
Total Estimated Annual Revenue					$763,000

11.1.3 Scenario C

HDR developed Scenario C as a facility cost that reflects the elements required for a facility that can process MSW in addition to the feedstocks processed by Scenarios A and B, and can produce a commercial compost product. The Scenario C cost includes the following categories:

Scenario C Capital Costs include:

- Site improvements
- Feedstock Receiving and Processing Building, including area for recovered materials and off-site transfer
- Rotating Drum Pretreatment System
- Digester tanks
- APS Digester components
- Gas clean-up and conditioning system
- Internal Combustion Engine
- Electrical system
- Digestate dewatering and Composting system for digestate stabilization
- Liquid effluent treatment system
- Odor reducing biofilter system
- General construction

Scenario C Operating Costs include:

- Labor
- Power
- Digestate hauling
- Effluent treatment
- Composting operations

Our estimate of the total cost for Scenario C of the project is as follows:

Table 20. Capital Cost for Scenario C

Description	Total Cost
General Items Subtotal	$2,373,000
Pre-Treatment Items Subtotal	$3,645,000
Digester Items Subtotal	$2,486,000
Digestate Management Items Subtotal	$821,000
Biogas Items Subtotal	$1,347,000
Effluent Items Subtotal	$561,000
Electrical/Mechanical	$3,369,000
Contingency Subtotal	$5,110,000
Construction Subtotal	$19,710,000
Engineering, Permitting, & Construction Management Subtotal	$4,000,000
Total Estimated Cost	$23,710,000

Table 21. Operations and Maintenance Costs for Scenario C

Cost Description	Qty.	Qty.	Cost	Cost	Total Annual Cost
Operator Labor	120	hr/week	$50	$/hr	$312,000
Power	110	Hp	$0.080	$/kw-hr	$57,000
Parts and Maintenance	1	Ls	$60,000	$/yr	$60,000
Liquid Effluent O&M Cost (Choose 1)					
Conventional Nit-Denit	1	Ls	$84,175	$/yr	$100,000
Biogas to Energy System					
IC Engine	3,995,567	kw-hr	$0.015	$/kw-hr	$60,000
IC Engine Rebuild Fund	1	Ls	$25,000	$/yr	$25,000
Compost Equipment and Ops	24,090	ton	$5	$/ton	$120,000
Bulking Materials	8,030	ton	$8	$/ton	$64,000
Rotating Drum Operations	8	Hr/day	$190,000	$/yr	$104,000
Rotating Drum Maintenance	1	Ls	62,500	$/yr	$62,500
Misc Chemicals	1	Ls	$50,000	$/yr	$50,000
Total Estimated O&M Costs					$1,040,000

Table 22. Expected Revenues for Scenario C

Revenue Description	Qty.	Qty. Units	Revenue $	Revenue Units	Total Annual Revenue
Avoided Disposal Costs from Organics	8,102	Tons	$30	$/ton	$243,000
Avoided Disposal Costs from MSW	4,794	ton MSW	$45	$/ton	$216,000
Beneficial use of Biogas					
IC Engine	3,995,567	kw-hr	$0.169	$/kw-hr	$675,000
Sale of Compost	7,500	Cy	$10	$/cy	$75,,000
Carbon Credits for IC Engine	4,559	MTCO2E	$20	$/MTCO2E	$91,000
Total Estimated Annual Revenue					$1,300,000

11.1.4 Net Present Cost

Our analysis summarizes the Capital and Operational Cost as well as the potential Revenues. HDR developed a Net Present Cost (NPC) summary of all capital costs, operational cost and revenues from the project. The NPC assumes an annual inflation rate of 3% and an interest rate of 6% for a thirty (30) year repayment schedule. **Table 23** shows the NPC for each scenario:

Table 23. Summary of Estimated Economics for all Scenarios

	Scenario A	Scenario B	Scenario C
Capital Cost	$8.3M	$14.3M	$23.7M
Annual O&M Cost	$700,000	$731,000	$1,040,000
Annual Revenue	$660,000	$763,000	$1,300,000
Net Present Cost (6%, 30 years)	$8.8M	$14.0M	$20.1M

Cost Discussion for Scenario A

The capitol costs for Scenario A are lower than that of B and C due to the elimination of digestate composting from the project components. The operating costs are also less than Scenarios B and C due to the elimination of composting operations. Although the capital cost of this scenario is lower than the others, this scenario relies on land application of the digestate which could be challenging in terms of regulatory acceptance of land applying the digestate. Implementing this scenario includes the possibility of increased cost to accommodate regulatory requirements for land application of the digestate in the future. Further study would be needed to resolve this issue.

Cost Discussion for Scenario B

Capitol costs for Scenario B are approximately double that of Scenario A as the windrow composting infrastructure will need to be constructed for management of the digestate. Operating costs are slightly higher than Scenario A for this reason but also includes the purchase of a bulking agent (chipped wood) needed to stabilize the digestate.

Cost Discussion for Scenario C

Scenario C includes MSW in the feedstock and subsequently costs are significantly higher for this scenario due to the rotating drum pretreatment system for the MSW feedstock. The greater volume of digestate to be processed will require more equipment, and related infrastructure, additional digester tanks, additional power generating equipment and additional odor control infrastructure. Scenario C requires the construction of a composting facility that has the capacity to handle nearly twice the volume of digestate that will be generated for Scenario B. Thus the operating costs are somewhat higher for operation of the larger facility which will require more staff, higher utility usage, more bulking materials, etc.

Revenue Discussion for Scenario A

Revenue generation and avoided cost benefits from the various scenarios are possible from the electricity output, biogas production and avoided tipping fees. There are avoided costs associated with Scenario A that apply to all of the scenarios over the status quo operations currently taking place on campus. These include the avoided cost of the disposal of manure and food waste (as is currently done). In terms of environmental benefits, carbon credits will be available for the reduced transporting and landfilling of the manure and food waste materials. Revenue from the scenarios will be generated through the sale of electricity and biogas generated by the digesters. Scenario A differs in that because there will be no composting of the digestate, no revenue will be generated by soil amendment sales. Similarly, no soil amendments will available for on campus use to avoid costs.

Revenue Discussion for Scenario B

In addition to the revenue and avoided cost benefits discussed for Scenario A above, because Scenario B includes composting of the digestate materials, finished soil amendments will be produced and can not only be used on campus thereby avoiding the need to purchase them, but the soil amendments can be sold to the public to generate revenue.

Revenue Discussion for Scenario C

Scenario C shares all of the revenue and avoided cost benefits of both Scenarios A and B. Scenario C has the ability to generate higher revenues and avoid more costs in that the feedstock to be processed will be 47 tons per day vs. 22 tons per day for Scenario A and B. Because Scenario C adds 25 tons per day of MSW to the feedstock to be processed by Scenario A and B, the costs of disposing that volume of MSW will be avoided, thereby generating more carbon credits than Scenario A and B.

The added feedstock volume that will be composted in this Scenario C will produce nearly double the finished soil amendment product to be sold to generate revenue. Electricity and biogas production will also be nearly double with this scenario. Therefore Scenario C has the greatest potential for cost avoidance and revenue generation.

11.2 Economic Comparison of Biogas Recovery Alternatives and Energy Revenue Rates

UC Davis has several opportunities for biogas recovery ranging from natural gas supplementation at the Primate Center boilers to the use of Fuel Cells to efficiently produce electricity and recoverable heat. In addition, the revenue rates for electricity and natural gas for the economic analysis can be evaluated at market rates or renewable rates. For the purposes of this analysis, market rates equate to the current value UC Davis pays for its electrical power and natural gas while renewable rates reflect the elevated rates of these utilities meeting renewable energy portfolio criteria. This Feasibility Report has thus far assumed renewable rates for electricity and natural gas revenue. UC Davis requested that HDR prepare an economic comparison between different biogas recovery alternatives at market and renewable energy revenue rates.

Three biogas recovery alternatives were considered for this comparison:

1. Conversion of biogas to electricity and recoverable heat using IC Engines at the READ facility.
2. Conversion of biogas to electricity and recoverable heat using Fuel Cells at the READ facility.
3. Conversion of biogas to steam using existing boilers at the Primate Center.

Electricity and natural gas rates typically fluctuate and rates presented in this report are likely to change over time. Nonetheless, rates were assumed for electricity and natural gas at market and renewable rates so that the impact of energy revenue on project present value economics could be evaluated. The assumed electricity and natural gas revenue rates are presented in **Table 24.**

Table 24. Summary of Assumed Market and Renewable Energy Revenue Rates

	UC Davis Market Rate	Renewable Rate
Electricity ($/kW-hr)	$0.08	$0.17
Natural Gas ($/therm)	$0.72	$1.50

Capital Cost, O&M Cost, Revenue, and Net Present Value were developed for Scenario C for each of the biogas recovery alternatives and energy revenue rates presented above. The table below reflects the Capital Cost, O&M Cost, Revenue, and Net Present Value developed for

Scenario B for each of the biogas recovery alternatives and energy revenue rates presented above. These economic parameters are summarized below in **Table 25**.

Table 25. Economic Comparison of Scenario B for Various Biogas Recovery Alternatives at Various Energy Revenue Rates

Biogas Recovery Option	IC Engine		Fuel Cells		Primate Center Boilers	
Revenue Rate Category	UC Davis Market	Renewable	UC Davis Market	Renewable	UC Davis Market	Renewable
Capital Cost	$14,400,000	$14,400,000	$18,000,000	$18,000,000	$14,500,000	$14,500,000
O&M Cost	$730,000	$730,000	$920,000	$920,000	$710,000	$710,000
Revenue	$560,000	$760,000	$620,000	$900,000	$510,000	$650,000
Present Value	$16,700,000	$13,900,000	$22,100,000	$18,400,000	$17,200,000	$15,200,000

Table 25 shows that the present value of the different biogas recovery technologies is approximately 15% lower at renewable energy revenue rates compared to market rates. The comparison also suggests that the capital costs and present value costs for IC Engine technology and utilizing biogas in boilers at the Primate Center are relatively similar. The primary difference between the IC Engine and Primate Center is the revenues for the biogas are less than the revenues from electricity generated by the IC Engines. The comparison also suggests that the capital costs and present value costs for IC Engine technology is the most cost effective biogas recovery option. The capital cost of Fuel Cells are higher than other biogas recovery alternatives and therefore yield a higher present value despite being more efficient in generating energy.

A similar study was performed for Scenario C. The table below reflects the Capital Cost, O&M Cost, Revenue, and Net Present Value for Scenario C for each of the biogas recovery alternatives and energy revenue rates presented above. These economic parameters are summarized below in **Table 26**.

Table 26. Economic Comparison of Scenario C for Various Biogas Recovery Alternatives at Various Energy Revenue Rates

Biogas Recovery Option	IC Engine		Fuel Cells		Primate Center Boilers	
Revenue Rate Category	UC Davis Market	Renewable	UC Davis Market	Renewable	UC Davis Market	Renewable
Capital Cost	$23,700,000	$23,710,000	$31,210,000	$31,210,000	$23,380,000	$23,380,000
O&M Cost	$1,040,000	$1,040,000	$1,300,000	$1,300,000	$990,000	$990,000
Revenue	$940,000	$1,300,000	$1,050,000	$1,540,000	$860,000	$1,110,000

Biogas Recovery Option	IC Engine		Fuel Cells		Primate Center Boilers	
Revenue Rate Category	UC Davis Market	Renewable	UC Davis Market	Renewable	UC Davis Market	Renewable
Present Value	$25,000,000	$20,100,000	$34,600,000	$27,900,000	$25,200,000	$21,800,000

Table 26 shows that the present value of the different biogas recovery technologies is approximately 15% lower at renewable energy revenue rates compared to market rates. The comparison also suggests that the capital costs and present value costs for IC Engine technology and utilizing biogas in boilers at the Primate Center are relatively similar. . The capital cost of Fuel Cells are much higher than other biogas recovery alternatives and therefore yield a higher present value despite being more efficient in generating energy.

11.3 Economic Evaluation of an Enlarged READ Facility

The focus of the feedstock development tasks has been on the digestion of organics generated on the UC Davis campus facilities. There may be an opportunity to incorporate organics from off-campus sources. These organic feedstock materials could include additional manure and also source separated organics from MSW generated in nearby off-campus sources. The READ facility economics would follow conventional economies of scale where the facility unit capital cost ($ per ton feedstock processed) would decrease as the size of the facility increased. However the revenue would essentially increase proportionately to the quantity of feedstock processed. Hence, a larger facility should offer a more attractive return-on-investment.

The economics of Scenario B were evaluated at three additional facility feedstock throughput capacity levels as follows: 50, 75, and 100 tpd (on an annual average basis) escalating at the same ratio as the feedstock to Scenario B (which uses an IC engine to produce power which is assumed sold an renewable energy rates) to evaluate how costs would be impacted. Capital costs were adjusted to reflect an enlarged facility and O&M costs and revenue were adjusted. A summary of this analysis is provided in **Table 27** below.

Table 27. Evaluation of Costs and Revenue for an Enlarged Facility with greater Feedstock Throughput for Scenario B

	Facility Annual Average Throughput			
	22 tpd	50 tpd	75 tpd	100 tpd
Capital Cost	$14,400,000	$23,570,000	$30,060,000	$35,720,000
O&M Cost	$730,000	$1,100,000	$1,350,000	$1,560,000
Revenue	$760,000	$1,740,000	$2,610,000	$3,480,000
Net Present Value	$13,900,000	$14,800,000	$12,800,000	$9,300,000
ROI (yrs)	480	37	24	19

As expected, a larger facility would yield a more favorable return-on-investment. It is unclear if adequate feedstock would be available within the Davis vicinity that could be imported for processing at the READ facility and would require further study.

The economics of Scenario C were also evaluated at three additional facility feedstock throughput levels as Scenario B above: 50, 75, and 100 tpd (on an annual average basis) escalating at the same ratio as the feedstock to Scenario C (which uses an IC engine to produce power which is assumed sold an renewable energy rates) to evaluate how costs would be impacted. Capital costs were adjusted to reflect an enlarged facility and O&M costs and revenue were adjusted. A summary of this analysis is provided in **Table 28**.

Table 28. Evaluation of Costs and Revenue for an Enlarged Facility with greater Feedstock Throughput for Scenario C

	Facility Annual Average Throughput			
	35 tpd	50 tpd	75 tpd	100 tpd
Capital Cost	$23,710,000	$29,370,000	$37,460,000	$44,510,000
O&M Cost	$1,040,000	$1,270,000	$1,580,000	$1,880,000
Revenue	$1,300,000	$1,860,000	$2,790,000	$3,730,000
Net Present Value	$20,100,000	$21,200,000	$20,800,000	$19,100,000
ROI (yrs)	91	50	31	24

Similar to Scenario B above, a larger facility would yield a more favorable return-on-investment. Again, it is unclear if adequate feedstock would be available within the Davis vicinity that could be imported for processing at the READ facility and would require further study.

12.0 Funding Opportunities

The current waste management operations on campus are less expensive than any of the project scenarios. Capitol, Operations and Maintenance costs are significant, particularly if Scenario C is the chosen project. In an effort to make the project more financially attractive, available grant funding may be necessary. Obtaining grant monies would allow UC Davis to choose the most favorable Scenario that meets sustainability or research/development goals rather than choosing based on economics. In an effort to improve the financial aspects of the facility, HDR initiated an exploration of possible grant funding opportunities for projects dealing with digestion, renewable energy, food waste, MSW, and renewable transportation fuels such as biofuels and biobased products.

There are a number of energy related grant programs through the various federal and state agencies and some foundations. The funding announcements are posted on special links of the agency websites. Grant opportunities generally cycle two times per year. When the announcements are issued, the time required for submittal of the grant application is generally very short, for instance one to two months. Most agencies require quite extensive application components which can take considerable time to prepare. Some examples of typical requirements for projects to be funded are as follows:

1. That the project be developed in a teaming arrangement
2. That matching funds are provided-up to 50% in some instances
3. An aggressive timeline for completion of the project as the funding programs have mandated deadlines to spend the funds (generally within 2 to 4 years)

HDR explored and identified approximately 12 funding announcements for grant opportunities that would be appropriate for biomass or organics to energy production. In general, the bulk of the grant opportunities that are offered are focused on reducing U.S. dependency in foreign oil and focus on alternative transportation fuel production. However, there are many programs for renewable forms of conversion to energy. In our search for renewable energy grant programs, numerous opportunities, particularly with the DOE and USDA, existed for research and production of renewable alternative liquid transportation fuels and by-products that are a replacement for fossil derived liquid transportation fuels and petroleum-based chemicals. Both the DOE and USDA focus on the production of these fuels from MSW and organic matter.

The following is a list of government agency's that post funding opportunities on a regular basis:

- The California Energy Commission
- California Center for Sustainable Energy
- United States Environmental Protection Agency (EPA)

- National Science Foundation
- Economic Development Administration (EDA) and United States Department of Commerce DOC
- The United States Department of Agriculture (USDA)
- The Department of Energy (DOE)

The American Reinvestment and Recovery Act (ARRA) of 2009 created several grant programs. One such program is the U.S. Department of Treasury's Section 1603 Program that provides Cash Payments for Energy Properties in Lieu of Tax Credits. The Section 1603 program will expire at the end of 2011 and would require congressional re-authorization to be valid in subsequent years. However, this is an example of possible funding mechanism that could be available if UC Davis elects to proceed with the project. Within the ARRA and the Unemployment Insurance Reauthorization and Job Creation Act of 2010, there is a funding mechanism making substantial cash payments to owners and operators of specified energy-producing properties. This program was created for organizations that don't have enough tax liability to offset the federal tax credits that are currently available for newly-constructed energy efficient properties. Organics to energy is eligible for this program. This funding mechanism would be limited for use by a private entity, insomuch as the benefit is in lieu of federal tax credits.

Eligible Governmental Entities may apply for ARRA grant funds to assist in increasing the amount of installed Distributed Renewable Energy Technologies. Distributed Renewable Energy Technologies refers to a variety of small, modular power-generating technologies that can be combined with load management and energy storage systems to improve the quality and/or reliability of the electricity supply. Distributed Renewable Energy Technologies are placed at or near the point of energy consumption, unlike traditional "centralized" systems.

The DOE administers the ARRA programs including the Advanced Research Projects-Energy or ARPA-E grant program. The ARPA-E program missions include:

To enhance the economic and energy security of the U.S. through development of energy technologies that result in;

1. Reductions of imports of energy from foreign sources,
2. Reductions of energy-related emissions, including greenhouse gases, and
3. Improvement in the energy efficiency of all economic sectors

Renewable energy is defined as generated from natural resources, such as biomass, anaerobic digestion, geothermal, solar, water (hydro), and wind —which are naturally replenished.

Another program offered by the USDA funds Biofuels product development from waste streams and feedstock development from waste streams for energy production. A focus of the program entitled Biomass Research and Development Initiative is to develop high-value biobased products to:

1. Enhance the economic viability of biofuels and power,
2. Serve as substitutes for petroleum-based feedstocks and products,
3. Enhance the value of coproducts produced using the technologies and processes; and
4. Develop a diversity of economically and environmentally sustainable domestic sources of renewable biomass or organics for conversion to Biofuels, bioenergy, and biobased products.

There are many opportunities available for grant funding for the READ project provided that the project components meet the funding requirements. Project features will be refined following this feasibility study during preliminary design to evaluate those grant opportunity requirements and make the project more attractive for funding. HDR concludes that the following steps should be taken with respect to securing additional funding to assist in improving the financial aspects of the project:

- Explore securing partners with pre-approved grant funds
- Consider altering the project to be attractive to transportation fuel grant funds
- Timing will be important so prepare for quick turn-around when submitting grant applications, identify teaming partners, refine development schedule, etc. so as to be attractive to the funding sources
- Determine the project construction completion timeline
- Explore pending congressional authorization or re-authorization of funding mechanisms.
- Explore possible funding programs such as Section 1603 described above and evaluate the proposed development team in light of possible funding requirements.

13.0 Conclusions

HDR provides the following technical conclusions regarding the treatment systems:

1. Digestion of organic materials to produce and recover biogas from the UC Davis campus including manure, food waste, and MSW is technically feasible, albeit relatively unattractive in financial terms.
2. The quantity of feedstock believed to be available to the facility is less than previously anticipated.
3. Based on the feedstock available to the facility, flexibility in treating varying levels of feedstock quality and quantity, furthering of educational opportunities, and an economic comparison of different technologies, High-Solids digestion appears to be the most preferable treatment technology. The APS technology was selected as a representative High Solid digestion technology for this study.
4. The use of manure and food waste as the primary feedstock appear to be attractive for digestion using the APS technology.
5. The use of MSW as a feedstock including a robust pretreatment system to remove the organic fraction of the MSW appears to be potentially attractive, particularly with respect to application of the technology to other jurisdictions.
6. In order to employ the lowest cost Scenario A, land application of the digestate from digesting the manure and food waste feedstock would require further study.
7. Digestate management from Scenario B and C includes dewatering and stabilization using composting.
8. For Scenario C, further demonstration of the rotating drum treating MSW would be appropriate to confirm the performance of this scenario before implementation.
9. The generation of biogas would approximately double if MSW is also digested at the facility (Scenario C).
10. A variety of biogas uses are available. This study concluded biogas used to fuel an internal combustion engine is the most economically attractive, however, the use of biogas as a supplement to natural gas boiler fuel at the Primate Center has relatively similar financial terms. The viability of using biogas at the Primate Center depends upon a site relatively close to the Primate Center. Consequently, further study of this issue is recommended.

HDR also offers the following conclusions regarding the potential sites:

1. Both the Hopkins Road site and the Campus landfill site provide the benefit of being in close proximity to the Primate Center for purposes of providing biogas to the Primate Center facility.
2. Hopkins Road has the added benefit of being located close to the future dairy operation feedstock sources if the dairy relocates to this site.

3. The WWTP site is not particularly beneficial because the use of biosolids in Scenario C was not considered, partly due to the current economically attractive management practice of using the dried biosolids at the Yolo County landfill as an alternative daily cover.
4. Either the Hopkins Road or Campus Landfill site would be the most attractive if the use of biogas is deemed attractive in boilers at the Primate Center.

HDR concludes the following financial issues regarding the use of the UC Davis-APS as the representative High Solid digestion technology:

1. Scenario A is the least costly scenario and therefore is attractive as an initial phase of the development. However, Scenario A would require further study regarding the land application of digestate to agricultural lands.
2. Scenario B reflects the mid cost option and includes an appropriate array of equipment to pre-treat the feedstock and to treat the post digester effluent and digestate. Scenario B is sized to treat the quantity of feedstock material UC Davis is known to generate and control in its collection system.
3. Scenario C would provide the ability to demonstrate the APS technology using a broader feedstock with more applicability to a broader array of municipalities and similar solid waste management jurisdictions.

Table 29 below provides a comparison of the capitol and annual operating costs and the potential revenues that can generated for Scenarios A, B and C. When revising for lower avoided cost (half of the actual costs of landfilling and manure management), these are the resulting costs.

Table 29. Comparison of Scenarios

	Scenario A	Scenario B	Scenario C
Feedstock (type)	Manures, Bedding, Food Waste	Manures, Bedding, Food Waste	Manures, Bedding, Food Waste, MSW
Feedstock delivered to the facility (annual average wet tons per day)	22.3	22.3	47.1
Feedstock Available for Digestion (annual average wet tons per day)	22.3	22.3	35.3
Expected Methane Generation (scfd)	59,500	59,500	109,000
Energy Contained (Million Btu/year) in Biogas	23,200	23,200	41,100
Capital Cost	$8.3M	$14.4M	$23.7M
Annual O&M Cost	$700,000	$731,000	$1,040,000
Annual Revenue	$663,000	$763,000	$1,300,000
Net Present Cost (6%, 30 years)	$8.8M	$14.0M	$20.1M

14.0 Next Steps

The next steps in this Feasibility Study will be to concur with the findings that the preferred technology is the High-Solids digestion technology. In order to do so, UC Davis should concur that the feedstock materials identified in this report are appropriate and that no green waste bulking-type materials are readily available within the control of UC Davis.

The following steps should be taken to further develop the READ facility project. These next steps will resolve outstanding issues and clarify details to continue forward with the project:

1. Further evaluate the benefits and drawbacks of the potential sites to identify the preferred site.
2. Proceed with the preliminary engineering design to 30% completion which will include a more detailed plant concept including:
   a) Confirm the facility feedstock identified in this report
   b) Select the preferred Scenario A, B or C.
   c) Determine the preferred use of the biogas, clarifying power transmission line and/or gas pipeline if needed.
   d) Finalize preferred liquid effluent management technology/strategy.
   e) Prepare schedule for design completion and implementing construction.
   f) Prepare a detailed budgetary cost estimate for capital and operating the facility after preliminary design is completed.
   g) Prepare Preliminary Engineering Design Report summarizing the 30% design elements.
3. Conduct on-going reviews of new potential project funding sources.
4. Complete final design of the READ facility.

Appendix A – Feedstock Matrix

Department	Facility	Waste Stream	Description	Quantity of Waste (tons/year)	Quantity of Digester Feedstock (tons/year)		Quantity of Composting Feedstock (tons/year)	Collection Frequecy	Current Disposal Method	Pre-Treatment Required	Operational Practice Changes Required	Infrastructure Improvements Required
					No Preprocessing (tons/year)	Preprocessing (tons/year)						
Sodexho (Food Waste)	Segundo	Compactor - Other	Food waste mixed with high amounts of other biodegadable material (cardboard, paper, utensils)			170			Segundo Compactor - Hauled to Jepson Praire Organics for sorting and composting	Sorting to remove contaminants	source-separating and additional staff training, haul to digester instead of composting facility	none
		Compactor - Food Pulper[5]	Food scraps washed off of trays and dishes and made into a pulp		80				Segundo Compactor - Hauled to Jepson Praire Organics for sorting and composting	none	source-separating and additional staff training, haul to digester instead of composting facility	none
		Compactor - Pre-Consumer Food Waste*	Food waste mixed with smaller amounts of other biodegadable material - From Culinary Support Center, Segundo Kitchen, and waste from dining platforms	250	0				Segundo Compactor - Hauled to Jepson Praire Organics for sorting and composting	none	new collection areas and additional staff training	new collection system specifically for pre-consumer food waste
		Waste Oil	Waste Oil from Segundo operations	3.12	3.12			quarterly	Picked up by Sacramento Rendering Company	May need a heated grease holding tank tank	none	Will need receptacles because currently renting those from SRC
	Tercero and Cuarto/Oxford Combined	Compactor[5]	Food waste mixed with other biodegadable material	170	54	116			Hauled to Zamora for composting.	Light sorting to remove contaminants	source-separating and additional staff training, haul to digester instead of composting facility	none
		Waste Oil	Waste Oil from Tercero and Cuarto	2.26	2.26			quarterly	Picked up by Sacramento Rendering Company	May need a heated grease holding tank tank	none	Will need receptacles because currently renting those from SRC
Olive Center	Olive Press	Olive Pomace	Pomace - Byproduct of olive oil production	10	10			yearly	Hauled to Zamora for composting	none	none	TBD - depending on if processing is done on campus in future years
Animal Science	Dairy	Manure	Manure only, over concrete. May contain trace amounts of sand bedding.	2600	2600			twice weekly	Stockpiled at campus landfill; picked up periodically by Green Belt Carriers, to be used for compost or land application	Sand will need to be removed, if no other bedding material can be substituted for the sand	Find alternative to sand bedding, if possible	none
		Manure + Rice Hull Bedding	Maure mixed with Rice Hull Bedding, over concrete	1200			1200	weekly		none	none	none
	Feed Lot	Manure + Straw Bedding	Mostly manure, some straw, over concrete	720	720					none	none	none
				720	720			weekly				
	Sheep	Manure + Straw Bedding	50/50 sheep waste and straw bedding	180	180					none	may need more frequent collection	none
				120	120			twice a year				
	Beef Barn	Manure + Straw Bedding	Mostly manure, some straw, over concrete	100	100			As needed (usually monthly)		none	may need more frequent collection, and at consistent time intervals	none
	Horse (Cole Facility)	Manure + Straw Bedding	From inside barn area	460	460			twice a year		none	may need more frequent collection	none
	Goat***	Manure + Straw Bedding	50/50 goat waste and straw bedding. Contains dirt and rocks.	150				twice a year	Stockpiled at goat facility; picked up periodically by Green Belt Carriers, to be used for compost or land application	removal of dirt and rocks	concrete under bedding, if possible, to eliminate dirt and rocks. may need more frequent collection	possible new concrete pad
	Swine**/***	Waste over concrete.	Currently washed into sanitary sewer. Take scrapings.					continuous (connected to sewer)	Connected to sanitary sewer	none	utilize valve that diverts waste from sewer line	Entirely new infrastructure to collect, store, and transport waste separate from sewer line
	Poultry								Landfill			
Center for Equine Health	Center for Equine Health[1]	Straw bedding	Bedding containing some manure and urine	371	371			daily	Picked up and taken to landfill	none	none	none
		Shavings bedding	Bedding containing some manure and urine					daily	Picked up and taken to landfill	none	none	none
		Dry Lots***	Manure. Contains dirt and rocks.	35				rotating schedule of collection	Picked up and taken to landfill	removal of dirt and rocks	concrete under bedding, if possible, or more accurate collection method, to eliminate dirt and rocks. may need more frequent collection	possible new concrete pad or new collection equipment

Department	Facility	Waste Stream	Description	Quantity of Waste (tons/year)	Quantity of Digester Feedstock (tons/year)		Quantity of Composting Feedstock (tons/year)	Collection Frequecy	Current Disposal Method	Pre-Treatment Required	Operational Practice Changes Required	Infrastructure Improvements Required
					No Preprocessing (tons/year)	Preprocessing (tons/year)						
Campus Recreation	Equestrian Center[2]	Barn	Maure mixed with a little bedding	1530	1530			daily	Picked up by Campus Refuse and taken to landfill	none	Keep separate from other streams (currently all streams mixed). Already collected by hand to minimize contaminants. Concreting not an option.	none
		Pasture	Manure, may contain dirt.	510		510		2-3 times per week	Picked up by Campus Refuse and taken to landfill	may require removal of dirt	Keep separate from other streams (currently all streams mixed). Already collected by hand to minimize contaminants. Concreting not an option.	none
		Spoiled Feed	Wet hay that can't be fed to horses	6			6	intermittently	Picked up by Campus Refuse and taken to landfill	none	Keep separate from other streams (currently all streams mixed).	none
ASUCD	Coffee House/MU	Pre-Consumer Food Waste[3]	Kitchen scraps	50	50			2-3 times per week	Project Compost			
		Post-Consumer Organics (Compactor)	from Compostables waste bins	See Note 4					Compactor			
Vet Med Center	Large Animal Clinic	Straw bedding	Mostly bedding, some manure and urine, may contain anti-biotics									
		Shavings bedding	Mostly bedding, some manure and urine, may contain anti-biotics	830	830							
	Pathology/Necropsy	Animal carcasses***	animals put down or used for study									
Med Center	New Facility	Pre-Consumer Organics*	Kitchen scraps, may include post-consumer plate scrapings									
		Post-Consumer Organics*	Pulper/Grinder waste									
		Post-Consumer Organics*	Waste collected in Compostables Bins in Cafeterias and other areas									
		Canola Shortening		11	11							
Custodial	All facilities containing restrooms	White Paper Towels		45		45						
		Brown Paper Towels		5		5						
Robert Mondavi Institute for Wine and Food Science	Winery	pomace	fruit waste from pressing	5	5			Once yearly - could happen anytime between August and November	Project Compost	none	none	none
Grounds and Landscaping Services				243			243					
Primate Center***	Primate Center***	Waste and leftover food	Animal waste and biscuits (feed), with a lot of pea gravel mixed in; Potential for Herpes B	2200				1-4 times weekly	Campus Landfill	Removal of gravel	Separation of gravel or use of different bedding	Removal of gravel
Animal Science	Meat Lab***	meat trimmings	includes meat, bones, digestive tracts, etc.	4.6					Sent to Sacramento Rendering Company			
Food Service	Cafeterias	Grease Trap Waste		104.25	104.25							
			Total Tons per year	12,635	7,951	846	1,449					
			Total Tons per day (365 days/year)	35	22	2	4					

*Not currently source-separated
**Not currently collected and hauled
*** Not considered as feedstock for Feasibility Study

1. Assume approximately 700 lbs/cy. Totals based on 530 cy of mixed bedding and 50 cy of dry lot scrapings per 6 months. Totals provided via phone message by Tanya Russel.
2. Assume 800 lbs/cy for barn and pasture waste. Assume 700 lb/cy for spoiled feed. Totals provided based on estimates given in phone call with Joe Murillo.
3. Based on estimate of filling one full toter (350 pounds) each work day. 350 pounds per day, 260 days ber year
4. Until 2011, post-consumer organics were taken to the Segundo compactor.
5. Based on Dining Commons waste audits, assume Pulper waste is 32% of the compactor waste.
6. Grease Traps assumed to be 25% full when empties

Appendix B – Research Report - Anaerobic Digestion of UC Davis Organic Waste Streams (Batch Digestion Study)

Research Report

Anaerobic Digestion of Various Organic Waste Streams from the UC Davis Campus

(Batch Digestion Study)

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Executive Summary

The anaerobic digestibility of various organic wastes from the UC Davis campus were studied under thermophilic conditions. The waste samples were collected from a multitude of campus departments and barns that have large organic waste streams seasonally or throughout the year, totalling about 10,000 tons per year for the campus; the cardboard stream is not included in this figure. Fifteen different materials tested include food waste, various animal beddings and manure from different animal operations on campus, olive pomace, coffee grounds, two types of paper towel, and two types of cardboard. Each waste stream was analyzed for solids content, and the digestibility of each waste stream was determined in terms of biogas yield, methane yield, and solids reduction using batch anaerobic digestion tests. Thermophilic digestion was carried out at a temperature of 50 ºC ± 2ºC and a food to microorganism ratio (F/M) of 1. In order to accommodate all the samples, two consecutive rounds of batch digestion tests were carried out, with 18 days for Round 1 and 35 days for Round 2.

In Round 1, the methane yields were 306, 356, 262, 329, 324, 350, and 608 mLCH4/gVS for thin cardboard, thick cardboard, white cardboard, white paper towel, brown paper towel, olive pomace, and food waste, respectively. In Round 2, the methane yields were 387, 263, 83, 154, 220, 367, 334, and 234 mLCH4/gVS for coffee grounds, horse manure from barns, horse bedding with wood shavings, cow bedding with rice hulls, horse manure from pasture, straw bedding (clean), cow bedding with straw, and cow manure from a cow given antibiotics.

For Round 1, the VS reduction was 40.8%, 30.9%, 25.6%, 53.4%, 32.9%, 76.6%, and 86.2% for thin cardboard, thick cardboard, white cardboard, white paper towel, brown paper towel, olive pomace, and food waste, respectively. For Round 2, the VS reduction was 65.6%, 48.5%, 81.5%, 69.7%, 45.5%, 54.4%, 70.6%, and 41.1%, respectively.

Based on the results of this study, a continuous digester operating on 13 of the 15 waste streams is possible. If the substrate mixture contains a large fraction of paper towels, cardboard, food waste, olive pomace, coffee grounds, barn horse manure, and/or straw cow bedding, digestion periods of 6 to 12 days could be expected. If the substrate mixture contains a large fraction of pasture horse manure or cow manure from cows on antibiotics, a longer retention time of 15-16 days could be expected. The data suggest that rice hull cow bedding and wood shaving horse bedding are not suitable feedstocks for digesters under the conditions of this study.

1. Introduction

Anaerobic digestion is a bioconversion technology that converts organic wastes into biogas, which can be used as fuel for heating or co-generation of electricity and heat. Anaerobic Digestion also produces solid and liquid fertilizer products; alternatively, the solid portion may be used as a building material. Benefits of using this technology include diverting organic materials from landfill, avoiding methane emissions due to landfilling, producing renewable energy to offset fossil-fuel use, and producing usable fertilizer products.

At UC Davis, which produces a significant amount of organic wastes annually (about 10,000 tons per year), a feasibility study is underway to design and construct a full-scale anaerobic digester, using the patented APS Digester technology developed on campus by Dr. Ruihong Zhang. The digester will be designed to process an array of organic waste streams produced by different facilities at the UC Davis campus in addition to the UCD Med Center in Sacramento. The collection and central digestion of these waste streams may be an invaluable practice to divert organic wastes from the campus landfill and provide a renewable energy source to the community. The lab tests reported in this paper represent one component of this feasibility study. Further testing will be carried out on a larger scale using the UCD Pilot APS-Digester facility, which is capable of processing up to 3 tons per day of organic waste.

An extensive characterization study was carried out to investigate the organic waste resources available on the UC Davis campus, its various animal facilities in and around campus, and the UCD Med Center in Sacramento for application of anaerobic digestion. Waste streams with the greatest potential for inclusion in the Campus Digester were sampled and tested in lab-scale batch digesters. Two rounds of batch tests were carried out over a 2 month period.

As Table 1 demonstrates below, waste streams sampled and tested include food pulper waste from the Segundo Dining Commons, one of three Sodexo-operated food restaurants on campus; coffee grounds from the ASUCD Coffee House, a student-run restaurant serving 7000 meals per day, olive pomace from the Olive to Bottle mobile olive mill, a private olive press company hired by UC Davis to press its olives into olive oil; paper towels from the custodial department which services restrooms all over campus; animal bedding and manure from the Campus Dairy and Feedlot which house a copious number of cows; animal bedding and manure from the Center for Equine Health and the Equestrian Center, which both house a large number of horses; and clean straw bedding and manure from a cow on a typical antibiotic regime from the Vet Med Center Large Animal Clinic. Additionally, various cardboards from an outside vendor were tested in conjunction with campus wastes.

Table 1. UC Davis campus waste streams tested and their source.

Substrate	Source
Round 1:	
Thin cardboard	Outside Vendor
Thick cardboard	Outside Vendor
White cardboard	Outside Vendor
White paper towel	Restrooms/Custodial
Brown paper towel	Restrooms/Custodial
Olive pomace	Olive to Bottle Olive mill
Food waste	Segundo Dining Commons dishroom
Inoculum, 1 week old	East Bay Municipal Utility District (EBMUD)
Round 2:	
Coffee grounds	ASUCD Coffee House
Horse Manure from barns	Equestrian Center
Horse Bedding - Wood Shavings	Center for Equine Health
Cow Bedding - Rice Hulls	Dairy
Horse Manure from pasture	Equestrian Center
Straw bedding, clean	Vet Med Large Animal Clinic
Cow Bedding - Straw	Feedlot
Cow Manure - from cow on antibiotics	Vet Med
Inoculum, 4 weeks old	East Bay Municipal Utility District (EBMUD)

Note: all beddings contain animal manure/urine unless described as "clean."

The second round of batch testing was initiated the day the first round was finished and used the same inoculum as the first round with the difference being the age and incubation of the inoculum; in round one, inoculum was used after a few days incubation whereas in round two, inoculum was used after 4 weeks of incubation. In both cases, the inoculum was still active. The following sample tables and graphs will show the rounds separately due to this difference in age of the inoculum.

In the first round of batch tests, which were initiated on January 19th 2011, the following organic wastes were tested: Olive pomace, food waste, two types of paper towels, and three types of cardboard. The first round was carried out over 18 days, concluding on February 8th, 2011.

In the second round of batch tests, initiated on February 8th, 2011, the following organic wastes were tested: coffee grounds, manure from the Equestrian Center's barns and pasture with small amounts of wood shaving bedding material, horse manure and wood shaving bedding material from the Center for Equine Health, cow manure and rice hull bedding material from the Campus Dairy, clean straw bedding material from the Vet Med Large Animal Clinic (no manure visible), one manure sample from a Vet Med cow on typical antibiotic regime, and cow manure and straw bedding material at the Feedlot. The animal facilities all use various types of bedding for the animals to stand on and to absorb their manure and urine. Each facility cleans out the bedding on a different schedule. Both the Dairy and Feedlot had bedding material saturated with cow manure and urine. The straw bedding material at the Vet Med Large Animal Clinic was devoid of any visible manure as Vet Med cleans out their bedding on a daily basis to keep stalls as clean as possible. The second round was carried out over 37 days, concluding on March 17th, 2011.

The main objective of this study was to determine the digestibility of these waste streams under thermophilic conditions in terms of biogas yield, methane yield, and volatile solids reduction. The results will then be used to determine the operating conditions (e.g., temperature, hydraulic retention time, and loading rate) of a continuous digester fed with a mixture of the different types of waste.

2. Material and Methods

2.1. Food waste collection and storage

Various organic wastes streams from campus were collected from December 2010 to February 2011. During each sampling event, the material was collected by hand and placed into 1-gallon plastic bags and kept frozen (-20 ºC) until the day before solids analysis and batch digestion tests, at which point they were placed in a laboratory refrigerator running at 4 ºC to thaw. As the only exceptions, cardboard and paper samples were pre-processed by soaking with a 10:1 water to fiber ratio, mixed in a powerful lab blender, then frozen.

On December 14th, 2010, Olive pomace was collected during a fresh pressing of campus olives into olive oil by Olive to Bottle Mobile Services, an 8-foot specially designed mobile olive mill, while it was stationed at a farm north of campus. Two grab samples were taken as pomace was exiting fresh from their processor and had a very moist, apple sauce-like consistency. The only additive used in the process was chemically inert talc powder (less than 1%), used to increase the oil captured in the pressing.

On January 5th, 2011, two types of clean paper towel rolls were provided by Custodial Services. One type was brown paper and the other was white paper. The Custodial Department plans to use mostly white paper in the next year (the specific kind is “Scott 2000”). Both paper towel samples were mixed with water and processed for 30 seconds in a heavy duty blender before solids analysis and lab testing.

On January 12-13, 2011, food waste from the Segundo Dining Commons, one of 3 Sodexo owned and operated restaurants on the UC Davis campus, was collected from its food pulper/dewaterer in the dishwashing room over 4 different meal periods (breakfast, lunch, dinner, and late-night). Employees scrape plate leftovers and napkins into a water stream, the food pulper macerates and presses out a significant portion of the water, and a homogenous material is discharged into a collection bin. The sampling times were 10am, 1pm, and 6pm on 1/12/11 and 10pm on 1/13/11, in each case, the sampling occurred when the pulper bins were more than ¼ full and more than an hour after the meal period so that material would accumulate adequately. The number of customers for each different meal period was provided by Sodexo staff; for analysis, the 4 samples were mixed in proportions equivalent to the meals served for the 4 different meal periods (see Table 2 below).

Table 2. Composite Food Waste mixture from Segundo Dining Commons

Meal Period	**# meals served**	**Proportion of Food Waste**	**Sampling Mixture (g)**
Breakfast 1/12/11	299	9.7%	38.6
Lunch 1/12/11	1080	34.9%	139.5
Dinner 1/12/11	1349	43.6%	174.3
Late-night 1/13/11	368	11.9%	47.5
Total	3096	100.0%	400.0

On January 14th, sludge samples were collected from East Bay Municipal Utility District's thermophilic digesters as inoculum for the batch tests. They were placed in an incubator maintained at 50 ºC ± 2ºC for an initial sludge stabilization period, allowing for gas pressure relief through a water seal. Sludge was kept in the incubator for 4 weeks in the case of round 2 testing and remained active enough for testing.

Various clean cardboard samples of different thicknesses and colors were supplied by an outside vendor. Three types chosen for sampling were identified as thin cardboard, thick cardboard, and white cardboard. These samples were cut roughly into 1" pieces, soaked in water at a 1:10 cardboard to water ratio for 24 hours, then processed for 30 seconds in a heavy-duty blender. Samples were kept frozen until solids analysis testing, in which case they were taken out of the freezer and allowed to thaw covered with aluminum foil at room temperature.

On January 27th, samples of straw bedding and manure were collected separately at the Vet Med Large Animal Clinic from a roll-off dumpster and from an animal pen, respectively. The straw bedding was visibly clean, no sign of manure present due to the fact the bedding is cleaned out on a daily basis, so manure does not accumulate. The manure sample was collected from a cow paddy from a pen housing a cow on a typical antibiotic regime. Though not representative of all manures from Vet Med, it reflects an initial consideration of the effects of Vet Med antibiotics on the digestion process.

On January 28th 2011, samples were collected at the Center for Equine Health, which houses a large number of horses. Material was collected from 2 yard trailers which had several different material streams. Only one stream was sampled: horse manure and wood shaving bedding material. Other streams were very similar to that of the Equestrian Center. Material from the trailers is emptied on a daily basis so was sampled no more than a few hours after collection from the barns.

2.2. Characterization of the Original and Prepared Substrates

All substrates were measured for their solid contents such as total solids (TS), volatile solids (VS), and fixed solids (FS, or ash). The prepared samples of round 1 were also measured for pH using a pH meter; substrates were too thick in round 2 to measure pH. Samples from both round 1 and round 2 were also measured for pH after sludge and water additions. The results are shown in Tables 3 and 4 below. Duplicate tests were performed for all samples.

2.3. Anaerobic Digestion Tests

2.3.1. Experimental Design and Set-up

Thermophilic (50 ºC ± 2 ºC) batch reactors were carried out for each waste stream. An organic loading rate of 6 gVS/L was used for all samples except olive pomace and food waste, which were loaded at 3 gVS/L, as was suggested from past tests. The food to microorganism ratio (F/M) was 1.0 for all samples. Seed culture for the reactors was collected from thermophilic anaerobic digesters fed with municipal waste water at East Bay Municipal Utility District (Oakland, CA). Sludge stabilization was performed by incubating the sludge at 50 ºC ± 2 ºC for 4 days, allowing gas to be vented through a water seal (note sludge was incubated for 4 weeks in the case of Round 2). Each of the batch reactors had a total and effective volume of 1130 and 500 mL, respectively. After the proper amounts of substrate and sludge were added, tap water was then used to bring the working volume up to 500 mL. The quantities used for each substrate of both round 1 and round 2 can be found in Tables 9 and 10 in the Appendix. Each different waste stream was tested in duplicates.

All the reactors were tightly closed with rubber septa and screw caps. The head spaces of the reactors were purged with argon gas for five minutes to assure anaerobic conditions. In both rounds of experiments, two blank reactors were also operated to correct for the biogas produced from the inoculum. Each of the blank reactors contained only inoculum and water.

2.3.2. Biogas measurements

Biogas production was calculated daily from the measurement of pressure in the head space of each reactor. Pressure was measured using a WAL-BMP-Test system pressure gauge (type 3150) with accuracy of 0.1%. After the pressure measurement, the biogas in the head space was released under water to prevent gas exchange between the head space and the ambient air. Then the pressure in the head space was measured again as an initial condition for the next-day measurement. Daily pressure differences were converted into biogas volumes using the following equation:

$$VBiogas = (P^* \ Vhead \ ^*C)/(R^*T)$$

Where:

VBiogas = daily biogas volume (L),
P = absolute pressure difference (Pa),
Vhead = volume of the head space (L),
C = molar volume (22.41 L mol-1),
R = universal gas constant (83.14 L.mbar.K-1.mol-1),
T = absolute temperature (K).

For round 1, biogas composition (CH4, CO2, H2) was measured after the first 24 hours of digestion, then daily for 5 days, then 2-3 times a week for 2 weeks using gas chromatography.

For round 2, biogas composition (CH4, CO2, H2) was measured after the first 24 hours of digestion, then daily for 2 days, then 2 times a week for 3 weeks using gas chromatography.

At the conclusion of the batch testing, all batch reactors were measured for their solid contents such as total solids (TS), volatile solids (VS), and fixed solids (FS, AKA ash) in duplicate. The samples were also measured for pH using a pH meter. All the analyses were performed according to standard methods (APHA, 1998).

3. Results and Discussion

3.1. Waste Characteristics

The solids analyses for the fifteen waste streams are shown in Tables 3 and 4. All samples were analyzed as-is with the exception of the three cardboard samples and two paper towel samples, which were sampled after they had been mixed with 10 parts water for 24 hours and blended. Cardboard is normally found in a fairly dry state and was tested after water addition; it's original TS content is estimated to be 90-100% depending on the storage environment. Size reduction in a large scale bio-digester system might involve liquid addition and size reduction through a Bio-drum reactor. Cardboard and paper towel samples can still be compared with the other samples based on VS/TS since that is not affected by water additions. One should consider the seasonal effects on the TS/VS content of the various animal beddings since these samples were collected in the wet winter and contain more water than would drier seasons. The only parameter than would not change seasonally is TS/VS, as shown below.

Total Solids (TS):
Of the 15 substates tested, the ones with the highest total solids content in their raw form include: all raw paper and cardboard samples (estimated 90-100%), clean straw bedding from Vet Med (61%), horse manure from the Equestrian Center pasture (40%), coffee grounds from the Coffee House (35%), and Wood shaving bedding/horse manure from the Center for Equine Health (31%).

The next highest TS contents belong to: Olive pomace (27%), rice hull bedding/cow manure from the Dairy (22%), Horse manure from the Equestrian Center barn (19%), and Food pulper waste from the dining commons (17%).

The samples with the lowest TS content include: straw bedding/cow manure from the Feedlot (15%), cow manure from Vet Med (10%), and the pre-watered cardboard and paper towel samples (6% and below). Note: the inoculum for rounds 1 and 2 had TS measurements of 3 and 4%, respectively.

Volatile Solids (VS):
Of the 15 substrates tested, the samples with the highest VS content include: all raw paper and cardboard samples (estimated 80-90%), clean straw bedding from Vet Med (54%), coffee grounds from the Coffee House (33%), Wood shaving bedding/horse manure from the Center for Equine Health (22%), horse manure from the Equestrian Center pasture (20%), and Olive pomace (23%).

The next highest VS contents belong to: rice hull bedding/cow manure from the Dairy (19%), Horse manure from the Equestrian Center barn (17%), and Food pulper waste from the dining commons (16%).

The samples with the lowest VS content include: straw bedding/cow manure from the Feedlot (13%), cow manure from Vet Med (9%), and the pre-watered cardboard and paper towel samples (6% and below). Note: the inoculum for rounds 1 and 2 had VS measurements of 3 and 1%, respectively.

Ratio VS/TS:
The following waste streams had a VS/TS ratio greater than 80% and are considered to be highly organic: white paper towel (98%), coffee grounds from the Coffee House (97%), Food pulper waste from the dining commons (96%), thin cardboard (96%), white cardboard (96%), brown paper towel (95%), thick cardboard (93%), olive pomace (92%), Horse manure from the Equestrian Center barn (90%), clean straw bedding from Vet Med (89%), Wood shaving bedding/horse manure from the Center for Equine Health (86%), and cow manure from Vet Med (82%).

The other materials with lower VS/TS ratios, but still considered fairly organic, include: rice hull bedding/cow manure from the Dairy (65%) and horse manure from the Equestrian Center pasture (65%). Note, the inoculum for rounds 1 and 2 had VS/TS ratios of 48% and 40%, respectively.

Table 3. Round 1: Solids analysis results of samples (standard deviation in parentheses).

Substrate	**MC (%)**	**TS (%)**	**VS (%)**	**FS (%)**	**VS/TS (%)**	**pH**
Thin cardboard[a]	94.1 (0.37)	5.94 (0.37)	5.70 (0.36)	0.24 (0.01)	96.0 (0.06)	7.58
Thick cardboard[a]	94.3 (0.16)	5.65 (0.16)	5.31 (0.16)	0.34 (0.01)	94.0 (0.08)	7.53
White cardboard[a]	94.2 (0.23)	5.80 (0.23)	5.54 (0.21)	0.25 (0.01)	95.6 (0.04)	7.32
White paper towel[a]	93.9 (0.34)	6.05 (0.34)	5.96 (0.34)	0.09 (0.00)	98.5 (0.03)	7.34
Brown paper towel[a]	94.6 (0.39)	5.41 (0.39)	5.16 (0.38)	0.24 (0.02)	95.5 (0.03)	7.49
Olive pomace	71.5 (0.25)	28.53 (0.25)	26.33 (0.21)	2.20 (0.03)	92.3 (0.05)	5.69
Food waste	82.3 (0.08)	17.67 (0.08)	17.04 (0.09)	0.63 (0.16)	96.4 (0.90)	5.57

a. These samples were analyzed with a ratio of 1g substrate, 10g water, blended
Note: The thermophilic seed culture used in Round 1 was also tested for solids content and had 2.98% TS and 49% VS/TS.

Table 4. Round 2: Solids analysis results of samples (standard deviation in parentheses).

Substrate	**MC (%)**	**TS (%)**	**VS (%)**	**FS (%)**	**VS/TS (%)**
Coffee grounds	61.8 (0.2)	38.2 (0.2)	37.4 (0.18)	0.85 (0.00)	97.8 (0.0)
Horse Manure from barns	80.6 (0.4)	19.4 (0.4)	17.6 (0.34)	1.75 (0.07)	90.9 (0.2)
Horse Bedding - Wood Shavings	68.1 (1.3)	31.9 (1.3)	27.7 (1.96)	4.12 (0.64)	87.0 (2.5)
Cow Bedding - Rice Hulls	75.0 (0.3)	25.0 (0.3)	20.2 (0.36)	4.76 (0.08)	81.0 (0.5)
Horse Manure from pasture	56.8 (1.4)	43.2 (1.4)	14.3 (0.10)	28.8 (1.28)	33.2 (0.8)
Clean Straw bedding	20.4 (0.3)	79.6 (0.3)	71.3 (0.27)	8.31 (0.04)	89.6 (0.0)
Cow Bedding - Straw	83.6 (0.2)	16.4 (0.2)	14.4 (0.42)	2.02 (0.20)	87.7 (1.4)

Substrate	MC (%)	TS (%)	VS (%)	FS (%)	VS/TS (%)
Cow Manure - from cow on antibiotics	86.3 (0.0)	13.7 (0.0)	11.4 (0.04)	2.27 (0.01)	83.4 (0.1)

Note: The thermophilic seed culture used in Round 2 was also tested for solids content and had 2.40% TS and 46% VS/TS.

3.2. Results of Thermophilic Batch Digestion

3.2.1. Biogas Yield and Production Rate

Biogas yields for the thermophilic digesters are provided in Tables 5 and 6 and Figures 1 and 2 below. The total digestion times for Round 1 and Round 2 were 18 days and 37 days, respectively, at which time the biogas production had leveled off for most of the digesters. Biogas yields for each substrate are reported after subtracting the quantity of biogas produced from the control group (sludge).

Round 1 biogas yields are shown in order from greatest to least in Table 5 and Figure 1. Food waste produced the highest yield by far, with 858 mL/gVS. Olive pomace produced much less, with 509 mL/gVS. Cardboard and paper towel samples ranged from 465 to 606 mL/gVS.

Table 5. Round 1: Biogas Yields (mL/gVS)

Food waste	858
Thick cardboard	606
Brown paper towel	547
Thin cardboard	529
Olive pomace	509
White paper towel	505
White cardboard	465

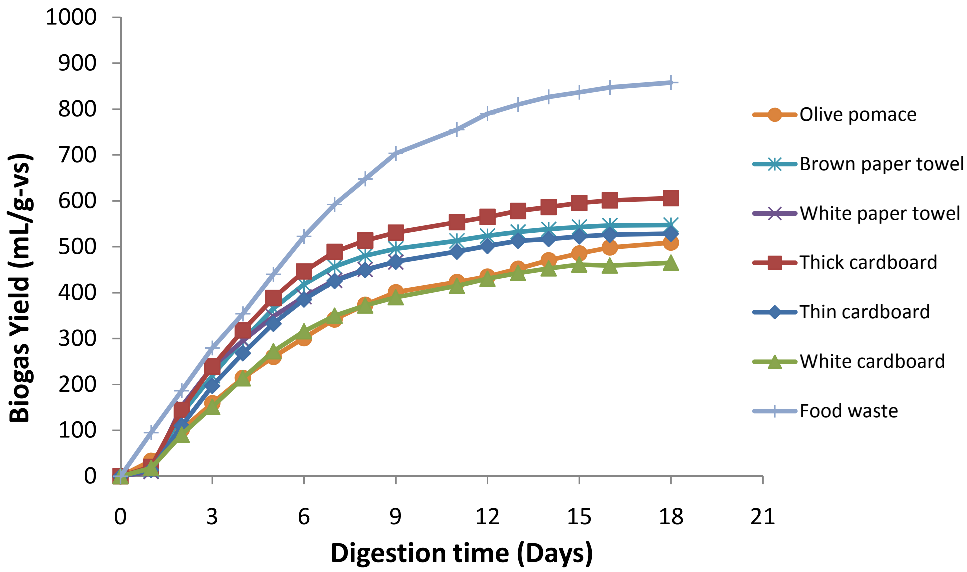

Figure 1. Round 1: Cumulative Biogas Yields from campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors.

Round 2 biogas yields are shown in order from greatest to least in Table 6 and Figure 2. The clean straw bedding from Vet Med produced the highest yield, with 577 mL/gVS, followed by coffee grounds (533 mL/gVS), and the straw bedding/cow manure from the Feedlot (477 mL/gVS). Materials that yielded less biogas include horse manure from the Equestrian Center barn (374 mL/gVS), cow manure from Vet Med (338 mL/gVS), horse manure from the Equestrian Center pasture (318 mL/gVS). The two materials which yielded the least biogas of round 2 samples were the rice hull bedding/cow manure from the Dairy (222 mL/gVS), and the wood shaving bedding/horse manure from the Center for Equine Health (96 mL/gVS). For the latter sample, the biogas yield was even less than that produced by the sludge control reactors (170 mL/gVS).

Table 6. Round 2: Biogas Yields (mL/gVS)

Straw bedding, clean	577
Coffee grounds	533
Cow Bedding - Straw	477
Horse Manure from barns	374
Cow Manure - from cow on antibiotics	338
Horse Manure from pasture	318
Cow Bedding - Rice Hulls	222
Horse Bedding - Wood Shavings	96

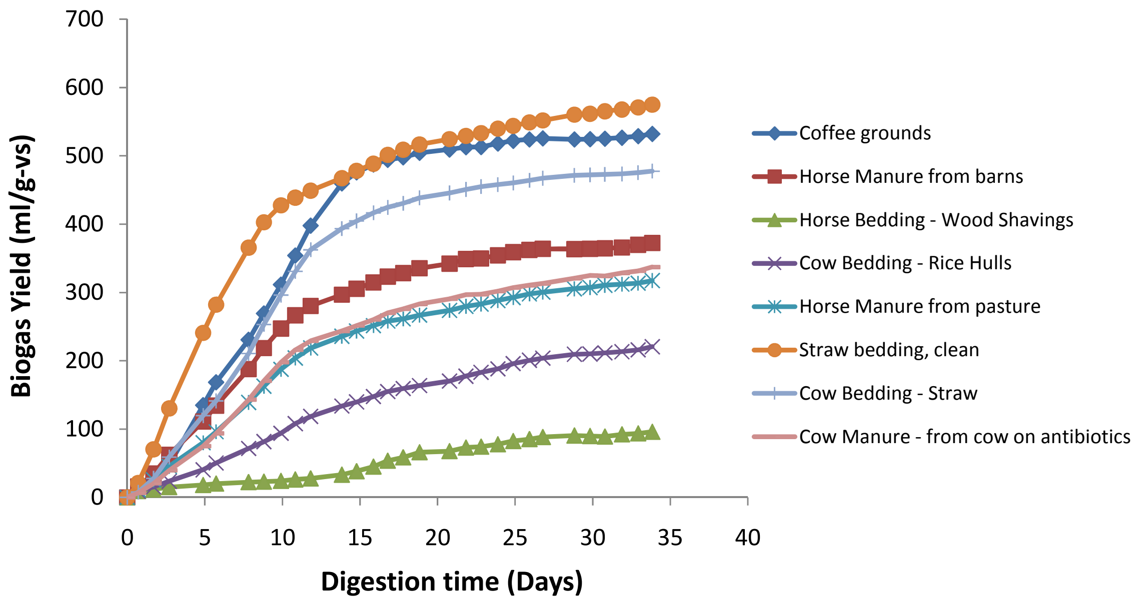

Figure 2. Round 2: Cumulative Biogas Yields from campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors.

Biogas production rates for the thermophilic digesters are provided in Figures 3 and 4 below. Round 1 samples all peaked within 5 days then tapered off for 2 more weeks.

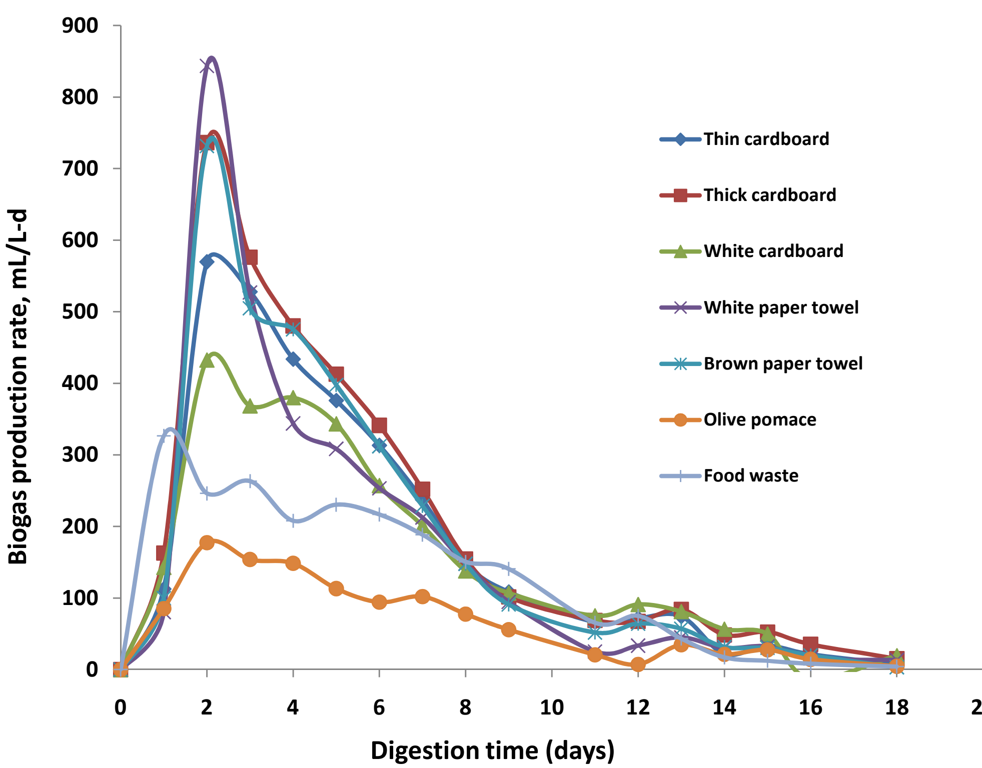

Figure 3. Round 1: Biogas production rates for campus waste streams under mesophilic conditions. Each data point is the average measurement of three reactors.

Round 2 samples were more variable, with most samples peaking within 10 days with the exception of coffee grounds and horse bedding-wood shavings, which saw peaks at 12 and 16 days, respectively. The latter sample also showed a low gas production rate throughout with a slight increase at 15-16 days. All samples tapered off for 3 more weeks of testing.

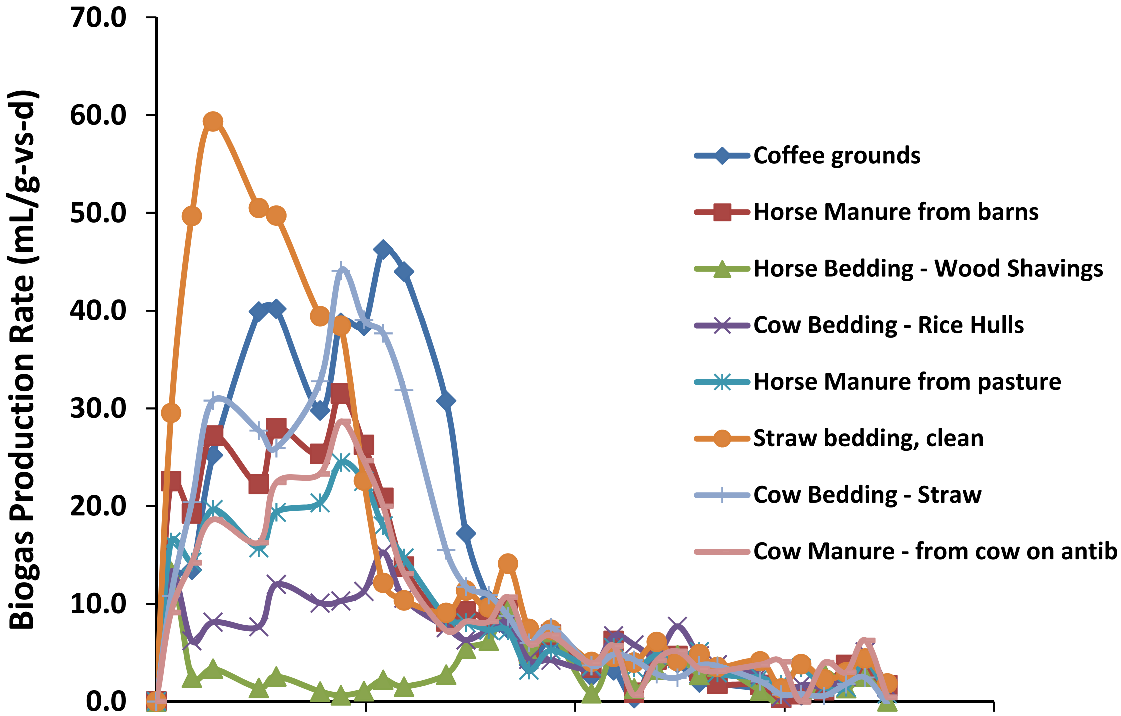

Figure 4. Round 2: Biogas production rates for campus waste streams under mesophilic conditions. Each data point is the average measurement of three reactors.

3.2.2. Biogas Composition

The methane contents of the campus waste streams over the digestion period are shown in Figures 5 and 6 below. Graphs of methane yield can also be found in the Appendix, Figures 7 and 8.

In the case of Round 1 samples, methane content was between 58 and 66% of the biogas after five days of digestion and was between 59 and 70% after 18 days of digestion.

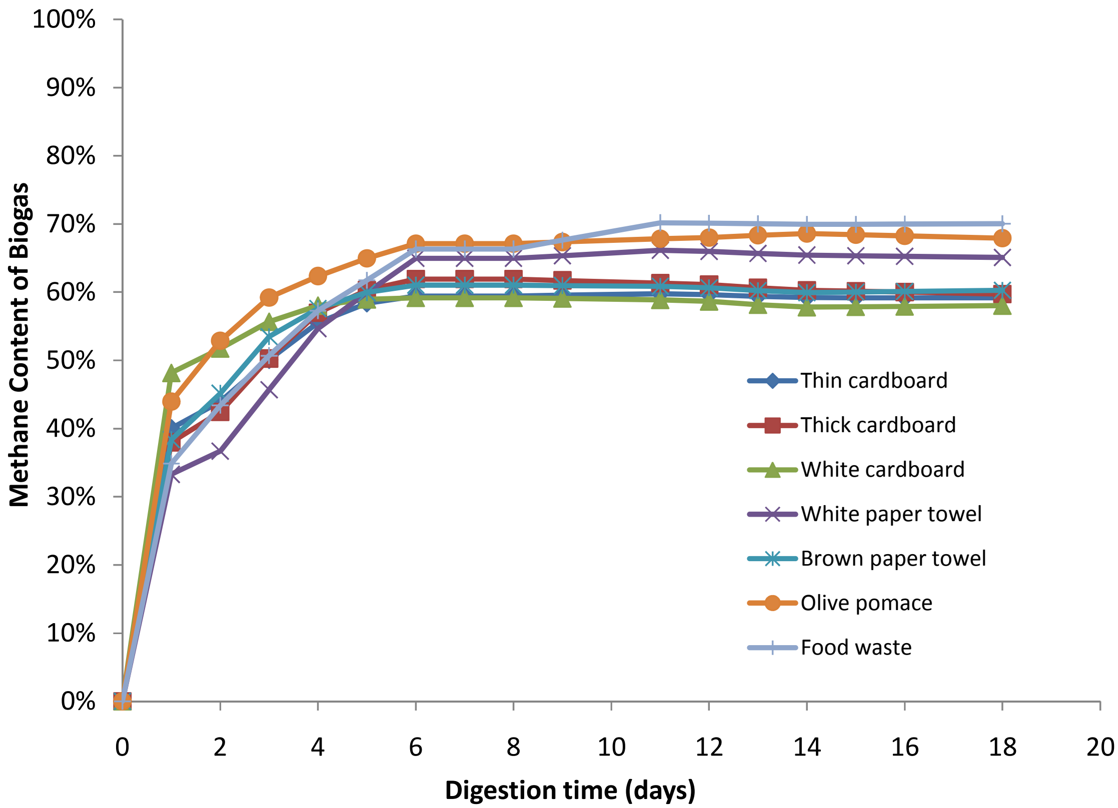

Figure 5. Round 1: Methane contents of biogas for campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors.

In the case of Round 2 samples excluding the horse manure sample, which clearly was an outlier, methane content was between 55 and 63% of the biogas after 7 days of digestion, between 64 and 69% after 14 days of digestion, and between 61 and 68% after 30 days of digestion. The horse manure – wood shaving sample showed a more gradual increase in methane content taking 12 days to reach 51% methane content, 17 days to reach 61%, and ending the testing period with 64% of biogas as methane.

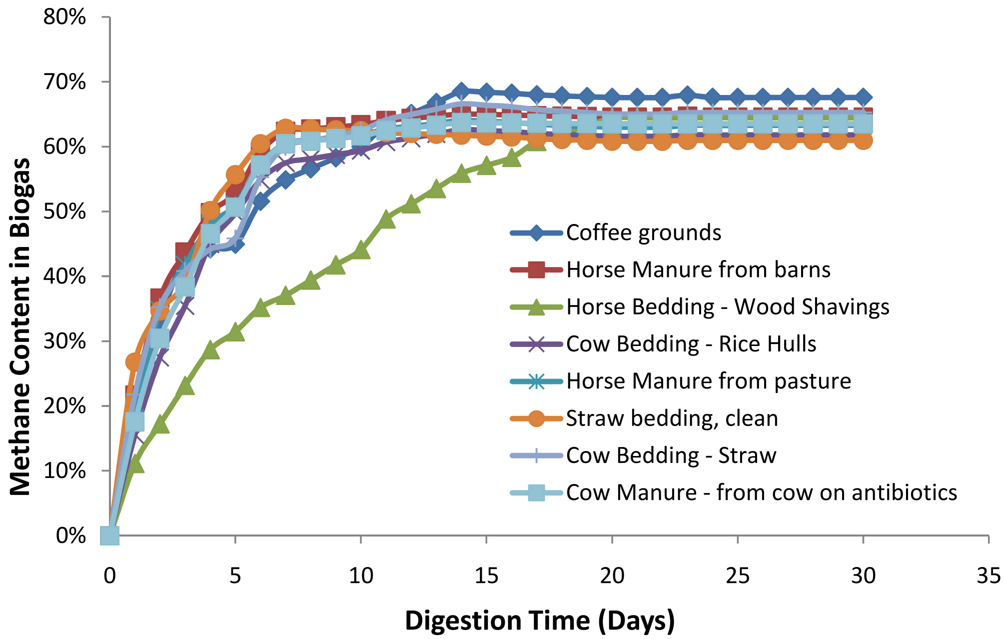

Figure 6. Round 2: Methane contents of biogas for campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors.

3.3. Final Characteristics

Effluent pH, TS, and VS were measured at the end of the digestion period. Tables 7 and 8 summarize the results of the thermophilic batch digestion study. The pH at the end of digestion was similar in all reactors, ranging from 7.13 to 7.25 for Round 1 and from 7.59 to 8.09 in Round 2. The volatile solids reduction in the campus waste streams after digestion ranged from 25.6% to 86.2% in Round 1 and from 41.1 to 81.5% in Round 2.

Table 7. Round 1: Biogas and methane yields and final characteristics of the campus waste streams after 18 days of thermophilic digestion at F/M of 1.0.

Parameter	Thin cardboard	Thick cardboard	White cardboard	White paper towel	Brown paper towel	Olive pomace	Food waste
Biogas Yield (mL/gVS)	529	606	465	505	547	509	858
Methane Yield (mL/gVS)	306	356	262	329	324	350	608
Final CH4 Content of biogas (%)	59.2%	59.7%	58.0%	65.1%	60.3%	67.9%	70.0%
Initial pH[a]	8.23	8.22	8.21	8.20	8.17	8.15	8.20
Final pH[a]	7.17	7.14	7.13	7.25	7.19	7.17	7.21
VS reduction (%)	40.8 (0.6)	30.9 (2.3)	25.6 (2.2)	53.4 (0.6)	32.9	76.6 (0.5)	86.2 (4.0)

a. The measured pH value includes substrate and sludge together.

Table 8. Round 2: Biogas and methane yields and final characteristics of the campus waste streams after 35 days of digestion.

Parameter	Coffee grounds	Horse Manure from barns	Horse Bedding - Wood Shavings	Cow Bedding - Rice Hulls	Horse Manure from pasture	Straw bedding, clean	Cow Bedding - Straw	Cow Manure - from cow on antibiotics
Biogas Yield (mL/gVS)	533	374	96	222	318	577	477	338
Methane Yield (mL/gVS)	387	263	83	154	220	367	334	234
Final CH4 Content of biogas (%)	67.6%	64.6%	64.4%	61.8%	63.3%	61.0%	65.2%	63.5%
Initial pH[a]	8.55	8.62	8.64	8.60	8.54	8.53	8.50	8.45
Final pH[a]	7.84	7.75	8.09	7.76	7.75	7.59	7.73	7.72

Parameter	Coffee grounds	Horse Manure from barns	Horse Bedding - Wood Shavings	Cow Bedding - Rice Hulls	Horse Manure from pasture	Straw bedding, clean	Cow Bedding - Straw	Cow Manure - from cow on antibiotics
VS reduction (%)	65.6 (5.1)	48.5 (2.5)	81.5 (3.2)	69.7 (1.5)	45.5 (6.2)	54.4 (20.3)	70.6 (0.8)	41.1 (2.3)

4. Conclusions

Batch anaerobic digestion studies were conducted on fifteen selected waste streams from the UC Davis Campus under themophilic conditions. The digestion studies were carried out over two different periods, 18 days for Round 1 and 35 days for Round 2. All tests were performed with a F/M ratio of 1.0. In Round 1, the methane yields were 306, 356, 262, 329, 324, 350, and 608 mLCH4/gVS for thin cardboard, thick cardboard, white cardboard, white paper towel, brown paper towel, olive pomace, and food waste, respectively. In Round 2, the methane yields were 387, 263, 83, 154, 220, 367, 334, and 234 mLCH4/gVS for coffee grounds, horse manure from barns, horse bedding with wood shavings, cow bedding with rice hulls, horse manure from pasture, straw bedding (clean), cow bedding with straw, and cow manure from a cow given antibiotics.

For Round 1, the VS reduction was 40.8%, 30.9%, 25.6%, 53.4%, 32.9%, 76.6%, and 86.2% for thin cardboard, thick cardboard, white cardboard, white paper towel, brown paper towel, olive pomace, and food waste, respectively. For Round 2, the VS reduction was 65.6%, 48.5%, 81.5%, 69.7%, 45.5%, 54.4%, 70.6%, and 41.1%, respectively.

Round 1 data suggests that for a continuous thermophilic digester operating under a F/M of 1.0, a hydraulic retention time necessary for the different materials would be 6 days for the two types of paper towels, 7 days for the 3 types of cardboard, 8 days for the food waste, and 9 days for the olive pomace.

Round 2 data suggests longer hydraulic retention times of 11 days for the clean straw bedding; 12 days for the coffee grounds, barn horse manure, and straw cow bedding; 15 days for the pasture horse manure, 16 days for the cow manure from cow on antibiotics; 21 days for rice hull cow bedding; and 22 days for the wood shaving horse bedding. These longer retention times may reflect the quality of the thermophilic inoculum used. Round 2 inoculum was aged 4 weeks longer than Round 1, so, perhaps, the viability of bacteria was compromised and the effective F/M ratio was much higher due to death of methanogens. VS reduction in the inoculum of Round 1 was 59.1%, whereas VS reduction in the inoculum of Round 2 was only 14.8%, indicating that at the beginning of testing, Round 2 inoculum was starved compared to that of Round 1.

Biogas from both the wood shaving horse bedding and rice hull cow bedding increased linearly throughout the testing period. This suggests that bacteria populations consuming these two substrates are slow growers. These materials also produced the lowest methane yields. Wood shavings contain a high lignin content and rice hulls have a tough coating that may inhibit digestion. Nevertheless, VS reduction for both were fairly high.

All 3 cardboard samples showed low VS reduction figures; however, in a full-scale composting facility that incorporates a composting stage, the extra solids remaining can contribute to the finished fertilizer product.

Based on the results of this study, a continuous digester operating on 13 of the 15 waste streams is possible. If the substrate mixture contains a large fraction of paper towels, cardboard, food waste, olive pomace, coffee grounds, barn horse manure, and/or straw cow bedding, digestion periods of 6 to 12 days could be expected. If the substrate mixture contains a large fraction of pasture horse manure or cow manure from cows on antibiotics, a longer retention time of 15-16 days could be expected. The data suggest that rice hull cow bedding and wood shaving horse bedding are not suitable feedstocks for digesters under the conditions of this study.

Ideas for future testing:

On February 16 2011, samples were collected from the UC Davis Med Center's grinder. This will be tested in a third round. A lot of plastic and Styrofoam trash was visible in the ground contents. As the Med Center is working on their composting system, they may have less contamination in the future, so more samples will be collected at a later date.

Additional tests should be conducted to determine the effects of different pre-processing methods for cardboard samples. The three treatments that should be compared (note the first treatment was applied in this study with no controls):

1. One inch pieces, soaked for 24 hours, 1 parts cardboard to 10 parts water, blended
2. One inch pieces, not soaked, 1 parts cardboard to 10 parts water, blended
3. Control – one inch pieces, not soaked, not blended

Another consideration for future testing will examine the effects of using inoculum of different ages. A standardized approach will eliminate the confounding effects of inoculum age/activity on digester performance. Round 1 and Round 2 tests cannot be compared with much certainty due to the significant difference in the age of the inoculum.

5. Acknowledgements

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6. References

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APPENDIX

Table 9. Round 1: Batch Set-up

Sample #	Description	Organic Loading (g VS/L)	F/M	VS (%)	Sludge Loading (g VS/L)	Substrate Loading (g)	Sludge Loading (mL)	Water (mL)	Total Working Volume (mL)
1	Thin cardboard	6	1	5.70	6	52.6	2.1	445.3	500.0
2	Thick cardboard	6	1	5.31	6	56.5	2.1	441.4	500.0
3	White cardboard	6	1	5.54	6	54.2	2.1	443.8	500.0
4	White paper towel	6	1	5.96	6	50.3	2.1	447.6	500.0
5	Brown paper towel	6	1	5.16	6	58.1	2.1	439.8	500.0
6	Olive pomace	3	1	26.33	3	5.7	1.0	493.3	500.0
7	Food waste	3	1	17.04	3	8.8	1.0	490.2	500.0
8	Inoculum, 1 week old			1.46	3	0.0	1.0	499.0	500.0

Table 10. Round 2: Batch Set-up

Sample #	Description	Organic Loading (g VS/L)	F/M	VS (%)	Sludge Loading (g VS/L)	Substrate Loading (g)	Sludge Loading (mL)	Water (mL)	Total Working Volume (mL)
1	Coffee grounds	6	1	37.36	6	8.0	263.4	228.6	500.0
2	Horse Manure from barns	6	1	17.60	6	17.0	263.4	219.6	500.0
3	Horse Bedding - Wood Shavings	6	1	27.75	6	10.8	263.4	225.8	500.0
4	Cow Bedding - Rice Hulls	6	1	20.25	6	14.8	263.4	221.8	500.0
5	Horse Manure from pasture	6	1	14.35	6	20.9	263.4	215.7	500.0
6	Straw bedding, clean	6	1	71.30	6	4.2	263.4	232.4	500.0
7	Cow Bedding - Straw	6	1	14.40	6	20.8	263.4	215.8	500.0
8	Cow Manure - from cow on antibiotics	6	1	11.39	6	26.3	263.4	210.3	500.0
10	Inoculum, 4 weeks old			1.10	6	0.0	263.4	236.6	500.0

Table 11. Round 1: Solids analysis results—alternative format (standard deviation in parentheses).

Substrate	**TS (g/kg)**	**VS (g/kg)**	**FS (g/kg)**	**TS (%)**	**VS/TS (%)**	**FS/TS (%)**
Thin cardboard	59.4 (3.7)	57.0 (3.6)	2.4 (0.1)	5.94 (0.37)	96.0 (0.06)	4.03 (0.06)
Thick cardboard	56.5 (1.6)	53.1 (1.6)	3.4 (0.1)	5.65 (0.16)	94.0 (0.08)	6.02 (0.08)
White cardboard	58.0 (2.3)	55.4 (2.1)	2.5 (0.1)	5.80 (0.23)	95.6 (0.04)	4.38 (0.04)
White paper towel	60.5 (3.4)	59.6 (3.4)	0.9 (0.0)	6.05 (0.34)	98.5 (0.03)	1.51 (0.03)
Brown paper towel	54.1 (3.9)	51.6 (3.8)	2.4 (0.2)	5.41 (0.39)	95.5 (0.03)	4.52 (0.03)
Olive pomace	285.3 (2.5)	263.3 (2.1)	22.0 (0.3)	28.53 (0.25)	92.3 (0.05)	7.71 (0.05)
Food waste	176.7 (0.8)	170.4 (0.9)	6.3 (1.6)	17.67 (0.08)	96.4 (0.90)	3.59 (0.90)
Inoculum	29.8 (1.7)	14.6 (0.9)	15.2 (0.8)	2.98 (0.17)	49.0 (0.13)	51.0 (0.13)

* cardboard and paper samples were tested after soaking in water and being blended into a slurry.

Table 12. Round 2: Solids analysis results—alternative format (standard deviation in parentheses).

Substrate	TS (g/kg)	VS (g/kg)	FS (g/kg)	TS (%)	VS/TS (%)	FS/TS (%)
Coffee grounds	382.0 (1.8)	373.6 (1.84)	8.5 (0.0)	38.2 (0.2)	97.8 (0.0)	2.2 (0.0)
Horse Manure from barns	193.5 (4.1)	176.0 (3.4)	17.5 (0.7)	19.4 (0.4)	90.9 (0.2)	9.1 (0.2)
Horse Bedding - Wood Shavings	318.7 (13.2)	277.5 (19.6)	41.2 (6.4)	31.9 (1.3)	87.0 (2.5)	13.0 (2.5)
Cow Bedding - Rice Hulls	250.0 (2.9)	202.5 (3.6)	47.6 (0.8)	25.0 (0.3)	81.0 (0.5)	19.0 (0.5)
Horse Manure from pasture	431.9 (13.7)	143.5 (1.0)	288.5 (12.8)	43.2 (1.4)	33.2 (0.8)	66.8 (0.8)
Clean Straw bedding	136.6 (3.1)	713.0 (2.7)	83.1 (0.4)	79.6 (0.3)	89.6 (0.0)	10.4 (0.0)
Cow Bedding - Straw	164.2 (2.2)	144.0 (4.2)	20.2 (2.0)	16.4 (0.2)	87.7 (1.4)	12.3 (1.4)
Cow Manure - from cow on antibiotics	136.6 (0.4)	113.9 (0.4)	22.7 (0.1)	13.7 (0.0)	83.4 (0.1)	16.6 (0.1)
Inoculum	24.0 (0.2)	11.0 (0.3)	13.1 (0.2)	2.40 (0.0)	45.6 (1.0)	54.4 (1.0)

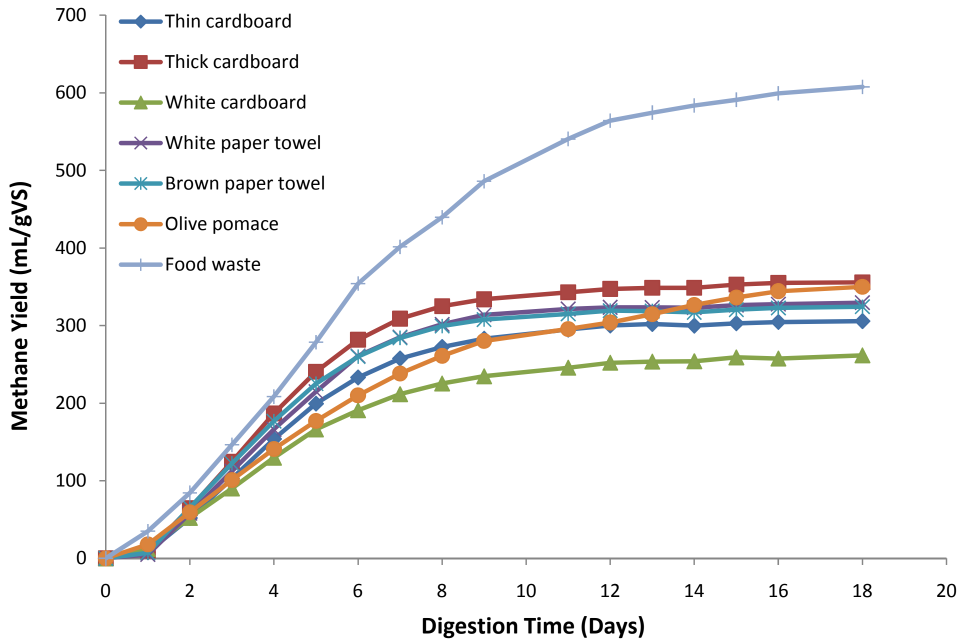

Figure 7. Round 1: Cumulative Methane Yield for campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors.

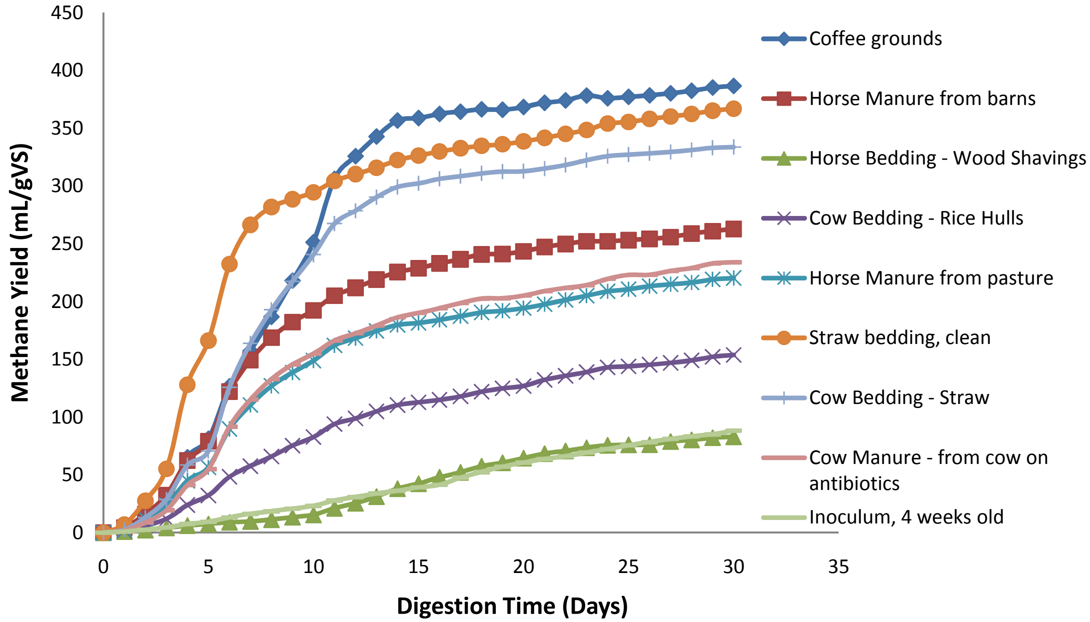

Figure 8. Round 2: Cumulative Methane Yield for campus waste streams under thermophilic conditions. Each data point is the average measurement of two reactors

Appendix C – Greenhouse Gas Emissions Modeling and Calculations

Description of Waste Management Scenario		GHG Impact of Scenario				
Alternative Scenarios	Annual Throughput (tons/year)[1]	Yearly GHG Emissions BASELINE SCENARIO ($MTCO_2E$)[2]	Yearly GHG Emissions ALTERNATIVE SCENARIO ($MTCO_2E$)[3]	Yearly GHG Emissions Reduction ($MTCO_2E$)[4]	GHG Emissions Impact per Ton Managed ($MTCO_2E$/ton)[5]	Equivalent # of Cars Removed from the Road for the Year[6]
A & B - UCD Proposed READ Facility - Organics only	8,102	-1,624	-2,025	400	0.05	73
C - UCD Proposed READ Facility - Organics + MSW through Drum	18,502	168	-3,103	3,271	0.18	599

1 - Assumes that 8,102 tons of organic feedstock are processed per year in both alternatives. Scenario B also contains 10,400 tons of MSW per year to be processed through the rotating drum equipment.

2 - EPA WARM model assumes that for Scenarios A and B, composting mixed organics is the baseline management strategy. Composting is the current practice for most organic waste streams on campus. EPA WARM model assumes that for Scenario C, composting mixed organics and landfilling MSW is the baseline management strategy. Assumes 75% landfill gas capture and that it is flared; transportation distances related to collection are assumed to be zero for all scenarios.

3 - For Scenarios A and B, this value includes EPA WARM modeling for composting digestate. For Scenario C, this value includes EPA WARM modeling for composting digestate and landfilling overs from the rotating drum. Values for all scenarios also include avoided grid GHG emissions from anaerobic digestion biogas net electrical generation using an internal combustion engine with 30% overall efficiency. Emissions are recorded as metric tones carbon dioxide equivalents ($MTCO_2E$); negative emissions indicate that a management scenario represents a net CO_2 sink relative to no management based on the U.S. EPA WARM model.

4 - Positive values indicate a GHG reduction from the Baseline scenario, with larger positive values indicating larger GHG reductions. Negative values indicate a GHG increase from the Baseline scenario.

5 - This value is reported in $MTCO_2E$ per ton of waste managed. Positive values indicate a GHG reduction from the Baseline scenario, with larger positive values indicating larger GHG reductions. Negative values indicate a GHG increase from the Baseline scenario.

6 - Based on average 5.46 $MTCO_2E$ of emissions per car per year from the EPA WARM model. A negative value indicates the number of cars that would be added to the road when compared to the Baseline scenario.

GHG Emissions Analysis -- Summary Report

Version 11

GHG Emissions Waste Management Analysis for HDR

Prepared by: Andrea Callison, PE

Project Period for this Analysis: 01/01/13 to 12/31/13

Note: If you wish to save these results, rename this file (e.g., WARM-MN1) and save it. Then the "Analysis Inputs" sheet of the "WARM" file will be blank when you are ready to make another model run.

GHG Emissions from Baseline Waste Management ($MTCO_2E$): (1,624)

Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	-	-	8,102.0	(1,624)
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GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): (1,624)

Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	NA	0.0	0.0	8102.0	(1,624)
						0
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Change (Alt - Base) $MTCO_2E$
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Total Change in GHG Emissions ($MTCO_2E$): -

Note: a negative value (i.e., a value in parentheses) indicates an emission reduction; a positive value indicates an emission increase.

This is equivalent to…		
Removing annual emissions from	-	Passenger Vehicles
Conserving	-	Gallons of Gasoline
Conserving	-	Cylinders of Propane Used for Home Barbeques
Conserving	-	Railway Cars of Coal
	0.00000%	Annual CO_2 emissions from the U.S. transportation sector
	0.00000%	Annual CO_2 emissions from the U.S. electricity sector

a) For explanation of methodology, see the EPA report: Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (EPA530-R-06-004)
-- available on the Internet at http://epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf (5.6 Mb PDF file).

b) Emissions estimates provided by this model are intended to support voluntary GHG measurement and reporting initiatives.

c) The GHG emissions results estimated in WARM indicate the full life-cycle benefits waste management alternatives. Due to the timing of the GHG emissions from the waste management pathways, (e.g., avoided landfilling and increased recycling), the actual GHG implications may accrue over the long-term. Therefore, one should not interpret the GHG emissions implications as occurring all in one year, but rather through time.

GHG Emissions Analysis -- Summary Report

Version 11

GHG Emissions Waste Management Analysis for HDR

Prepared by: Andrea Callison, PE

Project Period for this Analysis: 01/01/13 to 12/31/13

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GHG Emissions from Baseline Waste Management ($MTCO_2E$): (812)

Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	-	-	4,051.0	(812)
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GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): (812)

Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	NA	0.0	0.0	4051.0	(812)
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Change (Alt - Base) $MTCO_2E$
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Total Change in GHG Emissions ($MTCO_2E$): -

Note: a negative value (i.e., a value in parentheses) indicates an emission reduction; a positive value indicates an emission increase.

This is equivalent to…		
Removing annual emissions from	-	Passenger Vehicles
Conserving	-	Gallons of Gasoline
Conserving	-	Cylinders of Propane Used for Home Barbeques
Conserving	-	Railway Cars of Coal
	0.00000%	Annual CO_2 emissions from the U.S. transportation sector
	0.00000%	Annual CO_2 emissions from the U.S. electricity sector

a) For explanation of methodology, see the EPA report:
Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (EPA530-R-06-004)
-- available on the Internet at http://epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf (5.6 Mb PDF file).

b) Emissions estimates provided by this model are intended to support voluntary GHG measurement and reporting initiatives.

c) The GHG emissions results estimated in WARM indicate the full life-cycle benefits waste management alternatives. Due to the timing of the GHG emissions from the waste management pathways, (e.g., avoided landfilling and increased recycling), the actual GHG implications may accrue over the long-term. Therefore, one should not interpret the GHG emissions implications as occurring all in one year, but rather through time.

GHG Emissions Analysis -- Summary Report

Version 11

GHG Emissions Waste Management Analysis for HDR

Prepared by: Andrea Callison, PE

Project Period for this Analysis: 01/01/13 to 12/31/13

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GHG Emissions from Baseline Waste Management ($MTCO_2E$): 168

Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	-	-	8,102.0	(1,624)
Mixed MSW	NA	10,400.0	-	NA	1,792
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Note: a negative value (i.e., a value in parentheses) indicates an emission reduction; a positive value indicates an emission increase.

a) For explanation of methodology, see the EPA report:
Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (EPA530-R-06-004)
-- available on the Internet at http://epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf (5.6 Mb PDF file).

b) Emissions estimates provided by this model are intended to support voluntary GHG measurement and reporting initiatives.

c) The GHG emissions results estimated in WARM indicate the full life-cycle benefits waste management alternatives. Due to the timing of the GHG emissions from the waste management pathways, (e.g., avoided landfilling and increased recycling), the actual GHG implications may accrue over the long-term. Therefore, one should not interpret the GHG emissions implications as occurring all in one year, but rather through time.

GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): 168

Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$	Change (Alt - Base) $MTCO_2E$
Mixed Organics	NA	NA	0.0	0.0	8102.0	(1,624)	0
Mixed MSW	NA	NA	10400.0	0.0	NA	1,792	0
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Total Change in GHG Emissions ($MTCO_2E$): -

This is equivalent to…		
Removing annual emissions from	-	Passenger Vehicles
Conserving	-	Gallons of Gasoline
Conserving	-	Cylinders of Propane Used for Home Barbeques
Conserving	-	Railway Cars of Coal
	0.00000%	Annual CO_2 emissions from the U.S. transportation sector
	0.00000%	Annual CO_2 emissions from the U.S. electricity sector

GHG Emissions Analysis -- Summary Report

Version 11

GHG Emissions Waste Management Analysis for HDR

Prepared by: Andrea Callison, PE

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GHG Emissions from Baseline Waste Management ($MTCO_2E$): (437)

Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$
Mixed Organics	NA	-	-	6,651.0	(1,333)
Mixed MSW	NA	5,200.0	-	NA	896
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GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): (437)

Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$	Change (Alt - Base) $MTCO_2E$
Mixed Organics	NA	NA	0.0	0.0	6651.0	(1,333)	0
Mixed MSW	NA	NA	5200.0	0.0	NA	896	0
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Total Change in GHG Emissions ($MTCO_2E$): -

Note: a negative value (i.e., a value in parentheses) indicates an emission reduction; a positive value indicates an emission increase.

This is equivalent to…		
Removing annual emissions from	-	Passenger Vehicles
Conserving	-	Gallons of Gasoline
Conserving	-	Cylinders of Propane Used for Home Barbeques
Conserving	-	Railway Cars of Coal
	0.00000%	Annual CO_2 emissions from the U.S. transportation sector
	0.00000%	Annual CO_2 emissions from the U.S. electricity sector

a) For explanation of methodology, see the EPA report: Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (EPA530-R-06-004) -- available on the Internet at http://epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf (5.6 Mb PDF file).

b) Emissions estimates provided by this model are intended to support voluntary GHG measurement and reporting initiatives.

c) The GHG emissions results estimated in WARM indicate the full life-cycle benefits waste management alternatives. Due to the timing of the GHG emissions from the waste management pathways, (e.g., avoided landfilling and increased recycling), the actual GHG implications may accrue over the long-term. Therefore, one should not interpret the GHG emissions implications as occurring all in one year, but rather through time.

Power Requirements for Operating READ Facility		
	READ Operations kWh/year*	MMBTU/ year
READ Facility (Organics Only)	650,000	2,218
READ Facility (Organics + Drum Unders)	800,000	2,730

*Preliminary estimate of power needed to operate READ facility

Avoided GHG Emissions from Net AD Power Generation[1]		
	MMBTU/year[2]	**Avoided Electric Utility $MTCO_2E$/year**
READ Facility (Organics Only)	4,615	(1,213)
READ Facility (Organics + Drum Unders)	10,147	(2,666)

Emission Factor for Delivered Electricity (MMBTU/MTCE)	14.02
Emission Factor for Delivered Electricity (MMBTU/$MTCO_2E$)	3.81
MTCE/$MTCO_2E$	0.2715

1. Assumes use of Internal Combustion Engine at 30% overall efficiency
2. MMBTU produced by IC Engine, minus the energy required to operate the READ facility

Appendix D – Cost Estimates

Capital Cost Summary (Planning Level, +40%/-20%)

UC Davis - READ Facility

SCENARIO A - HIGH SOLIDS

Source Separated Organics, No MSW Feedstock, No Composting

MARK-UPS:	Percentage
ELEC/I&C	15%
MECHANICAL	15%
ALLOWANCE	5%
CONSTRUCTION CONTINGENCY	20%
OVERHEAD AND PROFIT	10%
DESIGN PROFESSIONAL FEES	12%
CONSTRUCTION MGMT.	4.0%
MISC. PROGRAM ADMIN.	2.0%

NO.	DESCRIPTION	QTY	UNIT	Budget UNIT $	Installation	TOTAL	RESOURCE
General							
Required							
1.	Mob/Demob/Bonds/Ins	1	ls	$80,000	0%	$80,000	
2.	Excavation	1	ls	$30,000	0%	$30,000	
3.	Backfill	1	ls	$30,000	0%	$30,000	
4.	Structural Fill	1	ls	$20,000	0%	$20,000	
5.	Misc Metal Fabrication	1	ls	$25,000	0%	$25,000	
6.	Yard Piping	1	ls	$75,000	0%	$75,000	
7.	Fencing & Lighting	1	ls	$25,000	0%	$25,000	
8.	Offsite Improvements	1	ls	900,000	0	$900,000	Average of estimated Offsite costs
9.	Landscaping & Roadways	1	ls	$217,800	0%	$217,800	
Optional							
9.	Visitor Center/Admin Building	800	sf	$80	0%	$64,000	trailer
General Items Subtotal						**$1,466,800**	
Pre-Treatment							
Optional							
10.	Feed Receiving Building	2,400	sf	$80	0%	$192,000	Membrane building
11.	Feed Receiving Building Foundation	67	cy	$425	0%	$28,333	70 x 90, 9 in composite thickness
12.	Scalehouse	1	ls	$80,000	0%	$80,000	Assumes 40 ft scale and prefabricated RFID entry system
13.	Misc Feed Receiving Area Concrete	1	ls	$20,000	0%	$20,000	Misc receiving facilities
Pre-Treatment Items Subtotal						**$320,333**	
Digester							
Required							
14.	Digester Tanks	215,000	gal	$1.00	0%	$215,000	Tank Tech recent quote, bolted steel, with SST top ring
15.	R&D Digester Tank	72,000	gal	$1.00	0%	$72,000	Tank Tech recent quote, bolted steel, with SST top ring
16.	Digester Foundations	38	cy	$500	0%	$19,010	Rough calc at composite 1 ft thickness
17.	Digester Covers	84	ft-dia	$2,000	15%	$193,200	
18.	Feed Receiving Concrete Pit	21	cy	$625	0%	$12,963	15 x 20 x 6 ft deep concrete pit, 1 ft walls
19.	Feed Receiving Concrete Pit Mixer	1	ls	$15,000	15%	$17,250	Submersible Vaughan mixer
20.	Feedstock Grinders	2	ea	$20,000	10%	$44,000	Boerger Multicrusher
21.	Digester Feed Pumps	2	ea	$13,000	10%	$28,600	Vaughan chopper pumps
22.	Digestate Transfer Pumps	3	ea	$13,000	10%	$42,900	
23.	Digester Mixers	6	ea	$30,000	10%	$198,000	2 per tank at 20 hp ea
24.	Centrifuge Feed Tank	20,000	gal	$1.20	10%	$26,400	with foundation
25.	Centrifuge Package	0	ls	$300,000	5%	$0	Haul digestate wet for land application
26.	Dewatered Solids Tank	15,000	gal	$1	0%	$15,000	
27.	Digestate Management Building	0	sf	$90	0%	$0	Membrane building
28.	Digestate Management Building Foundation	0	cy	$450	0%	$0	
Digester Items Subtotal						**$884,323**	
Digestate Management							
Optional							
29.	Greenwaste Grinding Pad	0	sf	$4.00	0%	$0	CTB pad
30.	Greenwaste Grinding Equipment	0	ls	$150,000	0%	$0	
31.	Composting Pad	0	sf	$4.00	0%	$0	CTB pad
32.	Curing Pad	0	sf	$4.00	0%	$0	CTB pad
33.	Storage Pad	0	sf	$4.00	0%	$0	CTB pad
34.	Storm water Retention/Detention Pond	0	sf	$4.00	0%	$0	
35.	Biofilter	3,600	sf	$25.00	0%	$90,000	
36.	Air Collection Manifold and Blowers	1	ls	$50,000	0%	$50,000	
Digestate Management Items Subtotal						**$140,000**	

NO.	DESCRIPTION	QTY	UNT	Budget UNIT $	Installation	TOTAL	RESOURCE
Biogas							
Required							
37.	Biogas Moisture Removal Skid	1	ls	$150,000	0%	$150,000	based on recent quote
38.	Iron Sponge Scrubber	1	ls	$75,000	10%	$82,500	
39.	Biogas Compressors	2	ea	$15,000	10%	$33,000	
40.	Biogas Skid Mounted Enclosure in ICE below	600	sf	$150	0%	$90,000	Class 1, Div 2
41.	Biogas Building Foundation	17	cy	$500	0%	$8,333	20 x 25, 9 in composite thickness
42.	Emergency Flare	1	ls	$50,000	10%	$55,000	
43.	Steam Boiler	0	ls	$50,000	10%	$0	Needed only if CNG or Primate Center options pursued
44.	Digester Heat Exchanger	1	ls	$30,000	10%	$33,000	
45.	Samplers	4	ea	$6,500	15%	$29,900	
Required (Choose 1)							
IC Engine							
46.	IC Engine System Subtotal	1	ls	$460,000	5%	$483,000	250 kW
CNG							
47.	CNG System Subtotal	0	ls	$610,000	5%	$0	
To Boiler at Primate Center							
44.	Biogas Pipeline to Primate Center Boiler	0	lf	$75	0%	$0	1 miles, 3 in HDPE
45.	Boiler Connection at Primate Center	0	ls	$50,000	0%	$0	estimate
Fuel Cells							
46.	Fuel Cell System Subtotal	0	ls	$2,000,000	50%	$0	1x DFC300
47.	SGIP Rebate for Fuel Cell	0	kW	($4,500)	0%	$0	$4500 per kW installed
Biogas Items Subtotal						**$964,733**	
Effluent Management							
Required (Choose 1)							
Conventional Nit-Denit							
48.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$430,000	10%	$0	Conventional Nit-Denit Subtotal
Ammonium Sulfate System							
49.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$420,000	10%	$0	Ammonium Sulfate System Subtotal
Annamox							
50.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$1,100,000	10%	$0	Annamox Subtotal
Effluent Items Subtotal						**$0**	
A	**FACILITY ELEMENTS SUBTOTAL**					**$3,776,190**	
B	*ELECTRICAL/I&C*	(% of A)				$566,428	
C	*MECHANICAL*	(% of A)				$566,428	
D	**ELECTRICAL & MECHANICAL SUBTOTAL**	**(B+C)**				**$1,132,857**	
E	**FACILTIY SUBTOTAL**	**(A+D)**				**$4,909,047**	
F	*ALLOWANCE*	(% of E)				$245,452	
G	*CONSTRUCTION CONTINGENCY*	(% of E)				$981,809	
H	*OVERHEAD AND PROFIT*	(% of E)				$490,905	
I	***CONTINGENCY SUBTOTAL***	**(F+G+H)**				**$1,718,166**	
J	**CONSTRUCTION SUBTOTAL**	**(E+I)**				**$6,627,213**	
K	*DESIGN PROFESSIONAL FEES*	(% of J)				$795,266	
L	*PERMITTING*	-				$300,000	Per Sid England Aug 1, 2011 email
M	*ENVIRONMENTAL REVIEW*	-				$150,000	Per Sid England Aug 1, 2011 email
N	*CONSTRUCTION MGMT*	(% of J)				$265,089	Assumes limited supervision
O	*MISC. PROGRAM ADMIN.*	(% of J)				$132,544	
P	**PROJECT ADMIN. SUBTOTAL**	**(K+L+M+N+O)**				**$1,642,898**	
	TOTAL ESTIMATED COST	**(J+P)**				**$8,270,111**	

O&M Cost Opinion Summary

OPERATING SCHEDULE	
Hours/day	24
Days/Week	7
Weeks/year	52

NO.	COST DESCRIPTION	QTY	QTY UNITS	COST $	COST UNITS	TOTAL	ASSUMPTIONS
a	Operator Labor	120	hr/week	$50	$/hr	**$312,000**	includes benefits
b	Power	100	hp	$0.080	$/kw-hr	**$52,100**	estimated operating HP
c	Parts and Maintenance	1	ls	$50,000	$/yr	**$50,000**	misc.
d	Liquid Effluent O&M Cost (Choose 1)						
	Conventional Nit-Denit	1	ls	$84,175	$/yr	**$84,175**	
	Ammonium Sulfate Option	0	ls	$22,206	$/yr	**$0**	
	Annamox Option	0	ls	$42,337	$/yr	**$0**	
e	Biogas to Energy System						
	IC Engine - power use	2,255,295	kw-hr	$0.015	$/kw-hr	**$33,829**	based on Jenbacher
	IC Engine - rebuild fund	1	ls	$25,000	$/yr	**$25,000**	based on similar size rebuilds
	CNG	0	therm		$/therm	**$0**	
	Boilers at Primate Center	0	ls		$/yr	**$0**	
	Fuel Cells	0	ls	$250,000	$/yr	**$0**	
f	Compost Equipment and Ops	0	ton	$5	$/ton	**$0**	$5/ton compost equip ops
g	Digestate Pumped and Land Applied	14,309	gpd	$6	$/gal per year	**$92,721**	land applied
h	Misc Chemicals	1	ls	$50,000	$/yr	**$50,000**	centrifuge polymer
i	**TOTAL ESTIMATED O&M COSTS**					**$700,000**	

NO.	REVENUE DESCRIPTION	QTY	QTY UNITS	REVENUE $	REVENUE UNITS	TOTAL REVENUE	ASSUMPTIONS
a	Avoided Disposal Costs from Organics	8,102	ton	$30	$/ton	**$243,049**	Based on the approximate avoided cost of manure and food waste management
b	Avoided Disposal Costs from MSW	0	ton MSW	$45	$/yr	**$0**	NA this scenario
c	Beneficial use of Biogas (choose 1)						
	IC Engine	2,255,295	kw-hr	$0.169	$/kw-hr	**$381,145**	Based on Solar PPA
	CNG	0	therm	$1.10	$/therm	**$0**	Based on cost to purchase Biogas
	Boilers at Primate Center	0	therm	$0.72	$/therm	**$0**	Biogas recovered with Primate Center main boilers, 90% recovered
	Fuel Cells	0	kw-hr	$0.169	$/kw-hr	**$0**	Based on Solar PPA
d	Beneficial use of Effluent (Optional)						
	Ammonium Sulfate Option	0	ls	$11,843	$/yr	**$0**	
e	Sale of Compost	0	ton	$20	$.ton	**$0**	
f	Carbon Credits (choose 1)						
	IC Engine	1,923	MTCO2E	$20	$/MTCO2E	**$38,460**	From GHG calculations
	CNG	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Boilers at Primate Center	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Fuel Cells	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
g	**TOTAL ESTIMATED ANNUAL REVENUE**					**$663,000**	

Capital Cost Summary (Planning Level, +40%/-20%)

UC Davis - READ Facility

SCENARIO B - HIGH SOLIDS

Source Separated Organics, No MSW Feedstock

MARK-UPS:	Percentage
ELEC/I&C	15%
MECHANICAL	15%
ALLOWANCE	5%
CONSTRUCTION CONTINGENCY	20%
OVERHEAD AND PROFIT	10%
DESIGN PROFESSIONAL FEES	12%
CONSTRUCTION MGMT.	4.0%
MISC. PROGRAM ADMIN.	3.0%

NO.	DESCRIPTION	QTY	UNT	Budget UNIT $	Installation	TOTAL	RESOURCE
General							
Required							
1.	Mob/Demob/Bonds/Ins	1	ls	$100,000	0%	$100,000	
2.	Excavation	1	ls	$40,000	0%	$40,000	
3.	Backfill	1	ls	$40,000	0%	$40,000	
4.	Structural Fill	1	ls	$20,000	0%	$20,000	
5.	Misc Metal Fabrication	1	ls	$25,000	0%	$25,000	
6.	Yard Piping	1	ls	$75,000	0%	$75,000	
7.	Fencing & Lighting	1	ls	$25,000	0%	$25,000	
8.	Offsite Improvements	1	ls	$900,000	0%	$900,000	Average of estimated Offsite costs
9.	Landscaping & Roadways	1	ls	$217,800	0%	$217,800	
Optional							
9.	Visitor Center/Admin Double Wide Trailer	800	sf	$80	0%	$64,000	
General Items Subtotal						**$1,506,800**	
Pre-Treatment							
Optional							
10.	Feed Receiving Building	13,227	sf	$80	0%	$1,058,160	Membrane building
11.	Feed Receiving Building Foundation	367	cy	$425	0%	$156,152	70 x 90, 9 in composite thickness
12.	Entrance Scale and Scalehouse	1	ls	$80,000	0%	$80,000	Assumes 40 ft scale and prefabricated RFID entry system
13.	Misc Feed Receiving Area Concrete	1	ls	$20,000	0%	$20,000	Misc receiving facilities
Pre-Treatment Items Subtotal						**$1,314,312**	
Digester							
Required							
14.	Digester Tanks	215,000	gal	$1.00	0%	$215,000	Tank Tech recent quote, bolted steel, with SST top ring
15.	R&D Digester Tank	72,000	gal	$1.00	0%	$72,000	Tank Tech recent quote, bolted steel, with SST top ring
16.	Digester Foundations	38	cy	$500	0%	$19,010	Rough calc at composite 1 ft thickness
17.	Digester Covers	84	ft-dia	$2,000	15%	$193,200	
18.	Feed Receiving Concrete Pit	21	cy	$625	0%	$12,963	15 x 20 x 6 ft deep concrete pit, 1 ft walls
19.	Feed Receiving Concrete Pit Mixer	1	ls	$15,000	15%	$17,250	Submersible Vaughan mixer
20.	Feedstock Grinders	2	ea	$20,000	10%	$44,000	Boerger Multicrusher
21.	Digester Feed Pumps	2	ea	$13,000	10%	$28,600	Vaughan chopper pumps
22.	Digestate Transfer Pumps	3	ea	$13,000	10%	$42,900	
23.	Digester Mixers	6	ea	$30,000	10%	$198,000	2 per tank at 20 hp ea
24.	Centrifuge Feed Tank	20,000	gal	$1.20	10%	$26,400	with foundation
25.	Centrifuge Package	1	ls	$300,000	5%	$315,000	complete with flocculation & polymer feed
26.	Dewatered Solids Tank	15,000	gal	$1	0%	$15,000	
27.	Digestate Management Building	6,795	sf	$90	0%	$611,550	Membrane building
28.	Digestate Management Building Foundation	189	cy	$450	0%	$84,938	
Digester Items Subtotal						**$1,895,811**	
Digestate Management							
Optional							
29.	Greenwaste Grinding Pad	0	sf	$2.50	0%	$0	CTB pad
30.	Greenwaste Grinding Equipment	0	ls	$150,000	0%	$0	Assumes purchase of chipped wood waste as bulking agent
31.	Composting Pad	27,945	sf	$4.00	0%	$111,780	CTB pad
32.	Curing Pad	15,700	sf	$4.00	0%	$62,800	CTB pad
33.	Storage Pad	5,546	sf	$4.00	0%	$22,184	CTB pad
34.	Storm water Retention/Detention Pond	9,881	sf	$4.00	0%	$39,526	
35.	Biofilter	7,400	sf	$25.00	0%	$185,000	
36.	Air Collection Manifold and Blowers	1	ls	$100,000	0%	$100,000	
Digestate Management Items Subtotal						**$521,290**	

NO.	DESCRIPTION	QTY	UNT	Budget UNIT $	Installation	TOTAL	RESOURCE
Biogas							
Required							
37.	Biogas Moisture Removal Skid	1	ls	$150,000	0%	$150,000	based on recent quote
38.	Iron Sponge Scrubber	1	ls	$75,000	10%	$82,500	
39.	Biogas Compressors	2	ea	$15,000	10%	$33,000	
40.	Biogas Building	600	sf	$150	0%	$90,000	Class 1, Div 2
41.	Biogas Building Foundation	17	cy	$500	0%	$8,333	9 in composite thickness
42.	Emergency Flare	1	ls	$50,000	10%	$55,000	
43.	Steam Boiler	0	ls	$50,000	10%	$0	Needed only if CNG or Primate Center options pursued
44.	Digester Heat Exchanger	1	ls	$30,000	10%	$33,000	
45.	Samplers	4	ea	$6,500	15%	$29,900	
Required (Choose 1)							
IC Engine							
46.	IC Engine System Subtotal	1	ls	$460,000	5%	$483,000	
CNG							
47.	CNG System Subtotal	0	ls	$610,000	5%	$0	
To Boiler at Primate Center							
44.	Biogas Pipeline to Primate Center Boiler	0	lf	$75	0%	$0	1 miles, 3 in HDPE
45.	Boiler Connection at Primate Center	0	ls	$50,000	0%	$0	estimate
Fuel Cells							
46.	Fuel Cell System Subtotal	0	ls	$2,000,000	5%	$0	1x DFC300
47.	SGIP Rebate for Fuel Cell	0	kW	($4,500)	0%	$0	$4500 per kW installed
Biogas Items Subtotal						**$964,733**	
Effluent Management							
Required (Choose 1)							
Conventional Nit-Denit							
48.	*LIQUID EFFLUENT TREATMENT PACKAGE*	1	ls	$430,000	10%	$473,000	Conventional Nit-Denit Subtotal
Ammonium Sulfate System							
49.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$420,000	10%	$0	Ammonium Sulfate System Subtotal
Annamox							
50.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$1,100,000	10%	$0	Annamox Subtotal
Effluent Items Subtotal						**$473,000**	
A	**FACILITY ELEMENTS SUBTOTAL**					**$6,675,946**	
B	*ELECTRICAL/I&C*	(% of A)				$1,001,392	
C	*MECHANICAL*	(% of A)				$1,001,392	
D	**ELECTRICAL & MECHANICAL SUBTOTAL**	**(B+C)**				**$2,002,784**	
E	**FACILTIY SUBTOTAL**	**(A+D)**				**$8,678,730**	
F	*ALLOWANCE*	(% of E)				$433,936	
G	*CONSTRUCTION CONTINGENCY*	(% of E)				$1,735,746	
H	*OVERHEAD AND PROFIT*	(% of E)				$867,873	
I	**CONTINGENCY SUBTOTAL**	**(F+G+H)**				**$3,037,555**	
J	**CONSTRUCTION SUBTOTAL**	**(E+I)**				**$11,716,285**	
K	*DESIGN PROFESSIONAL FEES*	(% of J)				$1,405,954	
L	*PERMITTING*					$300,000	Per Sid England Aug 1, 2011 email
M	*ENVIRONMENTAL REVIEW*					$150,000	Per Sid England Aug 1, 2011 email
N	*CONSTRUCTION MGMT*	(% of J)				$468,651	Assumes limited supervision
O	*MISC. PROGRAM ADMIN.*	(% of J)				$351,489	
P	**PROJECT ADMIN. SUBTOTAL**	**(K+L+M+N+O)**				**$2,676,094**	
	TOTAL ESTIMATED COST	**(J+P)**				**$14,392,379**	

O&M Cost Opinion Summary

OPERATING SCHEDULE	
Hours/day	24
Days/Week	7
Weeks/year	52

NO.	COST DESCRIPTION	QTY	QTY UNITS	COST $	COST UNITS	TOTAL	ASSUMPTIONS
a	Operator Labor	120	hr/week	$50	$/hr	**$312,000**	Assumes 3 fte staff and includes benefits
b	Power	100	hp	$0.080	$/kw-hr	**$52,100**	estimated operating HP
c	Parts and Maintenance	1	ls	$50,000	$/yr	**$50,000**	misc.
d	Liquid Effluent O&M Cost (Choose 1)						
e	Conventional Nit-Denit	1	ls	$84,175	$/yr	**$84,175**	
f	Ammonium Sulfate Option	0	ls	$22,206	$/yr	**$0**	
g	Annamox Option	0	ls	$42,337	$/yr	**$0**	
h	Biogas to Energy System						
i	IC Engine	2,255,295	kw-hr	$0.015	$/kw-hr	**$33,829**	based on Jenbacher
j	IC Engine - rebuild fund	1	ls	$25,000	$/yr	**$25,000**	based on similar size rebuilds
k	CNG	0	therm		$/therm	**$0**	
l	Boilers at Primate Center	0	ls	$7,000	$/yr	**$0**	
m	Fuel Cells	0	ls	$250,000	$/yr	**$0**	
n	Compost Equipment and Ops	16,060	ton	$5	$/ton	**$80,300**	$5/ton compost equip ops
o	Boiler Fuel for Digester Heating	0	therm	$1.10	$/therm	**$0**	Use waste heat from IC Engines
p	Bulking Materials for Compost of Centrif Cake	5,475	tpy	$8.00	$/ton	**$43,800**	bulking agent per compost calc to reach 60% moisture with centrifuge cake
q	Misc Chemicals	1	ls	$50,000	$/yr	**$50,000**	centrifuge polymer
r	**TOTAL ESTIMATED O&M COSTS**					**$731,000**	

NO.	REVENUE DESCRIPTION	QTY	QTY UNITS	REVENUE $	REVENUE UNITS	TOTAL REVENUE	ASSUMPTIONS
a	Avoided Disposal Costs from Organics	8,102	ton	$30	$/ton	**$243,049**	Based on the approximate avoided cost of manure and food waste management.
b	Avoided Disposal Costs from MSW	0	ton MSW	$45	$/yr	**$0**	NA this scenario
c	Beneficial use of Biogas (choose 1)						
	IC Engine	2,255,295	kw-hr	$0.169	$/kw-hr	**$381,145**	Based on Solar PPA
	CNG	0	therm	$1.10	$/therm	**$0**	Based on cost to purchase Biogas
	Boilers at Primate Center	0	therms/yr	$0.72	$/therm	**$0**	therm/year at 82% eff, 95% availability
	Fuel Cells	0	kw-hr	$0.169	$/kw-hr	**$0**	Based on Solar PPA
d	Beneficial use of Effluent (Optional)						
	Ammonium Sulfate Option	0	ls	$11,843	$/yr	**$0**	
e	Sale of Compost	4,997	ton	$20	$.ton	**$99,941**	Based on sales of bulk compost at WPWMA facility, Roseville CA
f	Carbon Credits (choose 1)						
	IC Engine	1,923	MTCO2E	$20	$/MTCO2E	**$38,460**	From GHG calculations
	CNG	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Boilers at Primate Center	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Fuel Cells	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
g	**TOTAL ESTIMATED ANNUAL REVENUE**					**$763,000**	

Capital Cost Summary (Planning Level, +40%/-20%)

UC Davis - READ Facility

SCENARIO C - HIGH SOLIDS

Source Separated Organics + MSW Feedstock

MARK-UPS:	Percentage
ELEC/I&C	15%
MECHANICAL	15%
ALLOWANCE	5%
CONTINGENCY	20%
OVERHEAD AND PROFIT	10%
DESIGN PROFESSIONAL FEES	12%
CONSTRUCTION MGMT.	4.0%
MISC. PROGRAM ADMIN.	2.0%

NO.	DESCRIPTION	QTY	UNT	Budget UNIT $	Installation	TOTAL	RESOURCE
General							
Required							
1.	Mob/Demob/Bonds/Ins	1	ls	$150,000	0%	$150,000	
2.	Excavation	1	ls	$40,000	0%	$40,000	
3.	Backfill	1	ls	$40,000	0%	$40,000	
4.	Structural Fill	1	ls	$20,000	0%	$20,000	
5.	Misc Metal Fabrication	1	ls	$25,000	0%	$25,000	
6.	Yard Piping	1	ls	$100,000	0%	$100,000	
7.	Fencing & Lighting	1	ls	$25,000	0%	$25,000	
8.	Offsite Improvements	1	ls	$900,000	0%	$900,000	Average of estimated Offsite costs
9.	Landscaping & Roadways; Entrance Booth and Scale	1	ls	$471,700	0%	$471,700	
Optional							
10.	Visitor Center/Admin Building	4,000	sf	$150	0%	$600,000	
General Items Subtotal						**$2,371,700**	
Pre-Treatment							
Optional							
11.	Feed Receiving Building	25,000	sf	$80	0%	$2,000,000	Membrane building
12.	Feed Receiving Building Foundation	694	cy	$425	0%	$295,139	70 x 90, 9 in composite thickness
13.	Rotating Drum	1	ls	$1,250,000	0%	$1,250,000	Rotating Drum per KS email Mar 10 11 for MK1 unit , 82 tpd capacity
14.	Entrance Scale and Scalehouse	1	ls	$80,000	0%	$80,000	Assumes 40 ft scale and prefabricated RFID entry system
15.	Misc Feed Receiving Area Concrete	1	ls	$20,000	0%	$20,000	Misc receiving facilities
Pre-Treatment Items Subtotal						**$3,645,139**	
Digester							
Required							
16.	Digester Tanks	408,000	gal	$1.00	0%	$408,000	Tank Tech recent quote, bolted steel, with SST top ring
17.	R&D Digester Tank	81,600	gal	$1.00	0%	$81,600	Tank Tech recent quote, bolted steel, with SST top ring
18.	Digester Foundations	72	cy	$500	0%	$36,075	Rough calc at composite 1 ft thickness
19.	Digester Covers	130	ft-dia	$2,000	15%	$299,000	
20.	Feed Receiving Concrete Pit	21	cy	$625	0%	$12,963	15 x 20 x 10 ft deep concrete pit, 1 ft walls
21.	Feed Receiving Concrete Pit Mixer	1	ls	$15,000	15%	$17,250	Submersible Vaughan mixer
22.	Feedstock Grinders	2	ea	$25,000	10%	$55,000	Boerger Multicrusher
23.	Digester Feed Pumps	2	ea	$16,000	10%	$35,200	Vaughan chopper pumps
24.	Digestate Transfer Pumps	3	ea	$16,000	10%	$52,800	
25.	Digester Mixers	6	ea	$35,000	10%	$231,000	2 per tank at 20 hp ea
26.	Centrifuge Feed Tank	28,000	gal	$1.20	10%	$36,960	with foundation
27.	Centrifuge Package	1	ls	$350,000	5%	$367,500	complete with flocculation & polymer feed
28.	Dewatered Solids Tank	25,000	gal	$1	0%	$25,000	
29.	Digestate Management Building	8,072	sf	$90	0%	$726,480	Membrane building
30.	Digestate Management Building Foundation	224	cy	$450	0%	$100,900	45 x 40, 9 in composite thickness
Digester Items Subtotal						**$2,485,728**	
Digestate Management							
Optional							
31.	Greenwaste Grinding Pad	0	sf	$4.00	0%	$0	CTB pad
32.	Greenwaste Grinding Equipment	0	ls	$150,000	0%	$0	Assumes purchase of chipped wood waste as bulking agent
33.	Composting Pad	41,918	sf	$4.00	0%	$167,670	CTB pad
34.	Curing Pad	21,500	sf	$4.00	0%	$86,000	CTB pad
35.	Storage Pad	8,323	sf	$4.00	0%	$33,290	CTB pad
36.	Storm water Retention/Detention Pond	12,915	sf	$4.00	0%	$51,661	
37.	Biofilter	13,300	sf	$25.00	0%	$332,500	
38.	Air Collection Manifold and Blowers	1	ls	$150,000	0%	$150,000	Ratio up per annual ton processed
Digestate Management Items Subtotal						**$821,121**	

NO.	DESCRIPTION	QTY	UNT	Budget UNIT $	Installation	TOTAL	RESOURCE
Biogas							
Required							
39.	Biogas Moisture Removal Skid	1	ls	$210,000	0%	$210,000	based on recent quote
40.	Iron Sponge Scrubber	1	ls	$90,000	10%	$99,000	
41.	Biogas Compressors	2	ea	$20,000	10%	$44,000	
42.	Biogas Building	800	sf	$160	0%	$128,000	Class 1, Div 2
43.	Biogas Building Foundation	22	cy	$500	0%	$11,111	20 x 25, 9 in composite thickness
44.	Emergency Flare	1	ls	$65,000	10%	$71,500	
45.	Steam Boiler	0	ls	$70,000	10%	$0	Needed only if CNG or Primate Center options pursued
46.	Digester Heat Exchanger	1	ls	$45,000	10%	$49,500	
47.	Samplers	4	ea	$6,500	15%	$29,900	
Required (Choose 1)							
IC Engine							
48.	IC Engine System Subtotal	1	ls	$670,000	5%	$703,500	
CNG							
49.	CNG System Subtotal	0	ls	$850,000	5%	$0	
To Boiler at Primate Center							
44.	Biogas Pipeline to Primate Center Boiler	0	lf	$75	0%	$0	1 miles, 3 in HDPE
45.	Boiler Connection at Primate Center	0	ls	$50,000	0%	$0	estimate
Fuel Cells							
46.	Fuel Cell System Subtotal	0	ls	$4,000,000	5%	$0	2x DFC300
47.	SGIP Rebate for Fuel Cell	0	kW	($4,500)	0%	$0	$4500 per kW installed
Biogas Items Subtotal						**$1,346,511**	
Effluent Management							
Required (Choose 1)							
Conventional Nit-Denit							
48.	*LIQUID EFFLUENT TREATMENT PACKAGE*	1	ls	$510,000	10%	$561,000	Conventional Nit-Denit Subtotal
Ammonium Sulfate System							
49.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$510,000	10%	$0	Ammonium Sulfate System Subtotal
Annamox							
50.	*LIQUID EFFLUENT TREATMENT PACKAGE*	0	ls	$1,310,705	10%	$0	Annamox Subtotal
Effluent Items Subtotal						**$561,000**	
A	**FACILITY ELEMENTS SUBTOTAL**					**$11,231,199**	
B	*ELECTRICAL/I&C*	(% of A)				$1,684,680	
C	*MECHANICAL*	(% of A)				$1,684,680	
D	**ELECTRICAL & MECHANICAL SUBTOTAL**	**(B+C)**				**$3,369,360**	
E	**FACILTIY SUBTOTAL**	**(A+D)**				**$14,600,559**	
F	*ALLOWANCE*	(% of E)				$730,028	
G	*CONSTRUCTION CONTINGENCY*	(% of E)				$2,920,112	
H	*OVERHEAD AND PROFIT*	(% of E)				$1,460,056	
I	**CONSTRUCTION CONTINGENCY SUBTOTAL**	**(F+G+H)**				**$5,110,196**	
J	**CONSTRUCTION SUBTOTAL**	**(E+I)**				**$19,710,754**	
K	*DESIGN PROFESSIONAL FEES*	(% of J)				$2,365,291	
L	*PERMITTING*					$300,000	Per Sid England Aug 1, 2011 email
M	*ENVIRONMENTAL REVIEW*					$150,000	Per Sid England Aug 1, 2011 email
N	*CONSTRUCTION MGMT*	(% of J)				$788,430	Assumes limited supervision
O	*MISC. PROGRAM ADMIN.*	(% of J)				$394,215	
P	**PROJECT ADMIN. SUBOTOTAL**	**(K+L+M+N+O)**				**$3,997,936**	
	TOTAL ESTIMATED COST	**(J+P)**				**$23,710,000**	

O&M Cost Opinion Summary

OPERATING SCHEDULE	
Hours/day	24
Days/Week	7
Weeks/year	52

NO.	COST DESCRIPTION	QTY	QTY UNITS	COST $	COST UNITS	TOTAL	ASSUMPTIONS
a	Operator Labor (digester)	120	hr/week	$50	$/hr	**$312,000**	Assumes 3 fte staff, includes benefits
b	Power	110	hp	$0.080	$/kw-hr	**$57,400**	estimated operating HP
c	Parts and Maintenance	1	ls	$60,000	$/yr	**$60,000**	misc.
d	Liquid Effluent O&M Cost (Choose 1)						
	Conventional Nit-Denit	1	ls	$100,298	$/yr	**$100,298**	
	Ammonium Sulfate Option	0	ls	$9,517	$/yr	**$0**	
	Annamox Option	0	ls	$50,447	$/yr	**$0**	
e	Biogas to Energy System						
	IC Engine - energy use	3,995,567	kw-hr	$0.015	$/kw-hr	**$59,934**	based on Jenbacher
	IC Engine - rebuild fund	1	ls	$30,000	$/yr	**$30,000**	based on similar size rebuilds
	CNG	0	therm		$/therm	**$0**	
	Boilers at Primate Center	0	ls	$10,000	$/yr	**$0**	
	Fuel Cells	0	ls	$350,000	$/yr	**$0**	
f	Compost Equipment and Ops	24,090	ton	$5	$/ton	**$120,450**	$5/ton compost equip ops
g	Bulking Materials for Compost of Centrif Cake	8,030	tpy	$8.00	$/ton	**$64,240**	bulking agent per compost calc to reach 60% moisture with centrifuge cake
h	Rotating Drum Power Cost	9,588	tpy	$2.00	$/ton	**$19,175**	Power cost to operate rotating drum per Keppel Seghers
i	Rotating Drum Labor	8	hr/day	$50.00	$/hr	**$104,000**	Operating 8 hr/day at 82 tpd, processing MSW + manures per KS recommendation
j	Rotating Drum Maintenance	1	ls	$62,500.00	$/yr	**$62,500**	5% of capital per KS using smallest drum at 1.25M per Ks
k	Misc Chemicals	1	ls	$50,000	$/yr	**$50,000**	centrifuge polymer
	TOTAL ESTIMATED O&M COSTS					**$1,040,000**	

NO.	REVENUE DESCRIPTION	QTY	QTY UNITS	REVENUE $	REVENUE UNITS	TOTAL REVENUE	ASSUMPTIONS
a	Avoided Disposal Costs from Organics	8,102	ton	$30	$/ton	**$243,049**	Based on the approximate avoided cost of manure and food waste management.
b	Avoided Disposal Costs from MSW	4,794	ton MSW	$45	$/ton	**$215,723**	Based on the avoided landfill tip fee at Yolo County. Includes tip fee and haul cost to landfill
c	Beneficial use of Biogas (choose 1)						
	IC Engine	3,995,567	kw-hr	$0.169	$/kw-hr	**$675,251**	Based on Solar PPA
	CNG	0	therm	$1.10	$/therm	**$0**	Based on cost to purchase Biogas
	Boilers at Primate Center	0	therm	$0.72	$/therm	**$0**	therm/year at 82% eff, 95% availability
	Fuel Cells		kw-hr	$0.169	$/kw-hr	**$0**	Based on Solar PPA
d	Beneficial use of Effluent (Optional)						
	Ammonium Sulfate Option	0	ls	$5,076	$/yr	**$0**	
e	Sale of Compost	7,499	ton	$10	$/ton	**$74,986**	Half the value of Bulk Compost due to presence of MSW source feedstock
f	Carbon Credits (choose 1)						
	IC Engine	4,559	MTCO2E	$20	$/MTCO2E	**$91,180**	From GHG calculations
	CNG	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Boilers at Primate Center	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	Fuel Cells	0	MTCO2E	$20	$/MTCO2E	**$0**	From GHG calculations
	TOTAL ESTIMATED ANNUAL REVENUE					**$1,300,000**	

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SECTION 2

RENEWABLE ENERGY ANAEROBIC DIGESTER FACILITY DESIGN AND OPERATIONS SUMMARY – University of California, Davis

Prepared by:

Kathryn Chapman, Applications Engineer - CleanWorld

September 2014

Technology Background

CleanWorld's core digestion technology is a proprietary, highly efficient High Rate Digestion (HRD) system that converts source-separated food waste into biomethane, reclaimed water, and liquid and solid soil fertilizer products. CleanWorld's HRD was developed and proven at the University of California, Davis (UC Davis) by Dr. Ruihong Zhang, Ph.D., a professor of biological and agricultural engineering known throughout the industry for her ability to reliably operate high rate digesters at thermophilic temperature. This HRD technology is currently licensed exclusively to CleanWorld for commercialization. CleanWorld selected this technology for its ability to efficiently digest high-solids waste streams such as food and agricultural waste without requiring substantial pre-processing. This technology also has a higher organic loading rate, shorter hydraulic retention time (approximately 20 days), and a longer solids retention time to maximize bacterial populations in the system.

System Design

Designed and built by CleanWorld, the UC Davis Renewable Energy Anaerobic Digester (READ) is a unique public-private partnership, enabling the university and its surrounding region to be a direct recipient of the many economic and environmental benefits of this third commercial high-solids anaerobic digester (AD) facility of its kind in North America. The goal of the project was to give the university an environmentally and economically sound alternative for disposing of all their organic waste streams. The project was sized for 50 tons per day of food waste to allow capacity for not only the university waste but also organic waste streams in the surrounding community. The project was designed to generate 5.6 GWh of renewable electricity as well as reduce greenhouse gas emissions by up to 13,500 tons annually, and produce over 4 million gallons of fertilizer and soil amendments – enough to provide low cost, natural fertilizers for 145 acres of California's farmlands every day.

Project and Technology Innovation

The high loading rate and high-solid digestion capability and small footprint of CleanWorld's biodigester technology make it particularly beneficial to institutional, commercial, and municipal solid waste producers. The processing system design – a patented three-stage proprietary system – allows for the higher rate capability and a greater yield of methane, among many competitively unique processing benefits. This facility blends with the landfill gas from the now closed UC Davis landfill to produce renewable electricity for the campus.

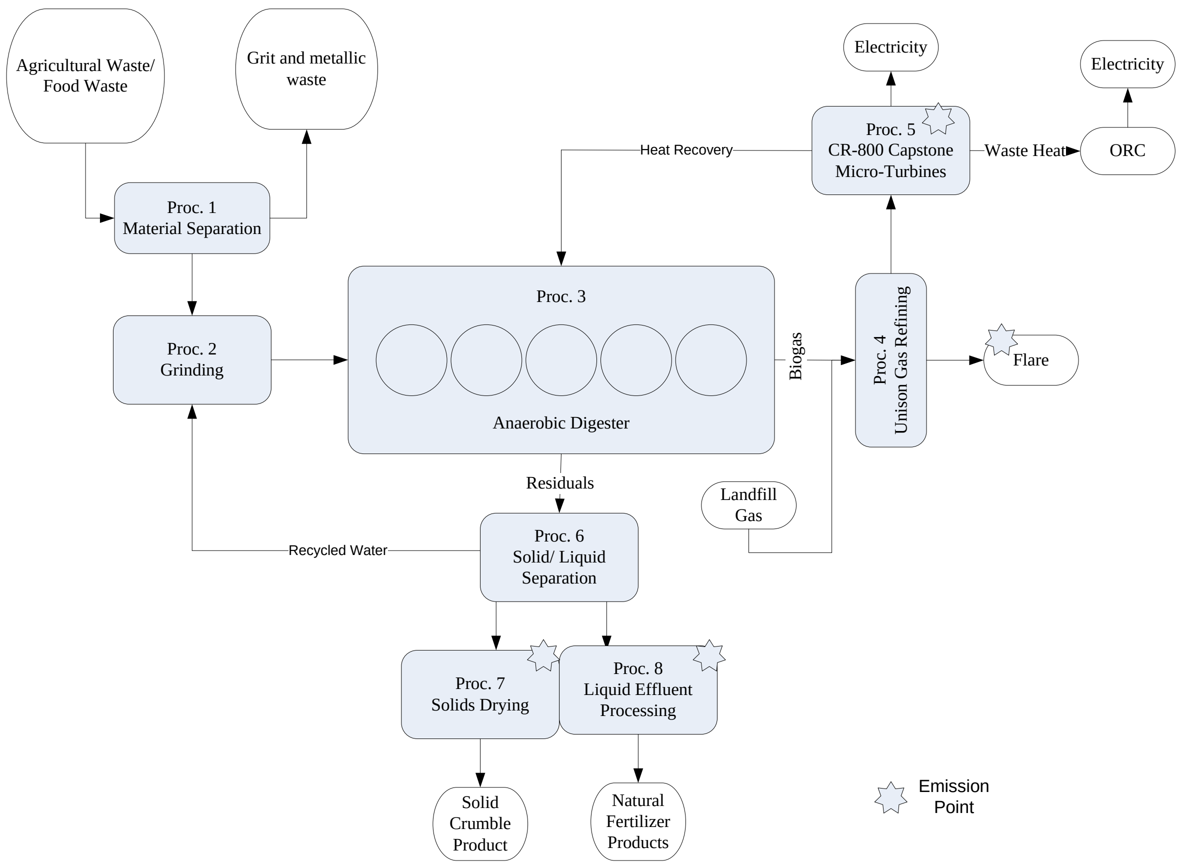

Figure 1 - Process Flow Diagram

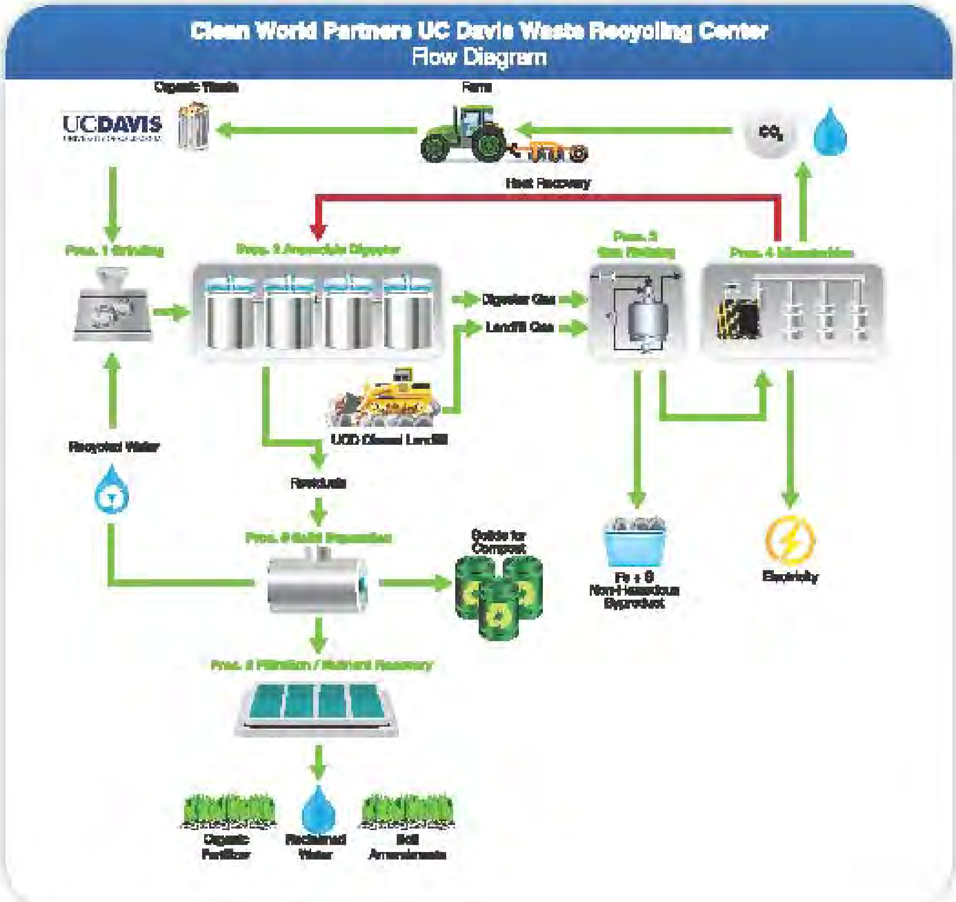

Figure 2 - Process Flow Diagram with Visual Aids

Major Components of the System

Feedstock Receiving

Receiving

The anaerobic food waste digester facility can accept and process up to 50 TPD of pre and post-consumer food waste. The following sections briefly describe the facilities, system components, equipment, and processes proposed to adequately handle and store food waste feedstock prior to anaerobic digestion.

At the receiving area waste hauling trucks dump their contents onto the tip floor and utilize a front loader to lift the material into the pre-processing unit. The tip floor allows for easy wash-downs of the

BioSeparator, any totes used to transport material, and surrounding areas. All water is directed to a sump pump that transfers it into the digester.

Pre-Processing Operations and Equipment Receiving and Visual Inspection

Pre-processing

All food waste loads received at the UC Davis READ facility are visually inspected by facility staff to identify highly contaminated loads prior to tipping. Loads determined to be highly contaminated with inorganics, or other non-food waste materials are rejected. The rejected loads are re-directed to landfills to be disposed of as garbage. The source of rejected loads is contacted to discuss the reasons for rejection and to develop measures to minimize future load rejections. Once the load is tipped on the tip floor, any large contaminants are removed by waste handlers.

Contaminant Removal and Grinding

The front loader transfers material into the top of the BioSeparator pre-processing system for removal of rocks, glass, metals, plastics, and other non-biodegradable materials. This process facilitates handling and material flow while reducing the amount of inert materials introduced into the digester vessels.

Figure 3 - UC Davis biodigester pre-processing facility

DODA is CleanWorld's technology partner for pre-processing of source separated food waste and food processor waste. CleanWorld's DODA based pre-processing systems are matched well for the UC Davis waste stream.

The first stage of the DODA BioSeparator system is a separation unit which separates non-organic content from the feedstock. The feedstock is then deposited directly into the loading hopper of the machinery, and the non-organic material or contaminants are separated out through a process of screens and augers.

The unit is powered by a 75 kW electric motor and can handle processing of up to 120 tons per day in 8 hours. The organic fraction of the feedstock is then transported to a grinder that prepares the feedstock for the digestion tanks.

One advantageous feature of this system is that if the moisture content is too low to create pumpable slurry, the DODA BioSeparator can pull hydrolysis liquid from the digester system and circulate it with the incoming feedstock. This reduces the need to add water for transferring the waste into the digester. Feedstocks that do not require any pre-processing can be pumped directly into the digester.

Nearly all of the non-organics, including plastic bags, are rejected by the DODA BioSeparator and deposited into a tote bin located to the left of the tip floor. These contaminants are hauled away when the bin is full to either a landfill or mixed recycling center, depending on the type of contamination that is removed from the feedstock. This is the only stream from a proposed project that may need to be transferred to a landfill.

Pre-Processing Solid and Liquid Residual Management

Throughout pre-processing, contaminants are removed from the food waste feedstock. These materials include plastics, metals, rocks, and other debris that would hinder the food waste digestion process. As part of pre-processing, these materials are separated and retained in containers suitable for handling solid waste. Periodically, these containers are serviced, and the materials transported to the landfill.

Due to the high moisture content of the incoming food waste stream, liquid may be released during pre-processing. Integral equipment drains, and under-drains located throughout the preprocessing facility channel the liquid residual to a central concrete sump. A sump pump periodically recycles the liquid material back into the treatment train or directly to the homogenization tank where it is blended with the other pre-processed materials.

Skid Systems

Modular Liquid Transfer Skid Systems

Metering pumps are critical to the operation of the anaerobic digester process, as the microbial communities responsible for the organic decomposition are reliant on a consistent flow of nutrient rich material to maintain healthy population levels and balance. These pumps are controlled and monitored with CleanWorld’s remote monitoring system to ensure that accurate digester loading is achieved.

Figure 4 - CleanWorld's modular, prefabricated skids lower cost substantially.

Modular Heating Skid Systems

In order to achieve thermophilic temperature, the digester utilizes waste heat from the microturbines.

Digester Tanks

CleanWorld's HRD system combines favorable features of both batch and continuous biological processes in a single system and makes it possible to achieve highly efficient and stable production of both hydrogen and methane gases from a variety of organic solid and liquid wastes, including grass clippings, food scraps, food-processing byproducts, crop residues, paper products, and animal wastes. The digester is a three-phased straight flow through, continuous-fed solids digester capable of steady biogas production.

The UC Davis READ facility is a 50 ton per day HRD system composed of hydrolysis tanks, methanogenic tanks, and polishing tanks. CleanWorld has also designed a buffer tank that is used for storage of processed feedstocks or effluent. The buffer tank gives UC Davis greater flexibility in feedstock loading rates as well as unloading schedules for effluent. The buffer tank was a minimal cost increase for the system because it can be run from existing skids included in the system design. When compared to traditional AD systems, the HRD Digester employs fewer moving parts; requires smaller volume tanks, as the material does not need to be hydro-pulped and is held for a shorter time; uses less energy to operate; is highly scalable; relies upon commercially available components; and possesses innovative design features that optimize the bacterial degradation of organic wastes and minimize pretreatment time.

Additionally, the system's exceptionally low parasitic load of approximately 76 kW increases system efficiency in comparison to traditional, power-hungry, high-liquid AD systems. The HRD system operates at a thermophilic temperature (125-130ºF) and destroys pathogens in the waste, making the residual materials safe for use as compost and organic soil amendment products.

Hydrolysis Tanks

CleanWorld's digestion technology divides the three stages of anaerobic digestion into three tanks in order to provide the different bacteria in each stage their most optimum environment. In the first stage - hydrolysis - slurried feedstock is consumed by bacteria and converted biologically to organic acids and nutrients that become feedstocks for methanogenic microorganisms. The solids content in this tank can be up to 15 percent, utilizing CleanWorld's proprietary combination of hydraulic and mechanical mixing technologies to properly maintain continuous circulation within the tank. The hydrolysis stage of digestion allows for a wide range of solid contents for feedstock to enter the system and become homogenized before entering the methanogenic stage where more uniform slurry is desired.

METHANOGENISIS TANKS

Methanogenesis Tank

In the second stage - methanogenesis - the organic acids are converted to methane and carbon dioxide biogas. The residual solids are further liquefied and the solids content is dramatically reduced in this tank as the organic material is degraded. Separating the hydrolysis and methanogenesis stages of digestion allow each tank to be kept at the ideal environment for the acidogens and methogens inside.

POLISHING TANKS

Polishing Tank

The third and final stage of CleanWorld's process is a polishing tank. The liquid from the methanogenesis tank is transferred to the polishing tank where any remaining acids are digested to maximize biogas production and to provide longer solids retention time while allowing for removal of liquid to maintain volume balance.

Biogas Generation and Conveyance

The following sections discuss the requirements for the treatment of the biogas, generated at the anaerobic food waste digester facility.

Hydrogen Sulfide and Water Removal

CleanWorld's biogas typically consists of 50 to 70 percent methane, 30 to 50 percent carbon dioxide and trace amounts of hydrogen sulfide. The biogas is also saturated with water vapor. Prior to combustion in a microturbine, the water and hydrogen sulfide must be removed. Hydrogen sulfide is removed using an iron sponge which can be regenerated by exposure to air. When the iron sponge can no longer be regenerated, the spent, non-toxic material can be disposed at the landfill or recycled. It may also be beneficial as a soil amendment for sulfur poor soils.

The microturbine package can be delivered including a biogas refining

Figure 5 - Skid Mounted Gas Refining Equipment and Microturbine package at the READ Facility

system that removes moisture and impurities that the microturbine cannot tolerate. The water knock-out uses a chiller to cool the gas to the dew point of water, causing the water to condense and settle into a condensate trap, which is periodically drained. Drained condensate is returned to the digester. The refining system also compresses the gas from the pressure coming off the headspace of the digester to the pressure needed to enter the gas refining system.

Biogas H2S and siloxane filter systems are used to reduce the content of hydrogen sulfide and siloxane in raw biogas and landfill gas providing a cleaner and less corrosive gas for the microturbines. Regenerated carbon filter systems are generally more cost-effective for microturbine modules and are the selected product used in Unison's system.

Inlet gas is initially cooled by passing it through an advanced counter flow heat exchanger and then an air cooled liquid chiller to further reduce the gas temperature. Using outlet gas to cool the inlet gas increases system efficiency. There is no need for external hot water to reheat the gas. The compact skid-mounted design minimizes installation costs and is also suitable for outdoor location. Once the biogas has been stripped of H2S and dried it is sent into the microturbines.

Energy Services - Electricity

Electrical Generation

The microturbine technology selected for the UC Davis READ project includes a fully integrated gas refining system. The system is composed of four 200kW microturbines, each in their own container and connected to a single control system. An organic Rankine-cycle generator (ORC) is also on site and converts excess waste heat off the microturbines to 125 kW of additional renewable energy. The total generating capacity of these units is 925 kW. The complete system is specified for the Air District's emissions limits and designed to exceed those metrics. CleanWorld has extensive experience with Unison's gas refining systems and Capstone microturbines as they are currently utilized at the CleanWorld's other commercial digesters in Sacramento. The microturbines were selected for their low maintenance costs, up to 99% up-time, CARB certification for easy permitting, and their inverter base allows for a net-permitting interconnect similar to solar panels with many utilities.

The renewable electricity generated from combusting the biogas from the food waste digester is first used to power parasitic load of the digester system (typically 10-14%). The excess renewable electricity is sold to UC Davis.

Energy Services - Waste Heat

Heat Generation (Boiler)

The heat from the microturbines is captured and used to heat the digester, thereby achieving high levels of energy efficiency. The hot exhaust from the Capstone package of 800kW in microturbines exits the microturbine through four individual exhaust ducts and will be combined through a common exhaust manifold. The hot exhaust enters the heat recovery module (HRM) first. The HRM is equipped with its own independent control system and an exhaust bypass diverter. The control system on the HRM modulates the exhaust bypass diverter to limit the amount of exhaust that is allowed into the HRM. The amount of exhaust allowed into the HRM varies based on the water supply temperature. The HRM can operate at a full exhaust bypass (zero heat recovery) or at a full heat recovery.

Energy Services - Waste Heat to Energy

After passing through the HRM, the remainder of the exhaust energy is sent to the ORC generator. The ORC consumes the rest of the available heat and provide up to an additional 125 kW of electricity.

On-Site Safety and Security Systems

Access to READ project is controlled by perimeter fencing. The site has one entry and exit point controlled by a locking gate. During business hours, the gate is open for facility access by waste trucks, employees, and visitors. The gate remains closed and locked when the facility is un-manned or after business hours. Overhead lighting provides illumination for the site after dark.

Closed circuit cameras provide monitoring at key security points within the facility. These points include: access gate, pre-process building access points, and exterior tank and equipment pads. An alarm system on the access gate and preprocessing building access points can summon emergency responders in the event of unauthorized entry.

Environmental safeguards include concrete lining of facility components to prevent infiltration of contaminants to underlying soils and groundwater and provision of gas tight facilities, and installation of vent scrubbers, to reduce air emissions and odors.

The READ facility operates 24x7x365 days and is automated with offsite data collection, remote monitoring and control capabilities. Both “Front End” operations (processing and loading new materials) as well as “Back End” operations (processing and removal of resulting liquid and/or solid byproducts) are performed by on site personnel. As a result, the site typically is staffed one shift per day Monday through Friday. The shift may be extended to accommodate peak periods.

Description of Monitoring System

The main anaerobic food waste digester systems, subsystems and pre-processing equipment are controlled and monitored via a human machine interface (HMI) system. In commercializing its existing systems, CleanWorld has developed a proven HMI system that is included in the READ Biodigester system. CleanWorld's system monitors and controls process parameters including digester feed and wasting rates, tank levels, pH, pressure, temperature, methane concentrations in the biogas, process and control equipment status, and gas production and conveyance systems. Alarms can be triggered based on operator pre-set parameters and these alarms can alert staff via text message or email. Historical data are collected by CleanWorld and processed for ease of reporting, system monitoring and troubleshooting. CleanWorld can provide regular reports as part of an ongoing service package. The data are held in a secure site and managed via proprietary software. CleanWorld may provide secure access to the data directly if required, or provide regularly updated web interfaces accessible by secure password.

During alarm events, all affected equipment can be automatically set to standby, an automatic message can be sent to the system operator on call, and, depending on the nature of the alarm, emergency first responders can be summoned. In addition to the HMI system, a facility operation and maintenance manual is prepared that provides operators with detailed daily, weekly, and monthly physical inspection, monitoring and sampling protocols.

Description of Metering System and Metering Approach

Overview of data to be collected (electricity, thermal energy)

System data collections fall into several categories:

- Process Parameters including temperatures, liquid pressure, gas pressure, fluid flow, gas flow, pH, tank levels, etc.
- Process Activities: Starting and stopping of all semiautomatic and automatic processes.
- Warnings and Alarms
- Sub system data which may include kW consumed, kW generated, heat recovered, sub system status, conditions, warnings and alarms.

The data are collected every 5 seconds and can be reported on variable time scales from 1 day to 5 years and frequencies from every 5 minutes to once per day depending upon the desired reporting and resolution requirements.

Photos of the project progression

The construction of the UCD READ project was extremely fast, with less than 6 months between the ground breaking and ribbon cutting ceremonies. This accelerated schedule was possible because of the modular design of the technology including pre-fabricated skid systems that were completed at FM Booth's mechanical fabrication facility in Marysville, CA and then connected to the tanks onsite. The tanks were also composed of pre-fabricated panels and were quickly assembled in three months of construction. The photos below depict the progression of the site from the ground breaking in November 2013 to the ribbon cutting in April 2014.

Figure 6 - Ground Breaking November 2013

Figure 7 - Installation of Skids

Figure 8 - Installation of Tanks

Figure 9 - Insulation Applied to Tanks

Figure 10 - Facility tours at grand opening

Figure 11 - Ceremonial loading of organic feedstock

Figure 12 - UC Davis READ facility as seen from Google Earth

SECTION 3

Research Progress Report

UC Davis Renewable Energy Anaerobic Digestion Project – Performance Assessment

Prepared by
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Josh Rapport, CleanWorld

7/23/2014

1. Biogas Production and Composition

Daily biogas and landfill gas production and methane content of biogas at READ facility are shown in Figures 1 to 3. For the period of June 1 to July 22, 2014, the average daily biogas production is 41,290 standard cubic foot (scf) and the average methane content of biogas is 59%. The average landfill gas supply is 72558 standard cubic foot (scf) per day for the period of March 24 to May 27. However, it decreased to a very low amount afterward. The methane content of landfill gas was about 40%.

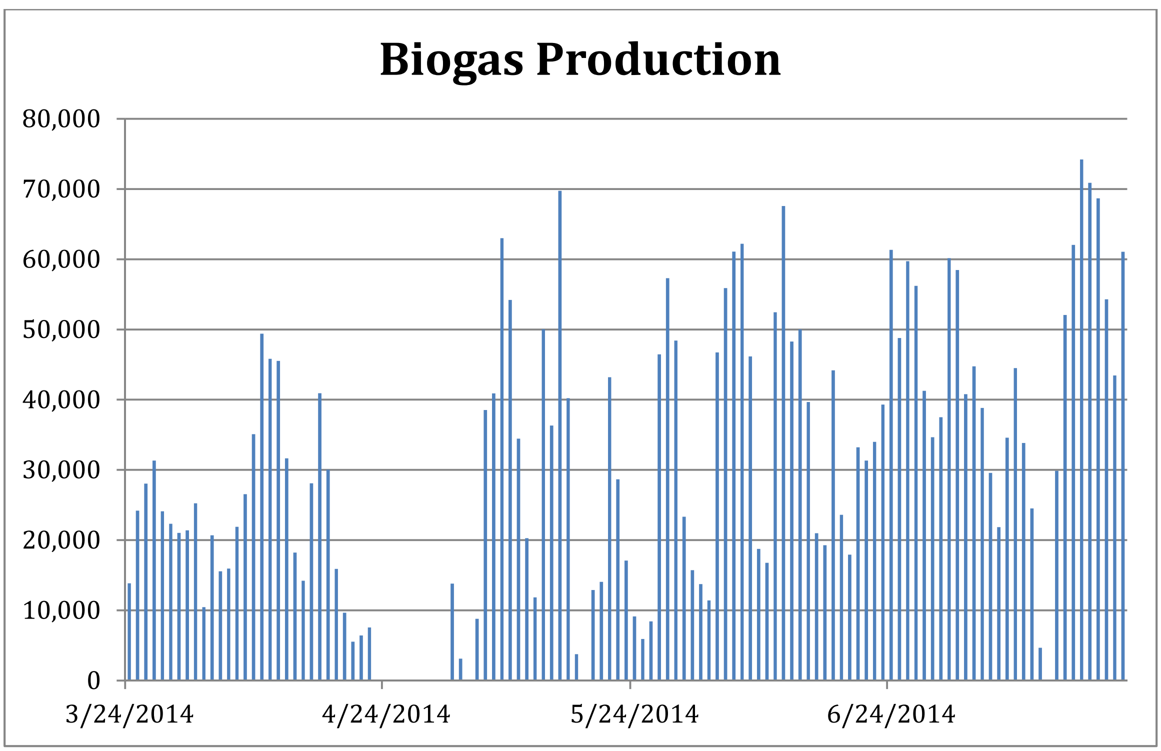

Figure 1. Daily biogas production of READ

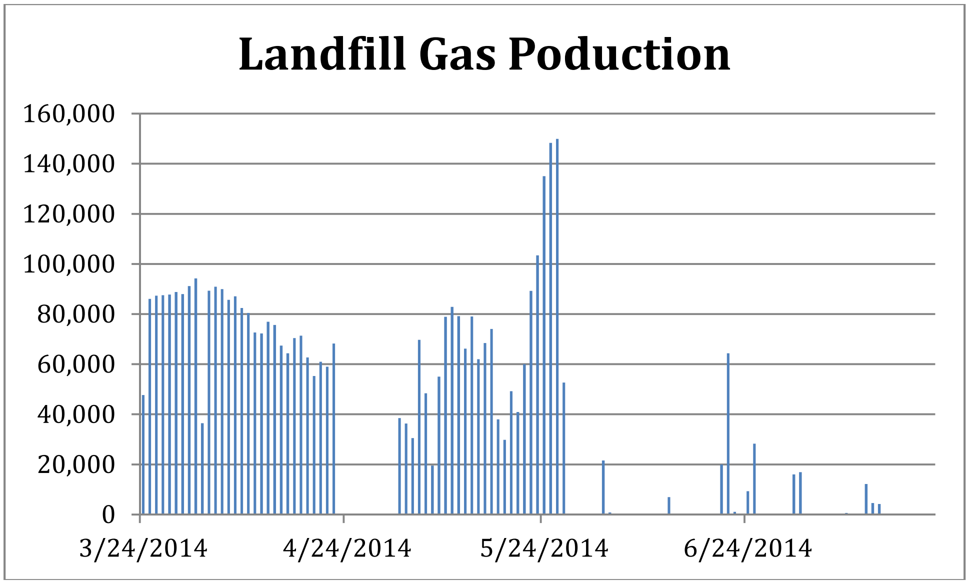

Figure 2. Landfill gas supply at READ facility

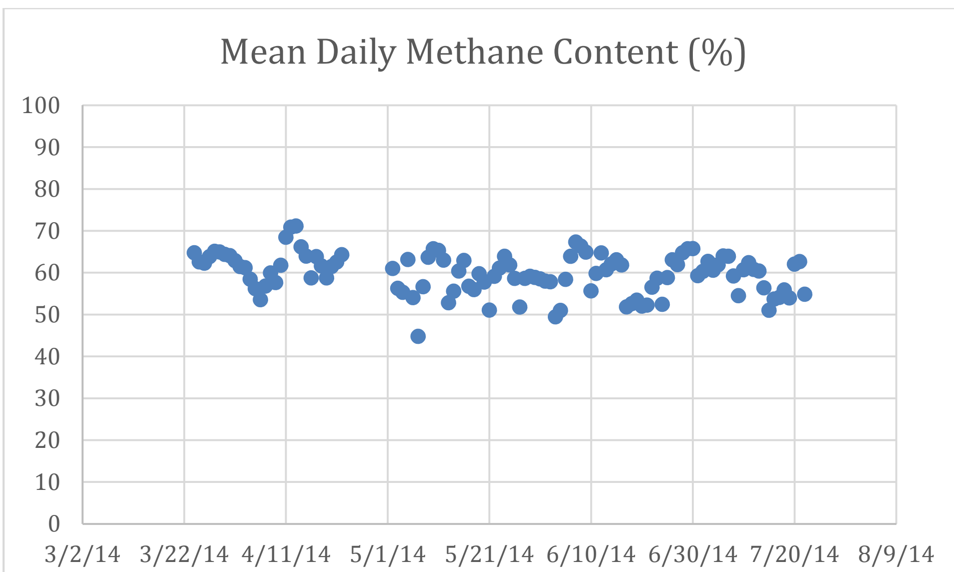

Figure 3. Methane content of biogas produced at READ

Figures 4 to 6 shows the gas sampling in the field. The laboratory analysis results of biogas are presented in Table 1. Port 1 is the sample port before biogas cleaning skid. Port 5 is the sample port after biogas cleaning skid. R1 and R2 means two repeat. Results before May 29^{th} were not presented because unstable condition caused by landfill pipe leaking. Only biogas produced from anaerobic digesters are presented in Table 1.

Table 1. Biogas composition analysis results

Date	Sample ID	H2	Air	CH4	CO2
5/29/2014	Port 1 R1	0.00%	1.20%	58.30%	40.50%
	Port 1 R2	0.00%	1.20%	58.40%	40.40%
6/6/2014	Port 1 A R1	0.00%	2.30%	60.50%	37.20%
	Port 1 A R2	0.00%	2.20%	60.80%	36.90%
	Port 1-D B R1	0.00%	2.30%	64.00%	33.70%
	Port 1-D B R2	0.00%	2.30%	64.10%	33.60%
	Port 5 A R1	0.00%	1.70%	59.50%	38.70%
	Port 5 A R2	0.00%	1.70%	59.60%	38.70%
	Port 5 B R1	0.00%	5.10%	57.50%	37.50%
	Port 5 B R2	0.00%	5.10%	57.40%	37.50%
	Standard	24.60%	1.30%	34.70%	39.40%
6/11/2014	Port1 R1	0.00%	1.20%	60.90%	37.90%
	Port1 R2	0.00%	1.10%	60.80%	38.10%
6/25/2014	Port 1 R1	0.04%	8.51%	53.92%	37.54%
	Port 1 R2	0.04%	11.19%	52.26%	36.51%
	Port 5 R1	0.04%	1.50%	58.51%	39.96%
	Port 5 R2	0.04%	1.51%	58.45%	40.01%
7/8/2014	Port 1 R1	0.02%	1.72%	60.18%	38.08%
	Port 1 R2	0.02%	1.91%	60.10%	37.98%
	Port 5 R1	0.01%	1.62%	59.91%	38.46%
	Port 5 R2	0.01%	1.60%	59.94%	38.46%

Figure 4. Biogas sampling at READ

Figure 5. Landfill gas sampling at READ

Figure 6. Gas samples from READ

2. Feedstock Measurement and Analysis Results

A total of 443 tons of biomass feedstock were processed in May and June, 2014. The feedstock included food waste from UC Davis dining halls, food waste from a commercial food supply company, horse manure from a UCD facility and mouse bedding from a commercial biotech company. The feedstock data for July are not available at this time. Figures 7 to 10 show the different feedstock processed at READ. Solids content analysis results are presented in Table 2. UCD food waste has about 30% totals solids and highest VS/TS ratio of about 94%. Commercial food waste has lowest total solids content about 12%. Mouse bedding has highest total solids content of about 88%. Horse manure has about 60% total solids content and lowest VS/TS ratio of about 70%.

Table 2. Characteristics of biomass feedstock

Sample Date	Sample ID	Sample Type	% MC (ww)	%TS (ww)	% VS (ww)	% FS (ww)	%VS/TS (dw)
5/6/2014	DH	UCD Food Waste	66.2	33.8	31.5	2.3	93.3
5/6/2014	RW	Commercial Food Waste	88.2	11.8	10.9	0.9	92.7
5/6/2014	MB	Mouse Bedding	12.6	87.4	81.4	6.1	93.1
5/7/2014	DH	UCD Food Waste	71.2	28.8	26.9	1.9	93.5
5/8/2014	RW	Commercial Food Waste	87.5	12.5	10.8	1.8	86.0
5/8/2014	HM	Horse Manure	46.1	53.9	39.8	14.1	73.9
5/12/2014	HM	Horse Manure	38.0	62.0	47.5	14.6	76.5
5/13/2014	DH	UCD Food Waste	70.9	29.1	27.4	1.7	94.0
5/13/2014	RW	Commercial Food Waste	86.4	13.6	12.1	1.5	89.1
5/13/2014	MB	Mouse Bedding	12.2	87.8	81.0	6.8	92.3
5/14/2014	DH	UCD Food Waste	71.2	28.8	27.1	1.6	94.2
5/15/2014	RW	Commercial Food Waste	88.0	12.0	11.1	0.9	92.3
6/12/2014	HM	Horse Manure	41.8	58.2	46.6	11.6	80.2
6/18/2014	HM	Horse Manure	42.0	58.1	37.4	20.7	65.7
6/25/2014	MB	Mouse Bedding	12.1	87.9	80.7	7.2	91.8
7/8/2014	MB	Mouse Bedding	11.4	88.6	83.3	5.3	94

Figure 7. Horse manure and bedding processed at READ

Figure 8. UC Davis food waste from dining halls processed at READ

Figure 9. Sample of commercial food waste

Figure 10. Sample of mouse dropping

3. Digester Liquid Analysis Results

The solids analysis results of all four tanks, including three digester tanks (T1, T2 and T3) and digester effluent storage tank (T4), are shown in Table 3. The solids content decreased through T1 to T4, which indicates organic waste was successfully digested by microbes. Ammonia concentration showed a trends of increasing from

1600 ppm to above 2000 ppm. The BOD concentration in T4 was measured weekly and the results varied from 775 ppm to 1263 ppm.

Table 3. Digester liquid Sample Analysis Results of Four Tanks

Sampling Date	Tank Sampled	MC (%)	TS (%)	VS (%)	FS (%)	VS/TS (%)	pH	NH3-N (ppm)	BOD (ppm)
5/29/2014	T1	97.97	2.03	1.36	0.67	67.06	7.35	1610	
5/29/2014	T2	98.64	1.36	0.8	0.56	59.01	8.05	1820	
5/29/2014	T3	98.95	1.05	0.59	0.46	55.99	8.17	1685	
5/29/2014	T4	98.92	1.08	0.6	0.48	55.75	8.07	1765	
6/5/2014	T1	97.78	2.22	1.54	0.68	69.51	7.51	1100	
6/5/2014	T2	98.37	1.63	1.03	0.59	63.56	7.67	1710	
6/5/2014	T3	98.59	1.41	0.84	0.56	59.94	7.45	1650	
6/5/2014	T4	98.79	1.21	0.69	0.52	56.86	7.4	1690	
6/11/2014	T1	97.86	2.14	1.47	0.67	68.65	7.42	1200	
6/11/2014	T2	98.39	1.61	1.02	0.59	63.46	7.7	1800	
6/11/2014	T3	98.59	1.41	0.85	0.57	59.99	7.45	1790	
6/11/2014	T4	98.69	1.31	0.75	0.55	57.79	7.55	1630	775
6/18/2014	T1						7.43	1320	
6/18/2014	T2						7.68	1890	
6/18/2014	T3						7.4	1780	
6/18/2014	T4						7.5	1820	1211
6/25/2014	T1	97.8	2.2	1.6	0.7	70.8	7.68	1890	
6/25/2014	T2	98.4	1.6	1	0.6	63.5	7.88	2070	
6/25/2014	T3	98.5	1.5	0.9	0.6	62	7.85	2200	
6/25/2014	T4	98.6	1.4	0.8	0.6	59.9	7.75	2200	1263
7/8/2014	T1	97.8	2.2	1.5	0.7	67.4	7.79	2040	
7/8/2014	T2	98.4	1.6	0.9	0.6	61	8.03	2110	
7/8/2014	T3	98.5	1.5	0.9	0.6	59.9	8.09	2130	
7/8/2014	T4	98.5	1.5	0.9	0.6	59.5	8.11	2060	