California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Sacramento Biorefinery No. 1

Technical, Environmental, and Economic Evaluations

Prepared for: California Energy Commission

Prepared by: Clean World Partners

Gavin Newsom, Governor

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PREFACE

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

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

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

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC’s annual Clean Transportation Program Investment Plan Update. The CEC issued ARV-10-026 to provide funding and financial assistance for the development of new, California-based biofuel production plants and enhance the operation of existing ethanol production plants to increase statewide biofuel production and reduce greenhouse gas emissions. In response to PON 09-604, the recipient submitted an application which was proposed for funding in the CEC’s notice of proposed awards August 12, 2010, and the agreement was executed as ARV-10-026 on March 17, 2011.

ABSTRACT

The CEC awarded a contract to Clean World Partners in 2010 to complete predevelopment studies, research, and activities necessary to site and build an anaerobic digestion system producing biomethane as a transportation fuel from food and green wastes. This system, "Sacramento Biorefinery #1," opened December 7, 2015, at the Sacramento South Area Transfer Station at 8550 Fruitridge Road in Sacramento, California. This project meets the principal goals of the CEC by stimulating local economic development and reducing greenhouse gas emissions, petroleum demand, and the environmental impacts associated with disposal of organic wastes in area landfills. The biorefinery also directly supports the legislative and regulatory objectives of the California Department of Resources Recycling and Recovery, the California Public Utility Commission, and the California Air Resources Board.

For this predevelopment project, tasks included site assessment, technical and economic feasibility studies, feedstock performance and materials assessments, feedstock and waste management plans, and engineering design and ancillary equipment review.

This project supported Clean World Partners in identifying and confirming the technological approach; evaluating equipment and vendors; proving financial feasibility; analyzing feedstock digestibility; satisfying federal, state, and local permitting requirements; and developing construction plans.

Also as a direct result of this report, Clean World Partners designed, permitted, fabricated, and constructed an eight-tons-per-day facility located at American River Packaging in March 2012. The project began on March 11, 2011, and was completed by September 1, 2012. The project leveraged more than $1.8 million in private investment and supported about 30 jobs in research, design, fabrication, and construction during the project period.

Keywords: Anaerobic Phased Solids Digester, High Rate Digester, anaerobic digestion, biogas, biomethane, renewable natural gas, CNG, food waste, pilot plant, operational report, renewable energy, waste treatment, high solids digestion, Sacramento Biorefinery #1

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EXECUTIVE SUMMARY

Project Background

In 2009, Clean World Partners, LLC—in collaboration with Atlas Disposal Industries, LLC, Carson Development, Otto Construction Company, Sacramento Municipal Utility District, and the County of Sacramento—began prospecting and project evaluation of an anaerobic digestion system capable of diverting 100 tons per day (36,500 tons per year) of source-separated organic waste away from area landfills. The system was designed to convert the waste into renewable natural gas, electricity, heat, fertilizer, soil amendments, and compost.

In June 2011, Atlas and Clean World Partners applied to the County of Sacramento to manage the abandoned South Area Transfer Station at 8550 Fruitridge Road, Sacramento, CA. Previously this land was industrially zoned property that served no value to the community. In July 2011, Atlas and Clean World Partners were notified that the County of Sacramento would award a lease for constructing technologies that increase waste diversion while creating renewable energy.

Made possible in part by this predevelopment grant from the CEC, a full technical, environmental, and economic feasibility study was prepared for the South Area Transfer Station site and submitted to the CEC in December 2011. Additional feedstock, equipment, and process studies as part of this project further affirmed site and technology feasibility.

In December 2011, Clean World Partners began fabrication of equipment necessary to construct a biorefinery at the South Area Transfer Station location. In June 2012, a public groundbreaking at the site was made simultaneous with the start of construction and installation of necessary tanks and other infrastructure. This Phase I, 25-tons-per-day facility began receiving waste by November 2012.

In April 2012, Clean World Partners received notice from the CEC that funding was approved to allow scale-up of the 25-tons-per-day facility to 100 tons per day in Phase II. This approval allowed Clean World Partners to begin site preparation and equipment fabrication and will help ensure that scale-up proceeds promptly. The full-scale system is planned for completion in 2013.

In May 2012, Atlas received notice from the CEC of an award for funding for alternative fueling stations. This award would support development and installation of an on-site NG vehicle fueling facility that will utilize the renewable NG produced at the biorefinery. This station will fuel solid waste transport, school district, and county-owned fleet vehicles.

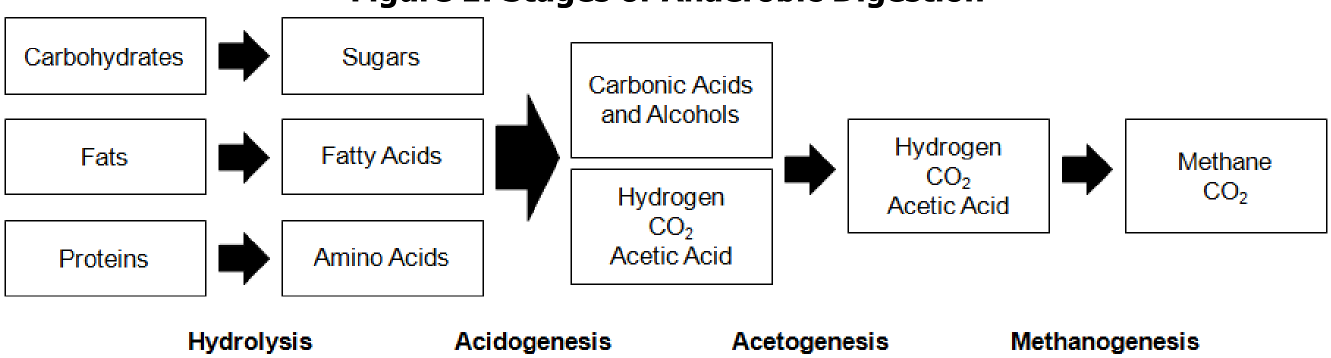
Technology Background

Anaerobic digestion is a process in which microorganisms break down biodegradable material in the absence of oxygen. This process is widely used to treat wastewater sludge and organic wastes because it reduces the volume and mass of the waste material while reducing the emission of greenhouse gases and producing useful products such as high-nutrient fertilizer and a biogas rich in methane. Project owners can use biogas to generate electricity and/or heat or convert it into compressed natural gas or liquefied natural gas for use as transportation fuel.

The core technology at the biorefinery is a proprietary, high-solids anaerobic digestion system that converts organic waste into biomethane, reclaimed water, and liquid and solid soil amendment by-products. The prototype for this technology was developed and demonstrated at the University of California, Davis, and funded, in part, by the CEC and the California Integrated Waste Management Board (now CalRecycle). Dr. Ruihong Zhang was instrumental to the development process. Her technologies—to which Clean World Partners holds five exclusive licenses—promote rapid and efficient digestion of high-solids feedstocks. This high-solids anaerobic digestion system allows system designers to dramatically reduce digester tank size, enabling numerous economical anaerobic digestion applications in a wide range of settings.

Most anaerobic digestion systems share common preprocessing stages, including separation of waste into biodegradable and nonbiodegradable components, shredding, slurry conversion, screening, and pasteurization. Following preprocessing, the feedstock travels to the digesters, where anaerobic microorganisms break it down. These microbes include acidogens that produce organic acids, carbon dioxide, hydrogen, hydrogen sulfide, and methanogens that produce carbon dioxide and methane. Through the anaerobic digestion process, the feedstock undergoes conversion into many different intermediate molecules (Figure 1) before final conversion into a biogas consisting primarily of methane and carbon dioxide, with traces of hydrogen and hydrogen sulfide.

Figure 1: Stages of Anaerobic Digestion



Source: Clean World Partners, LLC

Status of Sacramento Biorefinery One Project

As a result of this CEC project, Clean World Partners developed design, fabrication, and installation plans to construct the biorefinery in two phases. In Phase I, the facility was designed to treat 25 tons per day of food waste. Phase I was completed in December 2012. Phase II involves scaling up the facility to process 100 tons per day of organic wastes. Design, fabrication, and permitting of the Phase II facility are in process, and this phase of the facility is expected to be complete by 2013.

The Phase II facility is capable of diverting 100 tons per day (36,500 tons per year) of source-separated food waste away from area landfills and converting it via anaerobic digestion into

566,000 diesel gallon-equivalents of renewable natural gas per year; 3.17 million GWh of electricity and 190,000 therms of heat per year to power the facility; 8,000 tons per year of N-loaded zeolite for granular fertilizer; 7,500 tons per year of compost; and 5,450,000 gallons per year of liquid effluent that can be used as a fertilizer and/or remediated to reclaim the water.

The scaled-up biorefinery project will be the largest commercial-scale, high solids anaerobic digestion system in California and the first to produce renewable vehicle fuel. When Phase II is complete, Clean World Partners will produce enough renewable natural gas to run the full Atlas fleet of 20 waste hauling trucks (six days per week) with an additional 237,500 diesel gallon-equivalents of renewable natural gas per year made available to other local fleets. This project is critical to extending the life of the Sacramento landfill, reducing greenhouse gas emissions, achieving low-carbon fuel standards, and generating bioenergy and biobased agricultural products in California.

When complete, the biorefinery project will support the following CEC Clean Transportation Program goals:

- Demonstrate scale-up to commercial scale biofuel facility for revenue generation.
- Improve process-related energy economics.
- Improve the preprocessing system to allow for lower carbon feedstock, further reducing Low Carbon Fuel Standard metrics.
- Reduce GHG emissions through efficiencies scale-up.
- Reduce petroleum dependence by offering a renewable natural gas fueling station for fleets and public use.
- Stimulate economic development in California by developing a replicable plan for constructing phased anaerobic digestion projects.
- Display anaerobic digestion system integration for waste collection companies with compressed natural gas fleets.

American River Packaging

One of the 12 initial sites assessed as part of Project Task 2.1 (see Chapter 2) was the American River Packaging site in the Natomas area of Sacramento. As a result of this site assessment and additional technological, environmental, and economic studies conducted in this project, Clean World Partners and American River Packaging commissioned the American River Packaging Organic Waste Recycling Center (Figure 2) in March 2012 in Sacramento. This 10-tons-per-day facility converts wet food waste and unrecyclable corrugated cardboard into biogas, which is refined and fed to two 65-kilowatt (kW) microturbines to produce renewable electricity to power the digester and 35 percent of the adjacent American River Packaging plant. The heat from the generators will be used to heat up the digester as well as additional effluent processing equipment. The residual solids and liquids removed from the digester will be converted to useful agricultural products such as compost tea and liquid fertilizer.

Figure 2: American River Packaging Organic Waste Recycling Center

Photo credit: Clean World Partners, LLC

The American River Packaging anaerobic digestion project will serve as a food waste collection facility for several food producers in the Sacramento area. It will also provide a proving ground for new technologies developed by Clean World Partners before applying those technologies on a larger scale. However, the American River Packaging project is a fully commercial anaerobic digestion system.

Recommendations for Follow-Up and Ongoing Activities

Clean World Partners intends to manage and operate the biorefinery. The company will continue to develop formal feedstock agreements with area waste haulers and waste producers necessary to fully operate the scaled-up biorefinery facility. Additionally, Clean World Partners is actively developing a business plan to fully use the digestate produced by the biorefinery and maximize its economic value through product enhancement and sales agreements. Clean World Partners will also continue to investigate opportunities to expand the biorefinery to accept 250, 300, and 500 tons per day of organic wastes.

About Clean World Partners

Clean World Partners LLC (Figure 3) is a subsidiary of Synergex International Corporation, based in Gold River, California, an industry leader at the forefront of technology commercialization for more than 35 years. Clean World Partners offers a range of technologies and services designed to help manage the complexities associated with the disposal of organic wastes. Clean World Partners collaborates with businesses and communities to convert organic waste to renewable energy, soil enhancement products, and other valuable biobased products using proprietary technologies that are scalable, cost-efficient, and effective. The Clean World Partners research and development team also continually strives to develop innovative processes and technologies to improve biogas system efficiency, stability, and usability.

Figure 3: Clean World Partners Logo

Source: Clean World Partners, LLC

Clean World Partners provides effective waste management solutions based on anaerobic digestion, an ever-evolving technology that converts waste to renewable energy through a biological in-vessel system using a mix of naturally occurring bacteria. Currently, Clean World Partners offers three scalable, affordable, and resilient anaerobic digestion technologies: the anaerobic phased solids two-stage digester; the dynamic biofilm reactor single-stage system; and a novel, three-stage high-rate digester system that is well-suited for treating highly biodegradable solid wastes and mixed waste streams consisting of a solid and liquid fraction. Systems based on these technologies are capable of converting a wide variety of organic feedstocks into high-quality biomethane, marketable biobased products, and clean water. Clean World Partners also offers a variety of services, including feedstock analysis, feasibility studies, biogas use, residuals management, operational support, and process modeling.

Team members at Clean World Partners have extensive experience in developing and financing thriving businesses and large-scale public infrastructure projects, including Sacramento’s Raley Field and the Powerhouse Science Center. They also possess expertise in team building, executive management, government, waste management, energy systems, and waste diversion.

CHAPTER 1: Project Overview and Management

This report is the Final Report for the Sacramento Biorefinery #1 (SBR1) project (Agreement No. ARV-10-026) executed by Clean World Partners (CWP). The project began on March 11, 2011, and will be complete by September 1, 2012.

1.1 Initial Project Goals

The initial goals of this project were to:

- Evaluate the technical, economic, and environmental elements of the SBR1, a proposed biorefinery that utilizes proprietary anaerobic digestion technologies developed at the University of California, Davis, to convert food and green waste into renewable natural gas (RNG) and other products.
- Perform tests and material assessments to verify operating characteristics of the anaerobic digestion system.
- Refine and improve waste collection and biofuel production in an urban environment leading to a project that is ready to be financed and constructed.

1.2 Tasks and Objectives

In support of this project, CWP successfully completed the following tasks:

- Twelve Preliminary Site Evaluations to determine site characteristics, feedstock availability, and customer interest
- Six Site Evaluation Reports with detailed site analysis, permitting requirements, and feedstock availability
- Designation of a “Preferred Project” at South Area Transfer Station (SATS) and “Secondary Project” at American River Packaging (ARP) in Natomas
- Technical and Environmental Feasibility Study for Preferred Site and Secondary Site
- Market and Economic Analysis of Biomethane for Transportation Report
- Technology Transfer and Commercialization Plan
- Feedstock Characterization Report
- Performance and Materials Testing
- Feedstock Resource Assessment
- Feedstock Procurement Program
- Waste Handling and Preprocessing System Design
- Digester Design Summary Report
- Residual Processing and Filtration System Design Report
- Biomethane Cleanup, Conditioning and Delivery System Report

- Preliminary Engineering Design Report
- Preliminary Site Layout and Utilities Drawings

1.3 How Project Tasks Relate to Project Goals

CWP was awarded a grant in 2010 from the CEC to complete predevelopment studies, research, and activities necessary to site and build an anaerobic digestion system producing biomethane as a transportation fuel from food and green wastes. These tasks and objectives assured that CWP was committing public and private resources in an efficient, conscientious manner in order to site, construct, and operate a 100-tons-per-day (TPD) anaerobic digester in Sacramento, California. These predevelopment activities represent the critical elements of assessing technical, environmental, and economic feasibility of the proposed project.

As a direct result of these tasks, SBR1 is now under construction at the Sacramento SATS at 8550 Fruitridge Road in Sacramento, California. This project meets the principal goals of the CEC by stimulating local economic development, and reducing GHG emissions, petroleum demand, and the environmental impacts associated with disposal of organic wastes in area landfills. It also helps contribute to the AB32 commercial recycling and the California Department of Resources Recycling and Recovery (CalRecycle)'s Strategic Objective 6.1 to reduce organics in landfills by 50 percent.

1.4 Key Contractors and Subcontractors

The Project Manager is Synergex Ventures of Gold River, California. Synergex Ventures entered into a financial partnership with CWP in 2011, at which time it assumed responsibility for the execution of this Agreement. CWP operates as a subsidiary of Synergex Ventures. Synergex Ventures performed all site feasibility studies and site evaluation reports detailed in Chapter 2 and Chapter 3, below.

The lead Environmental Consultant for this project is Carson Development Company, 1722 Third Street, Sacramento, California. The lead Engineering Consultant is Otto Construction Company, 1717 Second Street, Sacramento, California. These firms provided critical engineering and environmental services in support of the project, as detailed in Chapters 3, 5, and 6, below.

The University of California, Davis performed monitoring and gas sampling, as well as numerous research and development activities detailed in Chapters 4, 5, and 6, below.

CALSTART, 48 South Chester Avenue, Pasadena, California, performed research and market analysis for biomethane in transportation and contributed extensively to Chapter 4, below.

Synergex, Inc., provided legal services in support of environmental feasibility and analysis, organizational structure, project communications and marketing, and project finance.

TSS Consultants, 2724 Kilgore Road, Rancho Cordova, California, was the lead consultant conducting environmental feasibility and analysis, and contributed extensively to Chapters 2, 3, and 6.

SMUD, 6201 South Street, Sacramento, California, performed the feedstock evaluation and assessment described in Chapter 4, below.

1.5 Key Activities

The organization of this Final Report mirrors that of the contracted tasks – e.g., Task 2 and its subtasks are detailed in Chapter 2, Task 3 in Chapter 3, and so on. Key activities included the tasks described below. Task 1 is excluded as it included tasks that are primarily administrative in nature. In Task 2, CWP completed a Site Evaluation Report of 12 sites in the greater Sacramento region. Six were selected for detailed evaluation, and of those, five were found appropriate for installation of an Anaerobic Digester system. Two of these sites – ARP and SATS – have been constructed or are currently under construction.

In Task 3, CWP utilized the Site Evaluation Report in Task 2 to develop and submit a Feasibility Study that demonstrates that a "Preferred Project" renewable biomass system is feasible. This "Preferred Project" at SATS was designated based on the ease of permitting, availability of private investment, proximity of substantial feedstock streams, site control, and the receptivity of a major waste hauling partner to support financing, management and operations. The Feasibility Study found that the SATS site was technically, environmentally and economically feasible for an anaerobic digestion system. Based upon this Feasibility Study, a 25-TPD system is under construction at the SATS site and scheduled to be operational by late 2012. A scale-up of the facility to 100 TPD is scheduled to be complete by mid-2013.

In Task 4, CWP analyzed samples of feedstocks collected from the sites evaluated in Task 2. The analyses quantified key physical and chemical characteristics of the feedstock streams (i.e. solids content and chemical composition) as well as the batch digestibility and biogas/methane (CH_4) potential of the feedstocks. These data were recorded in a database that allowed rapid mass and energy balance modeling of different mixes of these feedstocks as well as other feedstocks that were analyzed outside of the scope of work. The modeling efforts were used to prepare plant specifications for the Preferred Project (as well as other potential projects), including operating and design parameters, such as tank volumes, heat requirements, and mass flows.

In addition to the batch digestibility tests, a 150 gallon pilot-scale digester was built and operated on the feedstocks identified from Task 2. Laboratory testing was also performed on the liquid and solid residuals from the pilot digester. The solids were composted under various regimens. The liquid was filtered, evaporated, and mixed with additives designed to add agronomic value to the materials. Several commercial products were developed and their manufacturing processes were designed based on the lab work.

In Task 5, CWP prepared and submitted a Feedstock Resource Assessment Report, to support sustainable feedstock supply requirements for anaerobic digestion and codigestion possibilities at the facility. Additionally, CWP prepared a Feedstock Procurement Program Summary Report that presented an implementation program for procurement of sustainable feedstocks such as food wastes and other organic wastes.

In Task 6, CWP developed and submitted preoperational design specifications for a 25-TPD commercial Anaerobic Digester plant based on the physical and chemical characteristics of the biomass streams as determined in prior research and plans. Critically, CWP optimized the system design to improve overall system performance and the performance of the anaerobic digestion process. Utilizing research from previous tasks, CWP substantially increased the quality of the residuals recovered from the digester effluent.

CHAPTER 2: Site Evaluation Report

2.1 Key Findings and Conclusions

In Task 2, CWP completed a Site Evaluation Report of 12 sites in the greater Sacramento region. Six were selected for detailed evaluation, and of those, five were found appropriate for installation of an Anaerobic Digester system. Two of these sites – ARP and SATS – have been constructed or are currently under construction.

2.2 Background

In March 2012, CWP received a grant award from the CEC (Grant Award Number ARV-10-026) to conduct technical and economic feasibility for a proposed biorefinery that will convert food and green waste into renewable compressed natural gas (CNG), also known as biomethane.

Task 2.1 of the Agreement was to produce a Site Evaluation Report that identifies potential project sites in the Sacramento region capable of hosting a digester project in a manner that best serves the project's goals and objectives. The Site Evaluation Report evaluated sites for logistics, permit status, engineering, infrastructure, and environmental qualities and facilitates expeditious development, planning, construction, and operations.

Initially, twelve sites were considered in the Sacramento region. Of these sites, six sites were selected by the CWP Study Team for further site evaluation. These sites were visited, interviews of owners and operators of on-site facilities were conducted, and site information was collected and evaluated. The collected and researched information was compared in a site evaluation matrix and the six sites received numerical scores.

Five of the finalist sites were found to be appropriate for near-term establishment and operations of anaerobic digestion systems. Of those, two were selected for immediate development, and anaerobic digestion systems have been constructed or are currently under construction. Only Site Evaluation Report information on these two sites is presented here; information on the remaining four sites is considered proprietary and confidential.

2.3 Site Evaluation Report

Each of the six sites was evaluated based upon criteria that meet Task 2.1 needs and requirements. Each site evaluation section reviews the following general and specific information and criteria:

- Site details and description
- Facility and business information
- Site characteristics
- Site logistics
- Site engineering requirements
- Environmental factors

- Permitting requirements

The sections below contain Site Evaluation information for the two sites constructed or under construction at ARP and SATS. Additional ranking schemes and matrices are included for all six evaluated sites that demonstrate candidate sites' efficacy in hosting an anaerobic digestion system based on the evaluation criteria. (Site Evaluation Reports for all sites were submitted as Report 2.1.)

2.3.1 County of Sacramento SATS

The Site Evaluation Report recommended development of a 25-TPD anaerobic digestion facility at the SATS in Sacramento, California.

The County of Sacramento SATS (Figure 4) is a permitted municipal solid waste (MSW) transfer station that is now occasionally used for urban green transfer. Feedstock for this anaerobic digestion system will be food waste collected and brought to the site by Atlas Disposal, a Sacramento-based waste management company, and other waste collection companies in the region.

Figure 4: SATS Site

Photo Credit: Clean World Partners, LLC

Initially, a 25-TPD system was proposed. This has since been expanded to 100 TPD pursuant to additional feasibility studies, funding from the CEC, and additional private investment.

<u>Summary</u>

A Summary of the Site Evaluation Report for this site is below:

Address

8550 Fruitridge Road, Sacramento, CA 95828

Assessor's Parcel Number

#062-0090-021-0000

Owner

County of Sacramento, 9850 Goethe Road, Sacramento, CA 95827

Zoning

M-2S, County Use

Size

12.26 acres / 534,046 square feet

Products Produced

Currently the site does not produce anything. It is the site of the Sacramento County Solid Waste and Recycling Department's SATS.

Typical Amount of Product Produced

Currently the SATS site does not routinely operate.

Product Characteristics

All food waste feedstock will be brought to the SATS site.

Method of Managing Organic Solid Residue

Food waste feedstock will be collected by Atlas Disposal and transported to the SATS site by truck.

Length of Production Season

Year-round

Wastewater Production

No wastewater currently produced at SATS site.

Wastewater Removal/Disposal

County of Sacramento Regional Sanitation District sanitary sewer available at site.

Infrastructure

Power (Including NG and Electrical Consumption and Costs)

As no solid waste management activities are currently under way there is no significant electricity usage or any NG usage.

On-site Process Heat Requirements

None needed for SATS facility.

Water Supply and Wastewater Discharge

Water supply to SATS site is city water. Water is primarily for domestic sewage and landscaping.

Height Restrictions

All anaerobic digester equipment will be below any height restrictions set forth by the City of Sacramento.

Truck Access Into and From Site

Truck access is from Fruitridge Road. There is a dedicated driveway for vehicular traffic to enter and leave the site. The Solid Waste Facility permit for the SATS site allows up 522 vehicles per day.

On-site Heavy Machinery (Front-end Loaders, Hauling Trucks, etc.)

When the SATS site is operating there are front-end loaders at the site. Additionally, hauling trucks bring in solid waste, consolidating it into larger trucks for offsite disposal.

Current Waste Disposal (Methods, Quantity, Frequency, Cost)

The SATS site is not currently transferring waste for disposal. The food waste feedstock stream proposed to be brought to the proposed anaerobic digestion system at SATS is currently open composted outside of Sacramento County.

Site within Facility for Anaerobic Digestion System

Description

The anaerobic digestion system will be located in the northeast corner of the SATS site and occupy less than one acre.

Feedstock Details

Quantity and Type of Current Feedstocks (Including Their Security and Reliability)

It is planned to transport 25 TPD of food waste to the anaerobic digestion system at the SATS from commercial, industrial, or institutional sources. This would be a very small percentage of the food waste available in the Sacramento region.

Rate and Frequency of Production of Anaerobic Digestion Feedstock Stream

Food wastes are produced on a consistent and routine basis 365 days a year.

Collection Method and Delivery to Anaerobic Digestion System

Food waste for the SATS site anaerobic digestion system will be collected and transported to the site by Atlas Disposal trucks.

Potential for Additional Feedstocks from Nearby Sources

All feedstocks will come from offsite sources. The 25 TPD to be processed at the SATS site represents a small percentage of available food waste feedstock in the Sacramento Region.

Anaerobic Digestion System Installation and Operation Requirements Availability

Electric Needs and Host Facility Supply

Host facility has electrical service to the property. The anaerobic digestion system will be stand-alone and will need its own electrical connection.

Heat Needs and Host Facility Supply

The anaerobic digestion system can supply its own heat needs with a gas or propane fired water heater.

Anaerobic Digestion System Overall Integration with Host Facility

There will not be any integration with the host facility. The anaerobic digestion system will be a stand-alone facility within the SATS site.

Water Supply and Wastewater Discharge Integration with Host Facility

The anaerobic digestion system will tap into the on-site city water supply and discharge to the sanitary sewer system on site.

Labor for Operations, Routine Maintenance, and Repairs

As a stand-alone operation within the SATS site, the anaerobic digestion system will need to supply its own labor force.

Land Use

The site is of flat topography and contains structures and appurtenances associated with a solid waste facility conducting MSW transfer activities. More than half the site is paved with asphalt or concrete. Structures include an office, open ended MSW sorting buildings, a small maintenance and storage building, a small security gate building (on the driveway from Fruitridge Road), and an area where MSW can be loaded into large trucks for off-site transport to landfills. The portions not paved contain ruderal and weedy plant species. There are various trees and shrubs on the site, particularly along the driveway to the facility from Fruitridge Blvd. Landscaping is prevalent along the driveway.

There are no water features on the property site. Wildlife on the site would be expected to be that associated with ruderal and weedy plant species. The trees would harbor additional bird species. Being of flat topography and in a commercial-industrial area, scenic value is very limited. The buildings appear not to be of suitable age to be considered historic, nor are any cultural resources expected to be found on the property. The proposed anaerobic digestion system will be placed at the northeastern corner of the SATS property. This area is currently asphalt paved.

Air Quality and Greenhouse Gases (GHGs)

The SATS site currently has no operations requiring an air quality permit from the Sacramento Metropolitan Air Quality Management District (SMAQMD). The diversion of any food waste from disposal at landfills to the SATS anaerobic digestion system will reduce CH_4 emissions at the landfill site.

Hydrology and Water Quality

All water used at the site is city water and wastewater discharges are to the city's sanitary sewer. Water used by the proposed anaerobic digestion unit will also be city water with discharge to the city's sanitary sewer. No water from project operations will be discharged to the soil or to the storm water system.

Noise

The SATS site currently does not have operations to generate any noise. The proposed anaerobic digestion unit will create a low level of noise from the pumps and compressors used for operations.

There are no noise sensitive receptors next to the SATS site. The nearest residence is one mile to the east of the site.

Odor

There are no objectionable odors currently at the site. The proposed anaerobic digestion facility will not create objectionable odors as the digestion activities and biogas production occur in vessels and the biogas is piped to its end use.

Public Services and Utilities

There are adequate public services and utilities currently at the site, including water, sewer, electricity, and NG for addition of the proposed anaerobic digestion facility to the site.

Transportation

The SATS site is serviced by adequate roads designed for traffic in industrially zoned areas.

Aesthetics

The proposed anaerobic digestion facility will be located in the northeast corner of the SATS property. The facility will not be visible from Fruitridge Road to the north. It may be visible from the east, west, and south, but only to commercial, manufacturing, and industrial facilities. The nearest residences located to the east will not be able to see the facility due to distance and the industrial and commercial facilities and buildings between the SATS site and the residences.

Land Use

The SATS site is currently zoned M-2 and currently maintains a Solid Waste Facility permit. The City of Sacramento has indicated an anaerobic digestion system at the SATS will require only a minor modification to the permitted uses in an M-2 zone.

Building Permits

City building permits will be required for construction of the anaerobic digestion facility.

Fire Department

The SATS is currently in conformance with applicable fire safety standards of the City of Sacramento Fire Department. The anaerobic digestion system will also need to meet City standards.

Solid Waste Permitting (Local Enforcement Agency [LEA] and CalRecycle)

The SATS site currently has a solid waste permit for the handling and transfer of MSW up to 348 TPD.

Anaerobic digestion of compostable materials such as food waste is regulated under CalRecycle, via Section 17850 et seq, Title 14, California Code of Regulations, and requires a composting facility permit if the waste is brought from off site. It is being proposed that the SATS site anaerobic digestion facility will be a research composting facility. This does not require a full composting permit, but rather just a LEA (Sacramento Environmental Management Department) Notification. The Notification application must be accompanied by a research plan and documentation from the local land use agency (see Land Use above) stating that such use is allowed and/or has been permitted for the site. Discussions have been held with the Sacramento County LEA and this Notification process was deemed acceptable for the site and proposed anaerobic digestion system

Air Quality

The proposed anaerobic digestion project at ARP will have a source of potential air pollutant emissions in the biogas flare unit, which is used to combust the produced biogas during initial startup of the system and when the biogas conditioning system and end-use equipment are shut down due to emergency or routine maintenance. Discussions with the SMAQMD staff and management found that the flare unit will require an air quality permit.

Wastewater and Storm Water Discharge

Sanitary sewer access is available on the SATS site. There is an existing Industrial Storm Water permit to which the anaerobic digestion system can be added.

California Environmental Quality Act (CEQA) Review/Environmental Impact Report (EIR)

The minor use permit modification from the City of Sacramento is not considered a discretionary decision and therefore CEQA does not apply.

2.3.2 American River Packaging, Inc.

The Site Evaluation Report recommended development of an 8- to 10-TPD anaerobic digestion facility at the ARP facility (Figure 5) in the Natomas area of Sacramento, California. The facility was constructed and has been operating since March 2011.

Figure 5: ARP Site

Photo credit: Clean World Partners, LLC

Summary

A Summary of the Site Evaluation Report for this site is below:

Address

American River Packaging, Inc., 4225 Pell Drive, Sacramento, CA 95838

Assessor's Parcel Number

#237-0400-027-0000

Owner

Massie & Company/Clara K. Massie Family, 1801 Tribute Road, Sacramento, CA 95815

Zoning

M-1 / S-R, Light Industrial & Assembly

Size

Parcel: 7.69 acres / 334,934 square feet

Manufacturing building on site: 96,000 square feet (including offices)

Products Produced

Corrugated containers (cardboard boxes and paper byproducts)

Typical Amount of Product Produced

13,000—18,000 tons per year (50—70 tons per business day)

Product Characteristics

Corrugated Linerboard has about 8—14 percent organic solid residue moisture content (MC).

Method of Managing Organic Solid Residue

Their waste is characterized as left over scraps of corrugated cardboard from the display manufacturing process. On-site waste is currently collected and sold to a recycler. Current market value is $150 per ton. Price for recycled waste has varied over the years from close to $0/ton to $180/ton.

Length of Production Season

365 days

Wastewater Production

Approximately 1,500,000 gallons/year (5,800 gallons/business day)

Wastewater Removal/Disposal

There is no wastewater treatment on site. All wastewater is discharged to the sanitary sewer system.

Potential Revenue Streams From Company's Waste Products

Anaerobic Digestion and Gasification of waste product to generate electricity for sale into grid and/or for use at facility (offsetting retail cost of electricity).

<u>Infrastructure</u>

Power (Including NG and Electrical Consumption and Costs)

Electrical use of 50,000—70,000 kilowatt-hours/month with electrical demand of 227—245 kilowatts. Unit retail cost of 13—14 cents/kilowatt-hour.

NG Use

Minimal, for office space and water heating.

On-site Process Heat Requirements

No process heat required. NG used for generation of hot water and space heating of office spaces. Manufacturing area not currently heated. ARP may require some space heating in manufacturing area during winter months.

Water Supply and Wastewater Discharge

Water supply to ARP site is city water. Water used primarily for cleanup and miscellaneous uses. Process of manufacturing cardboard containers does not use water. Quantity used is approximately 1.8 million gallons/year.

Cost of water plus discharge of wastewater to sewer (discharge quantity same as water use quantity) is $2.40—$2.75/1,000 gallons. Site also paying $777/month for fire service water capability, storm drainage, and street sweeping.

Wastewater discharge of about 1.8 million gallons/year. Discharge is to city sewer. Two three-inch lines go from building to four-inch line which discharges into main sewer line in street. Another 1,000 gallons/day of discharge from proposed anaerobic digestion plant may potentially be discharged into the four-inch line.

Height Restrictions

All anaerobic digester equipment will be below any height restrictions set forth by governing agency.

Truck Access Into and From Site

Two gated accesses off of Pell Drive (only one is currently used).

On-site Heavy Machinery (Front-end Loaders, Hauling Trucks, etc.)

None. Standard size forklifts used in yard and manufacturing areas.

Current Waste Disposal (Methods, Quantity, Frequency, Cost)

Corrugated linerboard disposed of in quantity of 13,000—18,000 tons/year. All sold to recyclers at various prices (current price is $150/ton). From five to seven bales of waste linerboard are generated per day and shipped via truck to recyclers.

<u>Feedstock Details</u>

Quantity and Type of Current Feedstocks (Including Their Security and Reliability)

13,000—18,000 tons/year of corrugated linerboard. Security and reliability is good. However, reliability depends on the price offered for the linerboard by recyclers, which varies over time.

Previous Characterization (If Available)

Not applicable

Rate and Frequency of Production of Anaerobic Digestion Feedstock Stream

ARP manufacturing operates Monday through Friday throughout the year and often on weekends and holidays, as customer demand requires.

Seasonality of Anaerobic Digestion Feedstock Stream

Waste output is relatively constant with a decrease in the past during winter months of 25—30 percent. The future decrease in the winter will be considerably less than this.

Collection Method and Delivery to Anaerobic Digestion System

Delivered by forklift from adjacent manufacturing facility.

Potential for Additional Feedstocks from Nearby Sources

An additional 20 tons per day has been identified at nearby McClellan Business Park that could be available. In addition, there is the potential for up to 10 times the amount generated at ARP if waste generated by ARP customers is returned when ARP products are delivered to customers.

Anaerobic Digestion System Installation and Operation Requirements Availability

Electric Needs and Host Facility Supply

The ARP host facility appears to be reaching its capacity with present electricity to supply both the anaerobic digestion system and its own internal electrical demand. This could be rectified by installing a larger electrical panel.

Heat Needs and Host Facility Supply

The anaerobic digestion system could supply its own heating needs, i.e., maintaining correct temperature on digestion vessels via a small NG fired water heater. An NG line tie-in can be obtained on the site.

Anaerobic Digestion System Overall Integration with Host Facility

Integration should be good for electricity, water, and wastewater discharge.

Water Supply and Wastewater Discharge Integration with Host Facility

Water could be supplied and wastewater discharged using host's infrastructure.

Labor for Operations, Routine Maintenance, and Repairs

There is available labor at the host site during business hours. After business hours and weekends would require nonhost site labor.

Land Use

The land upon which the anaerobic digester unit will be located is occupied by ARP, which produces cardboard and linerboard products. The ARP building occupies approximately 30 percent of the land with the remainder either paved with asphalt or consisting of bare soil. The land is flat with no water features such as ponds creeks or lakes. Surrounding land and land uses consist of similar industrial operations, a railroad, and streets. The nearest residences are approximately 600 feet to the east of the land.

Air Quality and GHGs

The ARP facility has no adverse air emissions as all machinery is operated with electric power from the grid. The cutting of cardboard and linerboard creates some dust, which is collected within the ARP manufacturing building. Inks used in the manufacturing process are all water based.

Hydrology and Water Quality

All water used at the site by ARP is city water and wastewater discharges are to the city's sanitary sewer. Water used by the proposed anaerobic digestion unit will also be city water with discharge to the city's sanitary sewer.

Noise

Noise from the ARP machines is largely contained within the ARP manufacturing building. The proposed anaerobic digestion unit will create a low level of noise from the internal combustion (IC) engine or gas turbine used to drive an electric generator. Any noise from the anaerobic digestion project can be easily mitigated by locating equipment within sound attenuating enclosures.

Odor

There are no objectionable odors currently at the site. The proposed anaerobic digestion facility will not create objectionable odors.

Public Services and Utilities

There are adequate public services and utilities currently at the site, including water, sewer, electricity, and NG for addition of the proposed anaerobic digestion facility to the site.

Transportation

The site is close to a major freeway and access to the site from the freeway is direct via paved surface streets.

Aesthetics

The proposed anaerobic digestion facility will be located in the northeast corner of the ARP 7.7 acre property. The facility will not be visible from either the freeway to the south or to major streets to the north, west, and east of the property. No residences located to the east will be able to see the facility due to industrial and commercial facilities and buildings between the ARP property and the residences.

Land Use

Site is currently zoned M-1 (light manufacturing). The proposed anaerobic digestion system is considered a minor recycling facility by the City of Sacramento. Procedures in the City Code Section 17.24.050 Item 41 allow the operation of a recycling facility within the M-1 zone through the issuance of a Zoning Administrator's special permit.

<u>Building Permits</u>

City building permits will be required for construction of the anaerobic digestion facility.

Fire Department

ARP currently has a fire department permit.

Solid Waste Permitting (LEA and CalRecycle)

Anaerobic digestion of compostable materials such as cardboard is regulated under CalRecycle, via Section 17850 et seq, Title 14, California Code of Regulations. However, discussions with CalRecycle staff and management indicate that since the feedstock to be used is both generated and processed into biogas on site, a permit from CalRecycle, via the LEA (Sacramento Environmental Management Department), is not required. If additional cardboard waste or food waste is brought to the site, it may need a full composting permit.

Air Quality

There are currently no air quality permits required by the SMAQMD for existing operations at ARP. No volatile organic compound (VOC) containing products are used by ARP, as all inks used to label packing products are water based.

The proposed anaerobic digestion project at ARP will have a source of potential air pollutant emissions in the form of a biogas flare unit, which is used to combust the produced biogas during initial startup of the system and when the biogas conditioning system and end-use equipment are shut down due to emergency or routine maintenance. Discussions with the SMAQMD staff and management found that the flare unit will require an air quality permit.

Wastewater and Storm Water Discharge

All wastewater from the proposed anaerobic digestion facility will be discharged to the sanitary sewer. Currently no permit for discharge is needed at the facility. Additional wastewater from the anaerobic digestion unit (approximately 1,000 gallons per day) will not exceed any thresholds such that a discharge permit would be required.

CEQA Review/EIR

The Special Use Permit from the City of Sacramento requires initial CEQA review. However, given the size and nature of the project, and its location in an M-1 zone with no nearby sensitive receptors, there will be no need for an EIR.

CHAPTER 3: Technical, Environmental, and Economic Feasibility

3.1 Key Findings and Conclusions

In Task 3, CWP utilized the Site Evaluation Report in Task 2 to develop and submit a Feasibility Study that demonstrates that a "Preferred Project" renewable biomass system is feasible. This "Preferred Project" at SATS was designated based on the ease of permitting, availability of private investment, proximity of substantial feedstock streams, site control, and the receptivity of a major waste hauling partner to support financing, management, and operations. The Feasibility Study found that the SATS site was technically, environmentally, and economically feasible for an anaerobic digestion system. Based upon this Feasibility Study, a 25-TPD system is under construction at the SATS site and scheduled to be operational by late 2012. A scale-up of the facility to 100 TPD is scheduled to be complete by mid-2013.

3.2 Summary of Activities Performed

In Task 3, CWP performed the following tasks:

- Submitted a Technical and Environmental Feasibility Study which demonstrates that the proposed CWP system is technically and environmentally feasible (Task 3.1).
- Performed an economic and market analysis for the "Preferred Project" including coproduction of value-added products such as CNG, heat, auxiliary power, fertilizer, soil amendments, and water (Task 3.2).
- Developed a plan to make the knowledge gained, results demonstrated, and lessons learned available to decision makers in industry and government and prepared a commercialization plan for the deployment of integrated biomethane production systems for transportation application (Task 3.3).

3.3 Description and Results

The three subtasks are described below.

3.3.1 Assessing Technological and Environmental Feasibility

In February 2011, CWP submitted a completed Technical and Environmental Feasibility Study that included a detailed examination of economic, technical, and financial feasibility. The Study included financial projections, raw materials evaluation, a sensitivity analysis, and a risk analysis, as well as management feasibility determination and recommendations for implementation.

Critical issues evaluated in the Feasibility Study included:

- Economic feasibility determination
- Project site information

- Availability of trained labor
- Technical feasibility determination
- Basis for technical feasibility determination
- Project operation and development costs
- Financing feasibility
- Projected balance sheets and costs
- Cash flow projections for the life of the project
- Sensitivity analysis
- Project risk
- Environmental and permitting feasibility
- Project zoning
- LEA
- Air permitting
- CEQA status
- Feedstock
- Feedstock source management
- Feedstock collection, pretreatment, transportation, and storage

3.3.1.1 Results and Key Findings

The Feasibility Study found that both a 25-TPD and a future 100-TPD scale-up anaerobic digestion system at the SATS was technologically and environmentally feasible. Key findings from the Feasibility Study are presented below.

Capital Costs

Capital costs to design, fabricate, and construct the 25-TPD system were estimated to be between $4.1 million and $4.775 million, dependent on the availability of energy tax credits.

Operating Revenues

Revenues grow from approximately $1.3 million in Year One to $6.068 million in Year Four. Operating revenues are generated from the sale of granular fertilizer, RNG, hauling and tipping fees, incentives, compost, and electricity. Nearly 50 percent of operating revenues are from the sale of various products that utilize system digestate.

Operating Costs

Costs of $710,000 in Year One grow to $2.925 million in Year Four. Operating costs include fertilizer additives, depreciation, compensation, equipment repair and maintenance, administration, and rent. Nearly 50 percent of operating costs are from additives and other inputs necessary to process and market system digestate.

Net Present Value

The project's net present value was calculated over a 20-year period at a 6 percent discount rate. SBR1 was estimated to produce a net present value of $8,222,939 and an IRR of 22.2 percent per year. Public incentives, including design and construction grants, tax credits, RINS credits, and the California Alternative Energy and Advanced Transportation Financing Authority (CAEAFTA) sales tax exemption are critical to supporting an acceptable internal rate of return.

Re-use of Public Property

Placement of an anaerobic digestion system on the SATS site presents a distinct opportunity to re-use previously underutilized property. The site had been abandoned for nearly a decade. Previously, it had been an industrial site that served as a transfer station for the County of Sacramento. The site currently has no value to the local community.

LEA and CEQA Status

CWP communicated with the LEA for the project—The County of Sacramento, California, Community Development Department, Planning Division—and received notice that the proposed scale-up does not qualify as a project and counts, instead, as a minor modification to a Previous Approval, requiring only ministerial action. Section 17862 of Title 14, CA Code of Regulations, allows the proposed SBR1 100-TPD facility to be a research composting facility. SBR1 already has this designation approved by the Sacramento County LEA. The LEA Notification requires that the local land use agency (County of Sacramento, California, Community Development Department, Planning Division) is notified of the pending research composting activities and determines the CEQA process, if any, necessary for the project. The City's determination is that the special permit minor modification does not require further CEQA review. The project team expects to have a letter of approval from the LEA by March 15, 2012. CWP has attached a letter from the County of Sacramento stating that it is indeed the appropriate LEA, has jurisdiction for the project, and has discussed the required level of CEQA review with CWP.

Air Permitting

The existing SBR1 air permit from the Sacramento Metropolitan Air Quality Management District was issued on January 21, 2011, (Authority to Construct No. 23289). This permit was for the biogas flare to be used in order to safely vent biogas. The permit can be modified to include up to two 250 kW ultra-low emission Flex Energy Systems Inc. microturbines (or equivalent), and an increase in the limit on biogas flare use. This process should take less than 60 days and would be completed by May 1, 2012.

3.3.2 Market Analysis and Economics of Biomethane for Transportation Application

In October 2011, CWP submitted a completed Market Analysis and Economics of Biomethane (Task 3.2A) for Transportation Application report. This report presented an economic and market analysis for coproduction of value-added products such as renewable CNG, heat, auxiliary power, fertilizer, and water.

Critical issues evaluated in this Report included:

- Market analysis of biomethane for transportation
- Benefits of RNG as a transportation fuel
- Price point analysis and optimal pricing for fuel
- Pricing strategy
- Economic analysis
- Overview of anaerobic digester financing options
- Project-specific financing options

3.3.2.1 Results and Key Findings

3.3.2.1.1 Benefits of Conventional (Fossil) NG as a Transportation Fuel

Using any form of NG lowers exhaust emissions and GHG emissions compared to petroleum fuels. The actual emissions profile will depend on the engine design, but a good estimate was done by the United States Environmental Protection Agency (U.S. EPA) in 2002 based on the cleaner burning characteristic of NG.

The potential emission benefits of fossil CNG compared to gasoline, from U.S. EPA calculations, are:

- Reduced carbon monoxide emissions 90—97 percent
- Reduced carbon dioxide (CO_2) emissions 25 percent
- Reduced nitrogen oxide (NOx) emissions 35—60 percent
- Potentially reduced nonmethane hydrocarbon emissions 50—75 percent
- Fewer toxic and carcinogenic pollutants
- Little or no particulate matter
- Eliminated evaporative emissions

3.3.2.1.2 Representative CH_4 Use in Fleets

Currently, there are few users of RNG as a transportation fuel. However, there are a great number of vehicles using conventional NG. The distribution, dispensing, and use of NG as a vehicle fuel is well proven and developed, and market acceptance of NG as a vehicle fuel is increasingly rapid and widespread.

CALSTART, a subcontractor on this project, conducted an extensive inventory analysis of the California truck fleet. The data from this analysis of NG-fueled trucks is shown in Table 1.

Table 1: California Truck Fleet Usage

Class	Vehicles	Avg. NG Usage/yr. (gallons)	Total NG Usage/yr. (gallons)
2C	225	1,783	401,175
4	424	9,206	3,903,344

Class	Vehicles	Avg. NG Usage/yr. (gallons)	Total NG Usage/yr. (gallons)
5	56	2,976	166,656
6	493	16,299	8,035,407
7	1,516	10,016	15,184,256
8	4,673	41,583	194,317,359
Total	7,387	81,863	222,008,197

Source: Clean World Partners, LLC

An important factor to consider, for fleets not already using CNG/liquefied natural gas (LNG), is the cost for the fueling station. Such stations can cost millions of dollars and impact the business decision to shift to CNG/RNG. A rule of thumb is that a fleet must use over 60,000 diesel gallon-equivalents (DGE) per year to justify a station of their own. Public access stations often have a "throughput" requirement of 300,000 DGE/year or more.

The size of fleet needed to reach this threshold can be determined from the CALSTART data. Obviously the size of the truck matters: It takes only two class 8 trucks to reach the dedicated fueling station level of usage, but it would take eight school buses, each of which uses approximately 7500 DGE/year.

Transit but fleets are often cited as a significant market for RNG is. CALSTART is working with transit fleets that combined have over 5,000 buses running CNG/LNG. That number of buses consumes more than 80 million DGEs per year (with each bus consuming over 16,000 DGEs annually). Some city buses use over 19,000 gallons/year depending on routes, idle time, and other factors. Refuse fleets are another obvious target. Those vehicles are usually class eight and have very high fuel consumption, generally in the range of 12,000—15,000 gallons/year. The largest LNG dispensing station in the world serves the Los Angeles Sanitation Department, which operates more than 400 LNG-powered refuse trucks out of a total fleet of approximately 700 vehicles. This facility also provides a critical fueling location for a variety of other city-owned NG-powered vehicles, including street sweepers, transit buses, aerial lift trucks, dump trucks, passenger vehicles, and a variety of other vehicles in different applications.

Other "captive" fleets are appealing candidates for RNG: port drayage trucks, airport circulators, and (as mentioned above) city fleet vehicles. Often the challenge is delivering the RNG to the fleet location. The transportability of liquefied RNG is a benefit, until such time as pipeline delivery is more common.

As a simple scenario, we can look at the RNG demand generated by various fleet conversion rates. Given an RNG facility that can generate 71,000 MMBtu/year, or roughly 526,000 DGE/year, the output could serve:

- A transit bus fleet of about 33 buses
- A package delivery fleet of roughly 25 class six step-in vans and 14 class four vans

- A port drayage fleet of 13 class eight trucks
- A port drayage fleet of 15 trucks on an RNG85 (85 percent RNG) blend
- A city general purpose fleet of over 100 mixed trucks
- A school district with up to 70 buses

3.3.2.1.3 Pricing Strategy

Current pricing of RNG in California is largely anecdotal. The few companies using RNG as a transportation fuel keep their internal costs closely guarded. Waste Management uses CNG in a growing portion of its vehicle fleets, but will not release its costs of production or equivalent 'in-market' pricing. Hilarides Dairy has estimated its costs at under $2.00 per DGE but it is felt the Hilarides project is an exception in the level of hands-on work done by the owner, and several unique factors that don't apply to larger projects.

A 2009 estimate made by the U.S. EPA's Landfill Methane Outreach Program proposed that a large landfill-to-liquefied RNG project would have a cost of $0.65/gallon. That low cost came with a number of requirements: $20 million in capital investment, at least 3,000 standard cubic feet per minute (SCFM) of landfill gas (i.e., a large landfill), and the production of at least 15,000 gallons of liquefied RNG per day. For reference, Waste Management's Altamont plant produces 13,000 gallons per day, and the new Simi Valley plant will produce over 20,000 gallons per day. These data lend credence to anecdotal information that the Altamont plant has costs around $0.80/DGE.

A CALSTART study in 2010 examined the cost to produce an MMBtu of RNG from dairy manure. That study indicated an approximate range of $7.00—$11.00 per MMBtu.

The AGA/GTI study also endeavored to estimate production costs (capital expense and operating expense). Nationally, the estimate for average unit energy price under the study's "aggressive" scenario was from $6.00—$12.00 per MMBtu.

For California specifically, the AGA/GTI study estimates the following (again under the "aggressive" scenario):

- Capex: $26.39/MMBtu
- Opex: $8.06/MMBtu

In addition to this data, the report included a survey of industry experts conducted in September 2011. In sum, the following pricing conclusions can be drawn:

- Typical price for an MMBtu of RNG (not including credits): $8.00—12.00
- Target (preferred) price for an MMBtu (for projects seeking financing): $15.00

The consistency of the ranges across a variety of sources is encouraging and leads to confidence in the estimates for production costs and hence potential pricing in the market. This range of costs would translate to $1.08—$2.02 per DGE. "At-the-pump" prices would necessarily be higher. Fossil NG is (per the Energy Information Administration 9/14/11) $4.04/MMBtu on futures contract, which is equivalent to $0.55/DGE.

The ability to transfer these pricing ranges to actual selling prices for RNG as a transportation fuel is somewhat limited, as there is no true market yet. Transportation use will have to compete with the "Renewable Portfolio Standard (RPS) credit supported" price that utilities are willing to pay for RNG. Larger users (utilities, transit fleets) often have long-term purchase agreements and the negotiated price is a complex mix of factors.

For a market to grow, clearly RNG must have a value assigned to the benefits it provides: GHG reduction, renewability, etc. One very viable approach is blending – the gas equivalent of E85. Mixing RNG with fossil NG would mitigate the higher cost of RNG, while also accommodating limited production volumes in the early stages of market development. As production increases and costs come down, the percentage of RNG to fossil could be increased, with commensurate emissions benefits.

Once the CEC funded projects begin to come on line, the price for RNG will change due to increased supply. By the same token, it is believed there is significant latent demand. Transit fleets in particular are high-volume users of NG and are under pressure to reduce emissions and GHGs, so RNG should be appealing to fleet operators.

3.3.2.1.4 Overview of Anaerobic Digester Financing Options

In our review of potential financing programs for the various renewable energy projects under consideration, we were able to identify a number of options. The options that we felt were most applicable to those projects are described in detail below and include:

- California Pollution Control Financing Authority Tax-Exempt Bond Program
- CalRecycle Recycling Market Development Zone Loan Program
- California Statewide Communities Development Authority Tax-Exempt Bond Program
- New Markets Tax Credits Financing Program

3.3.2.1.5 SBR1 Financing Options

After reviewing the various financing programs available, CWP elected to analyze the financing structures from the California Pollution Control Financing Authority Tax-Exempt Bond Program, the Recycling Market Development Zone Loan Program, and the New Markets Tax Credits Financing Program. We excluded the California Statewide Communities Development Authority Tax-Exempt Bond Program because it is nearly identical to the program offered by the California Pollution Control Financing Authority except that it involves a joint powers authority rather than a state agency.

For this project, calculations show that while all three options generate positive cash flow and are viable options to finance the project, the CalRecycle Recycling Market Development Zone loan program generates the highest positive cash flow. The primary reasons the CalRecycle loan performs best in this case are the short term and low subsidized costs associated with this financing.

While the CalRecycle loan program may perform best purely on financial criteria, there are other nonfinancial factors to consider as well. One important consideration is administrative requirements. For example, the CalRecycle loan program only allows up to 75 percent of the project to be financed, up to a maximum of $2 million, which means that cash, grants, or other financing would need to make up the difference. Further, only $3 million of principal can be outstanding for any single organization, which means that this program could likely only be used toward one or two projects. Another important consideration to bear in mind is the timing needed to complete the financing.

Overall, there are several financing options that are well suited for this project. Deciding on which financing option to pursue is ultimately dependent upon a number of factors including the financing costs, the administrative requirements, and the timing of implementation. These factors should all be incorporated into the decision-making process when choosing the most appropriate financing for SBR1.

3.3.3 Commercialization Plan

In October 2011, CWP submitted a completed Commercialization Plan (Task 3.3A). This plan presented the basis for deployment of the proposed system.

Critical issues evaluated in this report included:

- Market focus
- Market drivers and barriers
- Policy drivers and barriers
- Technology drivers and barriers
- Key steps for market growth
- Competition

3.3.3.1 Results and Key Findings

3.3.3.1.1 Customer Groups

There are three broad customer groups described in the commercialization plan that are critical to the successful execution of anaerobic digestion projects. The commercialization strategies of RNG as a transportation fuel are the main focus of the plan. The three main consumer groups are as follows:

- Producers of organic waste, waste collectors, and disposal facilities. Since organic waste contributes to GHG accumulation as it breaks down, many organizations are focused on eliminating use of traditional disposal methods such as landfilling, composting, and land application. These organizations are looking to increase sustainability performance, while taking advantage of increased diversion credits and revenue opportunities.
- CNG fleet operators. Early deployment will focus on users who already have adopted CNG as the primary fuel for their fleet operations. These organizations tend to be government agencies, waste hauling operators, public transportation organizations, and fortune 500 companies (UPS, AT&T, etc.).
- Policy makers, government agencies, and other stakeholders. These organizations want the benefit from Anaerobic Digestion system developments and continue to make changes to laws that demand its use (AB 32. RPS, etc.), although there are numerous

policies contributing to the slow deployment of the technology. Projects such as CWP's SBR1 will help these organizations feel more comfortable with anaerobic digestion as an application, allowing them to make changes that will contribute to quicker deployment.

3.3.3.1.2 Technology Drivers and Barriers

Technology barriers are often a major hurdle for renewable energy. In the case of RNG, the basic technology is well proven and has existed for decades. Advances are, of course, occurring and are of significant importance in making RNG a viable fuel source.

Unlike many other renewable energy technologies, particularly renewable transportation fuels, no fundamental innovations or breakthroughs are required to produce RNG in commercial volumes. Similarly, no technological roadblocks prevent the use of RNG in transportation. Across all sizes and types of vehicles, from light-duty to class 8, NG (the fossil equivalent of RNG) has been proven as a fuel.

Since no technological barriers exist, the work needed is incremental and focused on improving the business case. The first order of business is to increase demand for the product, from which increased volume will follow. These technology improvements would contribute to increasing demand:

- Lowering gas cleanup technology costs and other costs of production
- Supporting trial projects and testing of RNG in all classes of vehicles
- Producing RNG engines that deliver near-zero tailpipe emissions
- Lowering costs for CNG/RNG systems in vehicles

3.3.3.1.3 Policy Barriers

Regulatory drivers, benefits, and barriers are the issues most commonly referenced in RNG discussions. As with other renewable energy efforts, adoption is currently driven by government action (regulations, incentives, grants, and other activities). Such policy-driven work is critical to advancing RNG in transportation, given the dynamics of the market for transportation fuels in the US.

To make greater use of RNG, the economic playing field needs to be leveled. Technology is not the issue. Presently, at the federal level, there is a significant tax credit for using biogas (a less pure form of RNG) to produce electricity, but no similar credit for fuel that has been cleaned and inserted into a pipeline or used in the transportation sector. Many fleet operators elect to use the fossil form of CH_4, NG, because it is much cheaper and easier to obtain.

A critical barrier for RNG deployment is transporting the fuel to the fleet operators. Not every waste creator has a need for RNG in their fleet operations Most RNG fleet operators do not have enough organic waste to fuel their fleets. In order for RNG to flourish as a fuel of choice, the industry must find a way to work with utilities to inject the RNG into the regional NG network and designate the gas to a particular customer.

Today, utilities are not working very hard to allow this and are keeping the costs of doing so exceptionally high, preventing these fuels from being easily transported to customers who can use RNG. While utilities are required to increase their RPS to 33 percent by 2020, they are largely planning to do so through solar, wind, and geothermal sources—not biogas. Biogas sources generally produce small quantities and are treated more like distributed generation systems and not large scale utility use. If the industry can find an economical way to insert the fuel into the NG pipeline and be granted the authority to do this by the utility companies, anaerobic digestion projects will flourish, as the gas can then be marketed more like a commodity.

3.3.3.1.4 Competition

Direct Competitors

Currently, Microgy, Orbit Energy, and Harvest Power (formerly Beckon USA) are the most prominent direct competitors with comparable business models.

Much of the competitive landscape consists of European companies that are developing systems abroad, but have begun to look at the California market. These organizations are generally licensing their technology to startup companies looking to play in this space. These organizations have the benefit of strong experience in deploying their technologies in Europe, where tipping fees run an average of $140 US per ton. The high capital expense of these facilities will allow for slow deployment since the revenue does not exceed the CAP X and operating expenses.

Waste companies that own their own landfills will be the most significant competition from within the hauling industry. They have traditionally protected the "status quo" because landfills provide significant EBITDA protection. Independent haulers may also provide competition, although this scenario is less likely because they currently pay disposal fees to the landfill operators. It is CWP's belief that the "MRF First" concept of locating waste to energy technologies at independent hauler facilities will be the optimal solution long term. Since most properties are land locked and do not possess necessary air and water permits this will take some time.

Indirect Competitors

- **Anaerobic digestion technology companies**: As anaerobic digestion companies become more sophisticated and profitable, they may begin to offer turnkey solutions to customers through the design/build/own/operate option. Most successful anaerobic digestion companies are based in Europe and use expensive high water/large tank models, although the US market is picking up momentum. Some of these companies include Dranco (Belgian); Linde (German); Biopercolat (German); ISKA (German); Waase (Finland); Valorga (French); APS (US); Bioconverter (US); Arrowbio (Israel); Ros Roca (German); Entec (Austria); OPS (US); Andigen (US); NewBio (US).
    - **Threat management:** Establish licensing agreements and/or invite the companies to participate in developed projects via an RFP process.
- **Waste haulers:** The large waste haulers have been operating in a relatively consistent and profitable environment for many years. Most have ownership of, control over, or relationships with the landfills and would therefore be resistant to hauling any portion of

the waste stream to an offsite anaerobic digestion facility. Some of these companies are Waste Management, Allied Republic, and Waste Connections.

  - **Threat management**: Establish waste agreements as an alternative to landfill disposal. When possible, joint venture projects are particularly desirable. Acquisition by a large waste hauling company is a possible exit strategy.

- **Landfill owner/operators and recycling operators:** This group of indirect competitors would see a portion of their waste streams diverted to offsite anaerobic digestion facilities. Several are exploring the addition of anaerobic digestion technology at their facilities, although the current regulatory environment and its increasing demands are limiting their ability to pursue this option. Competitors in this area include cities and counties, private landowners, Waste Management, Allied Republic, and Waste Connections.
  - **Threat management**: Joint venture on-site anaerobic digestion project development. Also, CWP can beat them on price, given its back-end revenue advantage.
- **Engineering firms specializing in anaerobic digestion**: These firms specialize in being comprehensive solutions providers and could provide competition when customers are considering developing and owning the anaerobic digestion systems.

3.3.3.1.5 Commercialization Considerations

If anaerobic digestion technology paid for itself strictly on high-solid waste streams, it would already have reached widespread market adoption. The problem in California is not a lack of desire or interest, but rather an economic problem restricting anaerobic digestion deployment. With an average tipping fee of $30/ton (compared to $160/ton in Europe), it is still much cheaper to landfill waste.

The Anaerobic Phased Solids technology proposed here shows exceptional promise in lowering anaerobic digestion deployment costs because it has only a 21-day retention time (as compared to 28 days for most European technologies) and can process high-solids waste (≥ 20 percent) in the vessels. Because it works faster and is capable of processing high-solids waste, the Anaerobic Phased Solids Digester can utilize smaller reactor vessels, lowering the initial capital cost of the anaerobic digestion components by 30—40 percent and enabling a faster market deployment.

The Anaerobic Phased Solids pilot at UC Davis has attained 90 percent reductions in total solids (TS) and volatile solids (VS); provided biogas (60 percent CH_4) at a rate of 4,600 cubic feet per ton; and maintained steady-state conditions consistent with full-scale CH_4 production. The pilot performance has provided a valuable, dependable basis for designing a full-scale system and for predicting full-scale operating conditions at SBR1. Design of reactor vessels, gas conditioning equipment, and instrumentation and control will be based on the pilot and can be easily scaled-up. The design approach and construction methods for the full-scale Anaerobic Phased Solids system are typical for the U.S. chemical processing industry. A desirable feature of the Anaerobic Phased Solids technology is its flexibility and adaptability to handle different feedstock wastes and its easy scalability by providing additional reactor volume.

3.3.3.1.6 New Site Opportunities

In California alone, there are 357 fully permitted transfer and processing facilities, all of which may accept and process waste using anaerobic digestion technology with only slight modifications—or in some cases revisions—to their existing permits as long as waste volumes do not exceed those currently allowed. For the purposes of commercializing the proposed technology, Atlas partner and CWP will focus only on facilities designated as "large volume transfer/processing facilities," as defined in Section 17402, (8), of Article 6, Chapter 3, Title 14, of the California Code of Regulations. A "large volume transfer/processing facility" is one that receives 100 tons or more of solid waste per operating day for the purpose of storing, handling, or processing the waste prior to transferring it to another solid waste operation or facility. These larger facilities represent CWP's primary target market. In California, there are currently approximately 100 such facilities.

3.3.4 Technology Transfer

In October 2011, CWP submitted a completed Technology Transfer Plan (Task 3.3B). This plan presented the basis to make knowledge gained, results demonstrated results, and lessons learned available to decision makers in industry and government.

Critical issues evaluated in this Report included:

- Market analysis
- Outreach and education

3.3.4.1 Results and Key Findings

3.3.4.1.1 Market Analysis

According to the U.S. EPA, Americans dump nearly 225 million tons of MSW in landfills every year (EPA, *Municipal solid waste in the United States: 2005 facts and figures*. 2005, US Environmental Protection Agency, Office of Solid Waste: Washington, D.C.). Between 25—40 percent of this waste stream is made up of food and agricultural waste, which, if left untreated, are major sources of harmful GHG emissions. In fact, emissions from such types of organic waste are 72 times more harmful than emissions from automobiles.

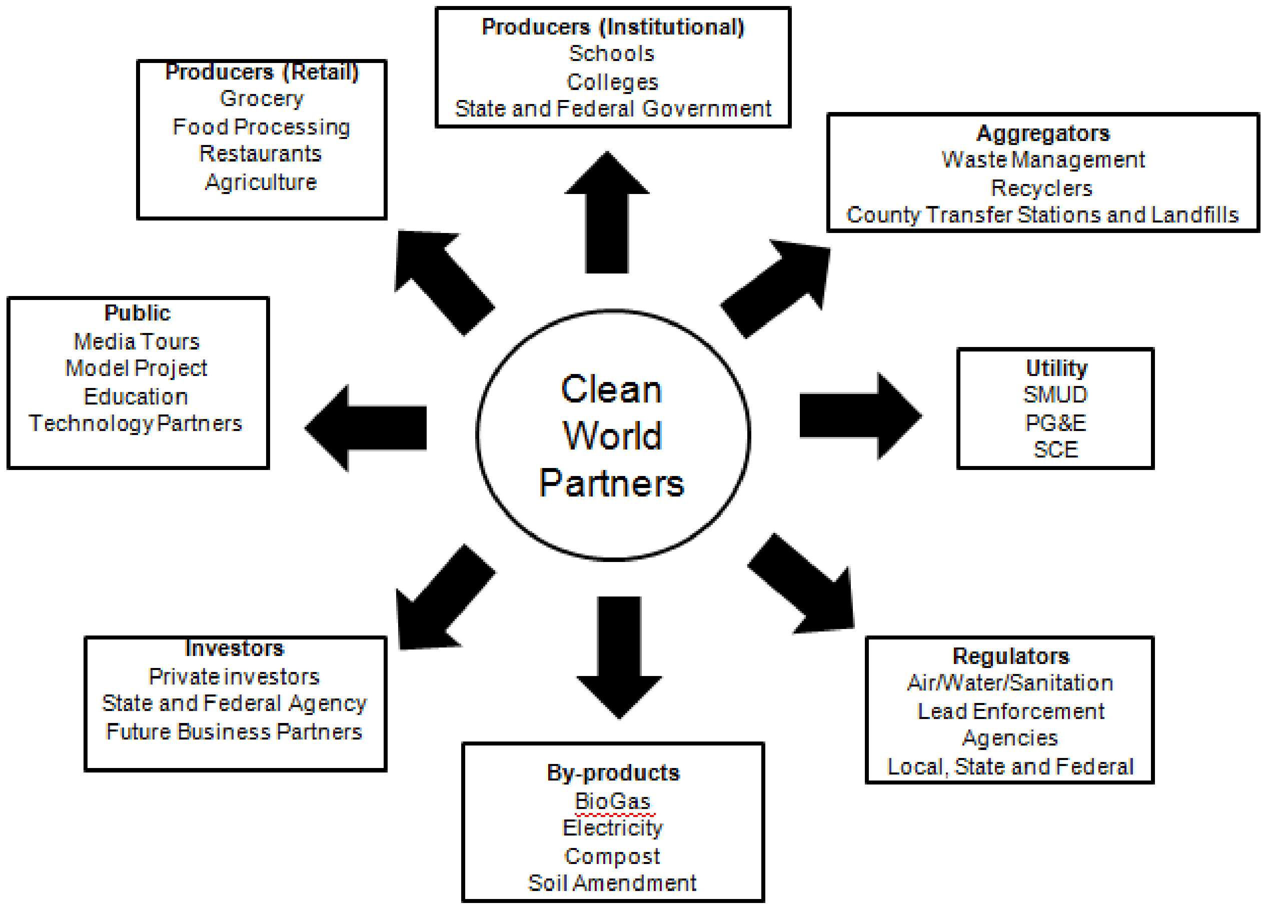
In California, private citizens, businesses, and public organizations landfill approximately 16 million tons of organic waste every year at an average cost of $40 per ton, or roughly $640 million per year. Over the next 25 years, California's population is projected to increase by 10 million people. In that time, Californians will add an additional **one billion tons of MSW** to landfills, much of it in the form of organic waste.

To reduce this waste stream and substantially reduce the resulting harmful GHG emissions, particularly CH_4, California has enacted strict mandates that require businesses, utility companies, and public agencies that produce high volumes of organic waste to seek more sustainable waste disposal solutions. These mandates, enacted through legislation, agency directive, and gubernatorial insistence, support dramatic expansion of waste to energy technologies and affirm Atlas Disposal's marketing and commercialization pathway.

3.3.4.1.2 Outreach and Education

The SBR1 facility is designed as a model for California that demonstrates a waste-to-transportation fuel technology that initially utilizes 25 TPD in organic food and green waste. The extent of CWP's communication and outreach targets is displayed in Figure 6.

Figure 6: Communication and Outreach Targets



Source: Clean World Partners, LLC

The facility represents tremendous cost efficiencies with dramatic improvement in the capture of nitrogen (N) and a new business model that reduces transportation costs for processed waste. This enhancement will serve as the platform for an extensive outreach and communication effort by CWP that includes both direct and indirect outreach to diverse producer audiences. CWP will publish and distribute research and demonstration papers to agencies, producers, and technical advisors throughout the United States. Additionally, CWP will invite elected officials, university representatives, industry leaders, agency officials, researchers, and technicians on tours of the completed facility, showcasing the improvements in renewable energy production and nutrient management at SATS. CWP will work to assist Californian and other American universities, as well as NRCS and USDA offices, in updating nutrient recommendations and technical guides relating to nutrient management. Demonstration materials will be available on company websites and made available to the broader research community. At agriculture and food-related conferences and tradeshows, CWP will also distribute brochures that highlight the consumer benefits of food grown on healthy soils, as well as the attendant environmental and ecosystems benefits.

3.3.4.1.3 Technology Transfer

Technology Transfer is the effort to make the results and knowledge gained from this study available to the Waste to Energy (Clean Energy) Industry and key decision makers. CWP researched and identified industry associations for possible membership to increase exposure of this technology (Table 2). CWP will ask to be listed in these associations' databases and to post the lessons learned from this study on their websites. This information will also be made available for presentations in future meetings.

Table 2: Potential Identified Partner Associations

Association Name	Acronym/ Abbreviation	Web Address
Advanced Biofuels Association	ABA	ABA (http://www.advancedbiofuelsassociation.com/)
American Biogas Council	ABC	ABC (http://www.americanbiogascouncil.org/)
American Council on Renewable Energy	ACORE	ACORE (http://www.acore.org/)
American Society for Agricultural and Biological Engineers	ASABE	ASABE (http://www.asabe.org/)
Biotechnology Industry Organization	Bio	Bio (http://www.bio.org/)
BioCycle		BioCycle (http://www.biocycle.net/)
Bio-Energy Interagency Working Group	BEWG	BEWG (http://groups.ucanr.org)
California Biomass Collaborative	CBC	CBC (http://biomass.ucdavis.edu)
Association of Compost Producers	ACP	ACP (http://www.healthysoil.org)
California Refuse and Recycling Council	CRRC	CRRC (http://www.crrcnorth.org)
CALSTART		CALSTART (http://www.calstart.org)
Clean Fuels Development Coalition	CFDC	CFDC (http://www.cleanfuelsdc.org)
Energy Institute		Energy Institute (http://www.energyinst.org)
Natural Gas Vehicles for America	NGVA	NGVA (http://www.ngvc.org/)

Association Name	Acronym/ Abbreviation	Web Address
Renewable Fuels Association	RFA	RFA (http://www.ethanolrfa.org/)
Teru Talk (Michael Theroux)		Teru Talk (http://www.terutalk.com)
US Composting Council	USCC	USCC (http://compostingcouncil.org/)

Source: Clean World Partners, LLC

CWP also plans to educate decision makers through public forums, workshops, and industry conferences such as the annual BioCycle conference, the Biomass Collaborative sponsored by UC Energy Week at UC Davis and the US Composting Council meeting. CWP is planning on attending the American Society for Agricultural and Biological Engineers, the Alternative Clean Transportation Act Conferences, Waste and Conversion Congress (west coast), and the Biogas West Conference in future years to raise awareness for this technology.

The CWP website will also be used to disseminate this information, and CWP will encourage the associations in which it holds membership to also make the report available on their websites. This will allow the public to learn about CWP's anaerobic digestion technologies and feasibility determinations from this study. CWP will also have a link on their website for potential customers to fill out a survey with their waste stream information that will allow CWP's engineers to evaluate the technical, financial, and economic feasibility of the potential site for an anaerobic digestion system generating transportation fuels with the information they gathered from this study.

CHAPTER 4: Performance and Materials Testing

4.1 Key Findings and Conclusions

In Task 4, CWP prepared and submitted a Feedstock Characterization Report, which determined the feedstock dependent parameters to properly size and estimate material handling and anaerobic digester performance. CWP also determined feedstock stream suitability for digestion and energy production potential, digester sizing and estimated performance parameters.

4.2 Summary of Activities Performed

In Task 4, CWP performed the following tasks:

- Submitted a Feedstock Characterization Report that quantified key physical and chemical characteristics of the feedstock streams (Task 4.1).
- Submitted a Laboratory Digestion Test Results report that presented lab and pilot scale digestibility studies of food and other organic waste streams and identified test parameters to be measured including biogas and CH_4 yields (Task 4.2).
- Prepared plant specifications, including operating and design parameters.

4.3 Description and Results

The Task 4 subtasks are described below.

4.3.1 Analyze and Characterize the Physical and Chemical Properties of Feedstock for Bioenergy

In March 2012, CWP submitted a completed Feedstock Characterization Report that quantified key physical and chemical characteristics of the feedstock streams. CWP collected representative samples of biomass feedstock and tested samples for MC, TS, and VS content, inorganic or nondegradable content, and bulk density and compressibility. Additionally, samples were analyzed for nutrients, metals, micronutrients, and chemical composition. A Feedstock Database was also developed in this task (Task 4.1).

4.3.1.1 Technical Considerations for Feedstocks

Feedstocks that have adequate N levels are more attractive technically because they enable the bacteria to break down the feedstock without an artificial N additive. The more uniform the feedstock, the more efficient the digestion because the bacteria's digestion will not be slowed by feedstocks that are slow or impossible to digest. Feedstocks such as food waste, which have higher energy levels, are also better economically because they will produce more biogas. The closer and easier a feedstock is to load into the digester, the less expensive the front end of the anaerobic digestion system will be.

Another important factor that contributes to the expense of front-end processing is the variability of contents within the feedstock. The basic steps in processing the feedstock include receiving the feedstock, separating contaminants, grinding, and transporting to the digesters. The most complex element in the processing stages is the separation techniques. Using the case of the food waste collection program, the front-end processing is vitally important in separating organic waste from the undesirable nonorganic waste. Although the feedstock is source separated, contaminants such as metals, plastics, paper products, and glass still exist. To efficiently operate the digesters, it is essential to separate out these products. The front-end processing thus increases in both size and cost as extra measures are taken to prepare the feedstock for the digesters. Although the capital cost increases, the value of successfully adding the front-end processing equipment allows the market for creating biofuel to grow. A good case for the implementation of separation equipment and technologies exists in Europe, where large scale systems are used for processing of organic waste. The difficulties associated with utilizing this equipment on CWP projects include lead time, cost, operational support, and scalability.

Alternatively, when the feedstock is homogenous, the front-end processing does not require as many safety measures to ensure a reliable and consistent feedstock. All the projects contain a certain level of preprocessing, but the complexity of designing and implementing a system for a homogenous waste stream decreases because simpler and less expensive equipment can be used in the separation stage, resulting in lower overall costs. Other factors that contribute to the design of the processing equipment include odor, leachate management, aesthetics, availability, and price. Finding a delicate balance between these factors and ensuring customers the optimal efficiency of their digester systems are the design considerations in the front-end design of the system.

4.3.1.2 Evaluation Criteria for Feedstocks

Feedstock that is collected offsite must be evaluated with multiple criteria to determine that collection is economically feasible. Criteria for evaluation include:

- Contamination levels of feedstock
- Proximity to digester
- Uniformity of feedstock
- Energy content
- Nitrogen additive necessary
- Tip fees currently paid
- Cost structure
- Amounts of feedstock available at location
- Seasonality
- Availability
- Current value of feedstock

4.3.1.3 Feedstock Assessment

After determining the availability of feedstocks, samples were collected in order to determine the energy content, chemical composition, and anaerobic digestibility of the feedstocks. These data were used to inform a process model that allowed for the sizing and design of the digester system as well as determination of the need to supplement the feedstock with water, nutrients or micronutrients.

4.3.1.4 Representative Feedstock Samples Selected by Industry Protocol and Standards

CWP evaluated several potential sites capable of hosting a digester project in a manner that best serves the project's goals and objectives, and facilitates expeditious development, planning, construction, and operation of SBR1. Several sites were considered in the Central Valley of California, with most centering on Sacramento. Of these sites, six sites were selected by the CWP study team for further evaluation. These sites were selected because they had the best chance for becoming full-scale commercial project sites, and because they represented a broad cross section of the industries that produce organic materials suitable for anaerobic digestion, including agriculture, food processing, MSW, and retail.

These sites were visited, and the information collected was included in the preliminary report for Grant Section 2.1. Feedstock samples were collected from each of these sites upon completion of the initial feasibility studies. In some cases, multiple feedstock types were collected from the same site. None of the samples that were analyzed in this report had been studied previously, although similar materials may have been reported in literature. The results of this analysis were compared with similar results reported elsewhere.

The objectives of sample collection and analysis were to:

- Provide data for predicting digester performance and effluent quality
- Determine key feedstock characteristics to analyze
- Populate a centralized database to facilitate digester design

Thirteen different biomass feedstock samples were collected and analyzed at the Bioenvironmental Research Laboratory of University of California, Davis. The samples include tomato processing waste, tomato pomace, rice straw, restaurant waste, supermarket waste, cannery waste, cereal manufacturing waste, egg processing waste, layer chicken manure, and cardboard. Physical properties, chemical compositions, and anaerobic biodegradability of these samples were investigated. All the samples were first characterized to determine the fraction of TS, VS, nutrient elements, and metals in the mass of the sample materials. The summary of feedstock studied in this report is shown in Table 3.

Table 3: Feedstock Collected for Analysis

Feedstock	Source	Sample Date
Tomato waste	Ranch	10/12/2011
Tomato pomace	Ranch	10/12/2011
Fresh rice straw	Ranch	10/12/2011
Mature rice straw	Ranch	10/12/2011
Fresh cow manure	Ranch	10/12/2011

Feedstock	Source	Sample Date
Mature cow manure	Ranch	10/12/2011
Restaurant waste	Waste hauler	10/25/2011
Supermarket waste	Distribution center	10/25/2011
Egg processing waste	Egg Farm	10/24/2011
Fresh chicken manure	Egg Farm	10/24/2011
Mature chicken manure	Egg Farm	10/24/2011
Cannery waste	Factory	10/25/2012
Cardboard	Packaging Plant	12/20/2011
Cereal waste	Factory	10/25/2011

Source: Clean World Partners, LLC

4.3.1.5 Collection, Sampling, and Storage of Feedstock Samples

Tomato waste, tomato pomace, fresh cattle manure, mature cattle manure, and rice straw were collected on October 12, 2011, from an agricultural ranch in California. At the ranch, the farm owner stored the tomato waste and tomato pomace in two uncovered piles near the cowshed. Both tomato waste and tomato pomace samples were collected by shovel randomly from the stockpiles. According to the farm owner, tomato waste and tomato pomace were delivered once per week from a nearby tomato processing facility. The facility was only in operation during the local tomato harvest season, during which the facility processed an unspecified quantity of tomatoes. While the exact amount of tomato waste available was unknown, the farm owner reported receiving over 100 tons per week and anecdotally reported that much more was available. The farm owner currently used the waste materials as animal feed. Trucks hauled the materials from the stockpile to the fields for the animals to eat, but the stockpiles were large enough to supply the material for many weeks.

At the farm, the tomato waste and pomace were stored in stockpiles left uncovered at ambient temperature. Tomato waste included green and overripe or rotting tomatoes and vines (10 percent tomatoes and 90 percent vines). The farm owner noted that this proportion would vary with different loads of wastes received. The tomato pomace stockpile included tomato skins and processing residues. There were no visible vines in the tomato pomace.

Representative samples of tomato waste (Figure 7) and tomato pomace (Figure 8) were collected from the stockpiles available at the time of collection. Both materials were collected in five-gallon buckets and transported to the lab by truck. A one-pound sample of each was homogenized in a food processor and then the homogenized samples were stored in the freezer at -4°F (-20°C) for future analysis.

Figure 7: Tomato Waste Stockpile

Photo credit: Clean World Partners, LLC

Figure 8: Tomato Pomace

Photo credit: Clean World Partners, LLC

Fresh cattle manure samples were collected from a beef-cattle feedlot randomly from the manure that was available at the time. Manure quality varied relative to the length of time it was exposed to the air. Samples were collected by shovel from the ground in the cowshed, with help from the farm owner, placed in a sample jar and transported to the BEE lab by truck.

About one pound fresh cattle manure sample was processed by a food processor to make it homogeneous and the prepared sample was then stored in a freezer -4°F (-20°C) for further analysis.

Mature cattle manure (which had accumulated over a six month period) was collected randomly from manure piles used for stockpiling and storing manure at the feedlot, which was later used as fertilizer. The mature manure pile (Figures 9 and 10) was located at the edge of the field, and was stored under ambient temperature with no cover. Samples were collected randomly throughout the pile using a bucket and transported to the BEE lab by truck. About one pound of manure sample was processed by a food processor to make it homogeneous and the prepared sample was stored in a freezer at -4°F (-20°C) for further analysis.

Figure 9: Mature Cattle Manure

Photo credit: Clean World Partners, LLC

Fresh rice straw was stored in a pile at the ranch under a black plastic cover. The sample was collected randomly from several straw bundles in the pile and was kept in a plastic bag for transport to the BEE lab by truck. The rice straw samples were homogenized in a food processor and then stored in a refrigerator for further use.

Mature rice straw had been stored similarly since the previous year. Because the material had been stored uncovered, it had been weathered more than the fresh rice straw. Samples were collected randomly from different straw bundles in the pile and transported to the BEE lab for storage along. The mature straw was processed separately from the fresh, but using the same protocol.

Figure 10: Old Cattle Manure Stockpile

Photo credit: Clean World Partners, LLC

Fresh and mature chicken manure samples, along with egg processing waste samples, were collected from an egg ranch in California. Fresh chicken manure (Figure 11) was transferred by belt from the chicken houses on a daily basis to a conveyor that tipped the manure into a truck bed. The truck delivered the manure to a storage stockpile about 500 meters from the chicken house. Fresh chicken manure stockpiles were warm as evidenced by active rising steam. Mature chicken manure had been sitting in the stockpile for up to two weeks.

Figure 11: Fresh Chicken Manure

Photo credit: Clean World Partners, LLC

Samples of the fresh and mature manure were collected randomly from different stockpiles. Visually, the different stockpiles appeared similar. Chicken manure samples were collected in a bucket and transported to the BEE lab, 260 miles away, by car. Upon arrival at the lab, one pound of each chicken manure sample was homogenized in a food processor and then stored in a freezer at -4°F (-20°C) for future analysis.

Egg processing waste consisted of substandard eggs that were separated out during the packing process. Eggs from the hen houses were conveyed to a centralized egg washing and packing facility, where they were inspected, washed, and packed using robotic equipment. An employee monitored the eggs as they passed through the inspection station and manually separated the substandard eggs into a rejects hopper (Figure 12). This egg waste was stored in drums for hauling to landfill for disposal. The egg waste included broken egg shells and the liquid contents of the eggs (egg liquid). Egg liquid stayed in the bottom of the rejects hopper while egg shells piled up above the liquid; therefore, the shells and liquid were sampled separately. Egg liquid was collected in a 500 ml sample bottle. Egg shells were collected randomly from the hopper and stored in a one-gallon polyethylene bag. The samples were hauled to the BEE lab along with the chicken manure samples. The egg liquid was homogenized in a food processor and then stored in a refrigerator at 39.2°F (4°C) for up to two weeks prior to analysis. The egg shells were stored in a freezer at -4°F (-20°C).

Figure 12: Egg Waste in Collection Hopper

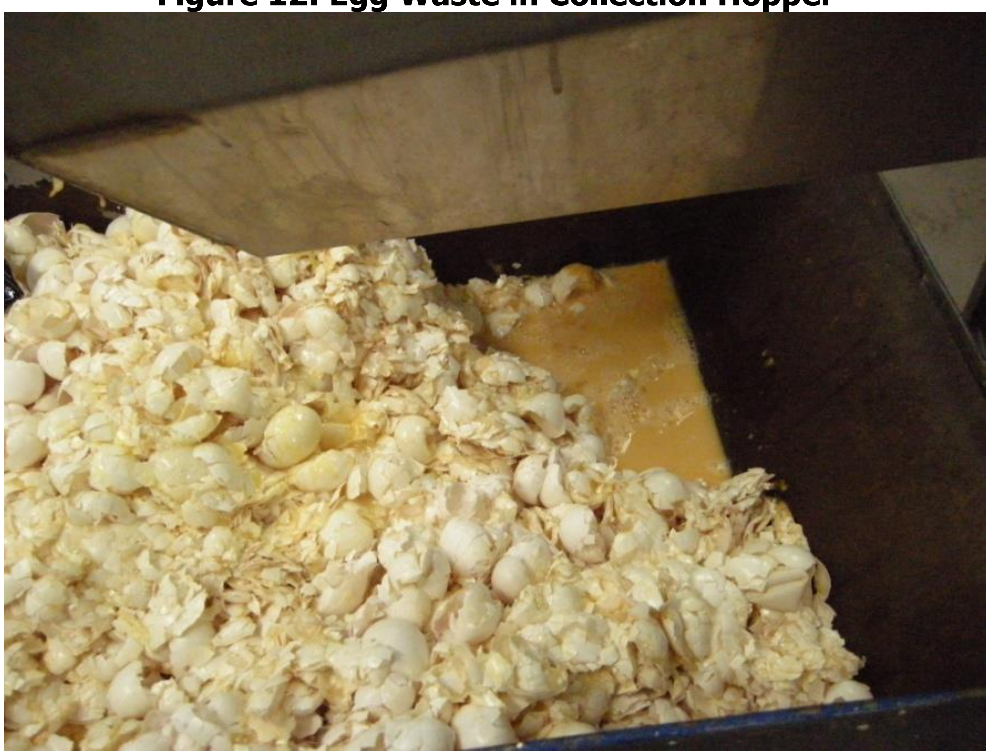


Photo credit: Clean World Partners, LLC

Restaurant waste, supermarket waste, and cereal processing tailings were received at the BEE lab on October 25, 2011. The three waste products originated from separate facilities. The restaurant waste was collected as part of a pilot source-separation program run by a waste collection company in Sacramento. Food scraps were disposed of by restaurant employees into designated roll-off totes. The waste collection company, which regularly hauled the waste to a farmer for use as compost feed, hauled four bins of the source-separated materials, along with a two-cubic-yard bin of supermarket waste, to the UC Davis Biogas Energy pilot plant facility. The five-hundred-pound load of restaurant waste was processed through a 10 HP industrial grade grinder for particle size reduction and homogenization prior to sampling. After grinding the restaurant waste and supermarket waste was ground similarly (Figures 13 and 14). Three five-pound samples of each type of material were brought to the BEE lab, further homogenized in a food processor, and stored in a freezer at -4°F (-20°C) for future use. The cereal tailings were collected in several one-gallon polyethylene bags and brought directly to the BEE lab for homogenization and storage.

Figure 13: Restaurant Waste Before (Left) and After (Right) Grinding at the UC Davis Biogas Energy Pilot Plant

Photo credit: Clean World Partners, LLC

Figure 14: Supermarket Waste Before (Left) and After (Right) Grinding at the UC Davis Biogas Energy Pilot Plant

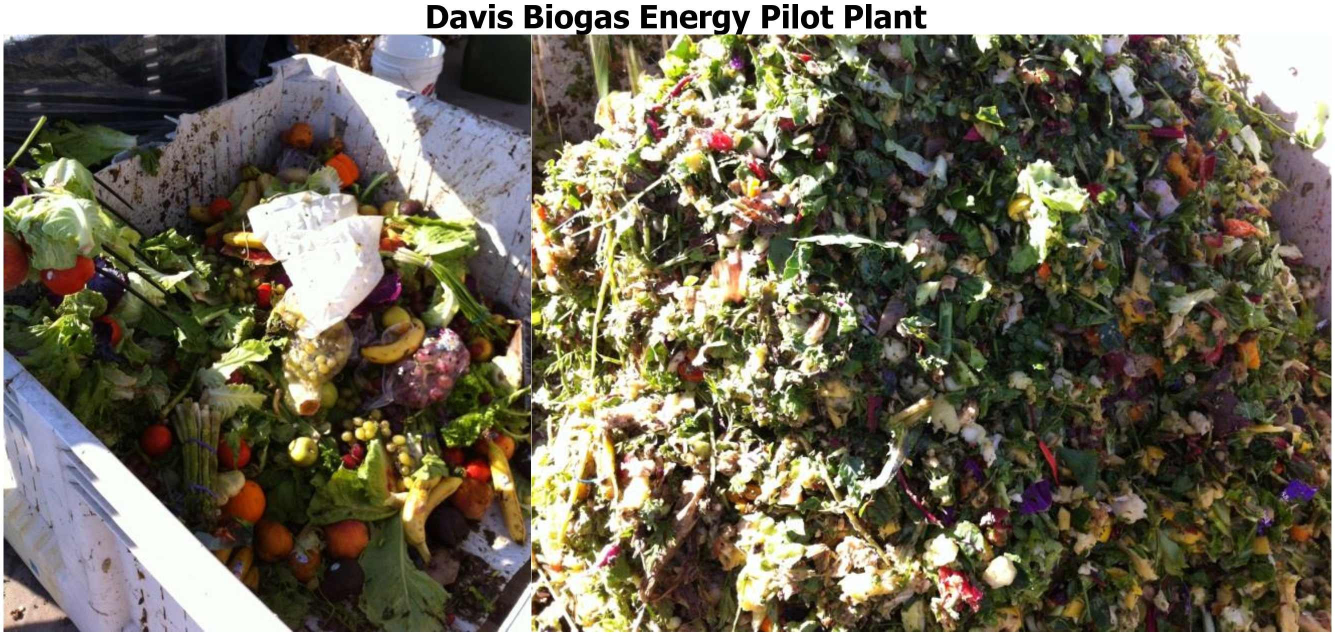


Photo credit: Clean World Partners, LLC

Food processing waste and cardboard packaging waste samples were received at the BEE lab on December 12, 2011. The food processing waste was sourced from a food producer in the Sacramento area. The facility directs all of the waste products and wash-down water to a 0.25-inch, rotating, stainless steel screen. The retained solids consist of a mixture of rice, beans, fruits, vegetables, and meat chopped to 0.25—0.75-inch pieces. A five-gallon sample was collected from the food processing plant and one-pound subsamples were selected at random for homogenization in a food processor before being stored in a freezer at -4°F (-20°C) for future use.

The cardboard was sourced from a packaging plant where scraps and back-hauled sheets passed through an industrial grade shredder that tore the sheets into four to eight inch pieces for baling. One 500-pound bale was hauled to the UC Davis Biogas Energy pilot plant for further particle size reduction. A grinder was tested on the materials, but was found to jam when the cardboard lodged between the grinder blades. The material was instead milled with an industrial-grade hammer mill (Model 10HMBL, Glen Mills, Inc.) fitted with a 0.75-inch screen (Figure 15). The milled cardboard was placed in a one-gallon polyethylene bag and stored in a refrigerator at 39.2°F (4°C) for future use.

Figure 15: Cardboard Waste Exiting the Baling Machine (Left) and After Passing Through the Hammer Mill at UC Davis (Right)

Photo credit: Clean World Partners, LLC

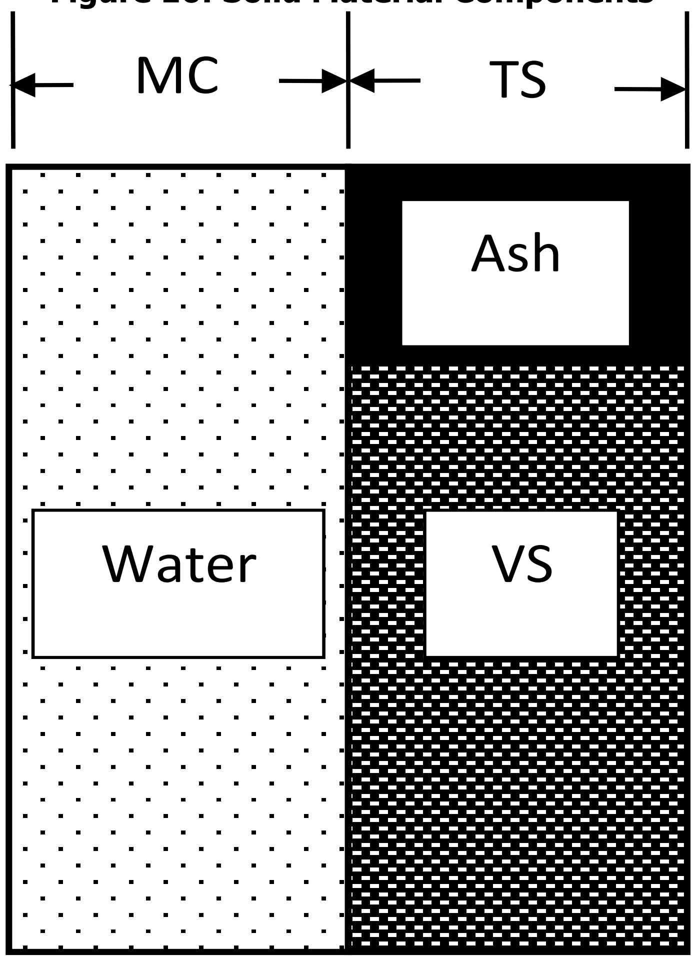
4.3.1.6 Analysis of Biomass Feedstock Samples for Nutrients, Micronutrients, and Chemical Composition

Feedstocks were analyzed for the most pertinent chemical and physical characteristics. The MC was measured, and the dry solids were analyzed for their individual components as well as overall noncombustible ash content. The chemical constituents analyzed were those that are most valuable for predicting biogas yield, nutrient value for horticultural and agricultural application of the resulting digestate and digester effluent, and contamination level by heavy metals and salts known to have environmental implications.

4.3.1.7 Feedstock Characterization Analytical Methods

Biomass feedstock samples were analyzed for TS, VS, and fixed solids (FS) at the BEE lab using gravimetric methods. Wet samples were weighed in a weighing dish, then measured for TS after evaporating the water for 24 hours at 221°F (105°C). The dry samples were then placed in a furnace for combustion of the volatile fraction at 1022°F (550°C) for three hours. The residue was weighed and recorded as FS. Volatile solids were defined as the difference of the dry mass of TS and FS (Figure 16). These analyses were conducted using the standard methods described in Standard Methods for the Examination of Water and Waste Water by American Public Health Association (APHA, 1998).

Figure 16: Solid Material Components



Source: Clean World Partners, LLC

4.3.1.8 Results of Analysis for Selected Feedstocks

Each of the feedstocks selected and sampled as described previously were analyzed for solids content. For the sake of comparison, fresh and mature samples were analyzed and reported separately. For the manure samples, both fresh and mature samples were further analyzed for nutrient and metals content in order to determine the effect of maturation on chemical composition. For the remaining samples where mature material was collected, it was not further analyzed as there would be no need to utilize the matured material after a digester had been installed. The results of the solids analysis are reported in Table 4, below.

Table 4: Proximate Solids Analysis for All Selected Feedstock Samples (W.B. = Wet Basis, D.B. = Dry Basis)

Sample	Date	MC (% W.B.)	TS (% W.B.)	VS (% W.B.)	VS (% D.B.)	Bulk density (kg/L)
Agricultural ranch						
Tomato waste	10/12/2011	85.22	14.78	11.96	80.93	0.63
Tomato pomace	10/12/2011	75.56	24.44	22.95	93.90	0.56
Mature rice straw	10/12/2011	41.21	58.79	49.30	83.85	NA
New rice straw	10/12/2011	12.88	87.12	72.38	83.07	NA
Mature cattle manure	10/12/2011	30.10	69.90	22.04	31.53	NA
Fresh cattle manure	10/12/2011	53.24	46.76	14.94	39.36	NA
Waste disposal company						
Food waste	10/25/2011	86.31	13.69	11.40	83.22	NA
Grocery store						
Vegetable waste	10/25/2011	88.11	11.89	11.08	93.15	NA
Egg ranch						
Fresh egg liquid	10/24/2011	77.55	22.45	21.39	95.31	NA
Fresh egg shell	10/24/2011	39.01	60.99	15.11	24.77	NA
Mature egg liquid	10/24/2011	81.87	18.13	17.07	94.14	NA
Mature egg shell	10/24/2011	43.22	56.78	12.90	22.72	NA
Fresh chicken manure	10/24/2011	68.59	31.41	19.87	63.27	NA
Mature chicken manure	10/24/2011	37.77	62.23	33.86	54.40	NA
Egg wash wastewater	10/24/2011	99.47	0.53	0.19	36.24	NA
Food producer						
Mixed Food waste	12/20/2011	75.75	24.25	23.72	97.80	NA
Food producer						
Cereal tailings	12/20/2011	7.02	92.98	89.61	96.37	NA

Sample	Date	MC (% W.B.)	TS (% W.B.)	VS (% W.B.)	VS (% D.B.)	Bulk density (kg/L)
Packaging plant						
Cardboard	12/20/2011	3.93	96.07	74.19	77.23	NA

Source: Clean World Partners, LLC

The above samples were further analyzed by the [UC Davis Analytical Laboratory](https://anlab.ucdavis.edu/) (https://anlab.ucdavis.edu/) for nutrients, salts, and metals according to the standard methods utilized by the UC Davis Analytical Lab. Nutrients evaluated included N, phosphorus, potassium (K), and carbon (C). Salt elements included chlorine (Cl), sodium (Na), magnesium (Mg), and boron (B). Heavy metals analyzed included zinc (Zn), manganese (Mn), copper (Cu), selenium (Se), lead (Pb), and nickel (Ni). Before the analyses, all samples were prepared by drying them at 122°F (50°C) in a vacuum oven and then grinding the dried material in a Wiley mill to particles that could pass through a 40 mesh (0.4 mm) screen. The results of the chemical analyses are shown in Table 5, below. The data are reported on a dry-mass basis.

Table 5: Nutrient and Metals Analysis (All Mass Fractions Presented on a Dry Basis)

	C	N	P	K	S	B	Ca	Mg
Sample Type	%	%	%	%	ppm	ppm	%	%
Tomato waste	40.3	3.1	0.3	1.1	3390	72.9	2.4	0.7
Tomato pomace	57.8	3.5	0.5	1.0	2350	17.6	0.3	0.3
Rice straw	38.6	0.5	0.1	2.8	610	6.6	0.2	0.2
Mature cow manure	18.0	0.8	0.2	0.8	1390	16.4	0.8	0.8
Fresh cow manure	21.0	1.4	0.4	0.9	5150	28.4	1.5	1.0
Egg liquid	61.8	7.8	0.6	0.7	7260	1.3	0.4	0.1
Mature chicken manure	28.1	2.8	2.2	3.5	7220	46.6	10.5	0.8
Fresh chicken manure	31.9	3.7	1.8	2.8	6100	34.6	10.3	0.6
Restaurant food waste	43.7	2.7	0.5	2.4	3050	18.7	3.5	0.2
Supermarket waste	45.6	2.1	0.4	2.9	2450	38.6	0.3	0.2
Cereal tailings	44.7	1.1	0.2	0.2	860	1.0	0.3	0.1
Mixed Food waste	47.5	3.3	0.3	0.4	2220	6.9	0.3	0.1
Cardboard	46.2	0.2	0.0	0.0	1765	42.4	0.4	0.0

Sample Type	Zn ppm	Mn ppm	Fe ppm	Cu ppm	Na ppm	Co ppm	Ni ppm
Tomato waste	40.1	183.6	4,482.8	23.6	1,528.5	2.5	14
Tomato pomace	40.1	53.8	510.3	14.3	477	0.4	3
Rice straw	33.5	492.2	432.2	4.9	2,054	1.3	2
Mature cow manure	97.1	574.5	20,209.2	37.7	1,590	10.4	41
Fresh cow manure	108.4	495.7	13,418	39.1	5,529	6.9	47
Egg liquid	18.1	1.5	68.0	15.9	7,165	<0.1	5
Mature chicken manure	407.7	404.4	1,914.5	45.6	5,105.0	1	9
Fresh chicken manure	325.3	312.2	739.4	36.1	4,162	0.5	12
Restaurant food waste	170.8	34.1	443.7	9.1	3,443	0.4	2
Supermarket waste	126.6	22	187.1	10.4	1,669.5	0.2	15
Cereal tailings	197.5	21.5	219.7	2.2	9,005	<0.1	<1
Mixed Food waste	41.1	33.9	490.9	8.0	2,764	0.2	13
Cardboard	18.6	26.3	255.8	10.3	1,950.5	0.3	3

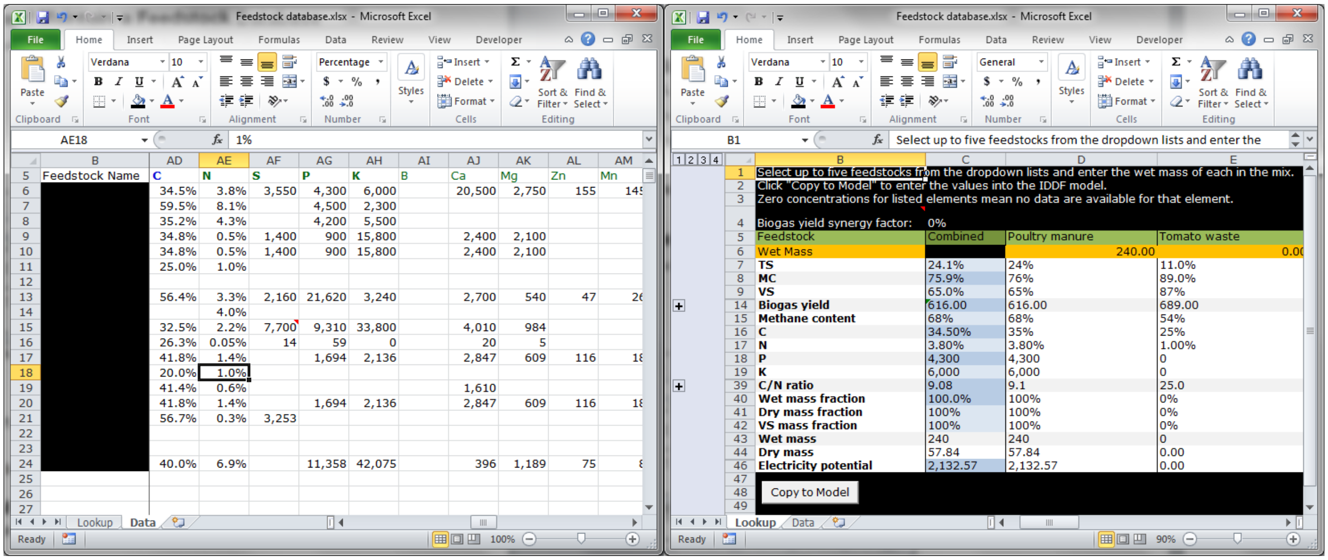
Source: Clean World Partners, LLC

4.3.1.9 Development and Maintenance of a Feedstock Database

In addition to analyzing the different waste samples, a database was created to allow for rapid storage and retrieval of the data. In addition to those samples analyzed as part of this study, other feedstock samples were added to the database where the source of the feedstock and quality of the data were well known. Some of these other analyses included characteristics and chemicals that were not analyzed in the current study because they were not considered critical for the operation of the digester or use of the residuals. However, these properties and constituents were added to the model for completeness.

Maintaining a reputable database of feedstock characteristics enables the user to simulate feedstock mixes, predict biogas yields, and determine solids contents of the hypothetical blends. To facilitate the simulation, a lookup table was added to the database which allows the user to choose which feedstocks to mix at what proportions and produce a new blended feedstock with properties proportional to the original materials (Figure 17). In addition to chemical composition, biogas yields from batch CH_4 potential tests were also included in the model. These data were used to predict the expected biogas yield for the blended feedstock. However, it has been well documented that synergistic effects can result in greater biogas yields than the proportional combination alone would predict. Therefore, a synergy factor was added to the lookup table that would have to be determined empirically.

Figure 17: Screenshot of Data (Left) and Lookup Table (Right) From Feedstock Database



Source: Clean World Partners, LLC

The resulting feedstock blends could be imported into an existing anaerobic digester model for prediction of biogas production rate, digester efficiency, dilution factors, and expected resulting concentrations of the nutrients and metals analyzed and their degradation products. The database was programmed to facilitate the transfer of the data from the database to the process model. This will greatly speed up the design process, allow for access to markets by determining the optimal blends of feedstocks and combinations of feedstocks from different sources, simplify regulatory applications by accurately predicting emissions and product qualities, and allow for more stable digester operation by predicting where shortages or excessive concentrations of key chemical constituents could occur.

4.3.1.10 Resampling of Biomass Feedstock Stream to Determine Levels of Variation in Parameters

For the current scope-of-work, only an initial feedstock sample and analysis was performed for each source of interest. Once commercial projects have been further developed at the selected sites, feedstocks can be re-sampled periodically to determine variations for accurate system design. Where data were already available for some of the selected feedstocks (at least in terms of production rates and MC), the variability was analyzed.

4.3.2 Determine the Digestibility, Digestion Rate, Biogas and CH_4 Yields of Biomass Feedstock, and Develop Optimum Design Parameters

In May 2012, CWP submitted a completed Laboratory Digestion Test Results Report that determined feedstock stream suitability for digestion and energy production potential, digester sizing, and estimated performance parameters (Task 4.2).

4.3.2.1 Lab-scale Digestibility Studies of Prospective Feedstocks

The same biomass feedstock samples characterized in Section 4.1 (with the exception of fresh chicken manure, mature rice straw, and cattle manure) were analyzed for their anaerobic digestibility using a batch anaerobic digestion test. This test consists of exposing a fixed volume of inoculum (anaerobic microorganisms) to a fixed mass of feedstock in a controlled environment for an extended period of time. The experiment is designed to allow sufficient time for full degradation of the feedstock, allowing the determination of ultimate biogas and CH_4 yield as a prediction of full-scale anaerobic digester performance.

The batch anaerobic digestibility test was conducted at the thermophilic temperature of 50 ± 2°C with a preset initial volatile solids loading of three, four, and six g/L, depending on the expected digestibility of the feedstock, with higher initial loading for less digestible materials. The reactors were loaded with sufficient anaerobic inoculum to achieve a food-to-microorganism ratio (F/M) of 1.0 and 2.0, based on the VS content of the feedstock and inoculum. Duplicate tests were run for each feedstock. The volume of biogas production and CH_4 content of the biogas were measured at the same time each day, and the biogas and CH_4 yields were reported on a daily and running cumulative total basis. A blank batch was also run to account for biogas production due to residual organic material in the inoculum. The biogas production from the blank was subtracted from each of the test batches.

The objectives of the batch anaerobic digestion test were to:

- Determine the biogas and CH_4 yields of selected biomass feedstocks that can be potentially used for anaerobic digestion.
- Utilize the results of the digestibility test to design and model full-scale application of anaerobic digestion to those feedstocks deemed most feasible.

4.3.2.2 Batch Anaerobic Digestion of Biomass Feedstocks

In the previous sections, a number of feedstocks were selected for characterization based on the feasibility of creating full-scale digester projects at the study sites. Most of these feedstocks were also analyzed for their anaerobic digestibility, with a few exceptions. For the farm-based projects, mature rice straw and fresh chicken manure were not determined to be representative of the feedstocks that would be utilized in a full-scale project. Therefore they were omitted. The cattle manure samples were not tested because of their low VS content, indicating very low quality for anaerobic digestion. Furthermore, the low VS indicated that the cattle manure collection process most likely introduced excessively large quantities of soil into the manure, necessitating alternate collection methods before considering the material as a useful feedstock for anaerobic digestion. The cannery waste had been thoroughly studied previously. Therefore, for this study the material was studied in codigestion with the cardboard waste, since such codigestion had been proposed for a potential project. TS mass ratios of 3:1 and 1:1 for food waste and cardboard, respectively, were selected for this study.

4.3.2.3 Experimental Methods

Thermophilic batch digestion experiments were conducted at 50 ± 2°C using glass bottles with a total volume of 1130 mL. Each of the batch reactors was loaded with 500 mL of inoculum and water. The reactors were loaded with enough feedstock to provide 1.5 g VS for each reactor, except chicken manure and food waste/cardboard mixes, which started at 2.0 g VS per reactor, and rice straw, which started at 3.0 g VS per reactor. The mass of feedstock was calculated based on the previously determined TS and VS contents. To achieve F/M of 1.0, the volume of inoculum containing a mass of VS (based on the VS concentration of the inoculum) equal to that of the feedstock was added to each reactor except for the two cannery food waste and cardboard mixtures. For the codigestion feedstocks, an F/M 2.0 was used. After adding the inoculum, tap water was added to make up 500 mL working volume. All the reactors were sealed tightly with rubber septa and screw caps to prevent biogas from escaping. The head space of reactors was purged with argon gas for five minutes to assure anaerobic conditions prior to beginning the batch. Blank reactors with only inoculum and tap water were also loaded to correct for the biogas produced by the inoculum. The initial headspace pressure for each reactor was measured, and then the reactors were placed in a 122°F (50°C) incubator. All samples were tested in duplicate. Each reactor was manually shaken once a day for 30 seconds prior to measuring the biogas volume.

The daily biogas production volume was calculated by measuring the pressure increase in the reactor headspace using a pressure gauge (Type 3150, ±0.1 percent accuracy; WAL-Meβ-und Regelsysteme GmbH, Germany). After measuring the headspace pressure, the biogas in the headspace was released through a water seal to prevent back flow of air. The pressure in the headspace was then measured again and recorded as the initial pressure for determining the next day's biogas pressure increase. Daily pressure increases were converted to biogas volumes at standard temperature and pressure using the ideal gas relation as follows:

$$V_{Biogas} = \frac{P\,V_{head}\,C}{RT}$$

Where:

V_{Biogas} = Daily biogas volume (L)

P = Absolute pressure difference (kPa)

V_{head} = Volume of the head space (L)

C = Molar gas volume at STP (22.41 L/mol)

R = Universal gas constant (8.314 (L kPa)/(K mol))

T = Absolute temperature (K)

The CH_4 and CO_2 contents of biogas were measured using a gas chromatograph (Agilent GC 6890N, USA) equipped with a thermal conductivity detector. Argon was used as a carrier gas at a flow rate of 30.1 mL/min. The injector, oven, and detector temperatures were 248°F (120°C), 212°F (100°C), and 248°F (120°C), respectively. A simulated biogas standard (Scott Specialty Gases, USA) containing 30 percent (v/v) CH_4, 30 percent H_2 and 40 percent CO_2 was used to calibrate the GC. The CH_4 and CO_2 content of the biogas was measured every day for the first four days, and then every two days for the rest of experiment. The average CH_4 volume produced over the digestion period was calculated based on daily biogas production and CH_4 content for each day on which measurements were taken. When measurements were not taken, the CH_4 content for that day was interpolated linearly from the CH_4 contents before and after that day.

The pH in each reactor was measured before and after the digestion test using an ion selective pH probe (Accumet). The final TS and VS concentrations of the reactors were measured using well mixed 20 mL aliquots according to standard methods (APHA, 1998). To determine the bioconversion efficiency, TS and VS reductions were calculated using the following equations:

$$TSR = 1 - \frac{m_{dbmr}}{m_{dbml}}$$

$$VSR = 1 - \frac{m_{vsr}}{m_{vsl}}$$

Where:

TSR = Fraction of TS reduced

VSR = Fraction of volatile solids reduced

m_{dbmr} = Mass of dry biomass remaining at the end of treatment (g)

m_{dbml} = Mass of dry biomass loaded at the beginning of treatment (g)

m_{vsr} = Mass of volatile solids remaining at the end of treatment (g)

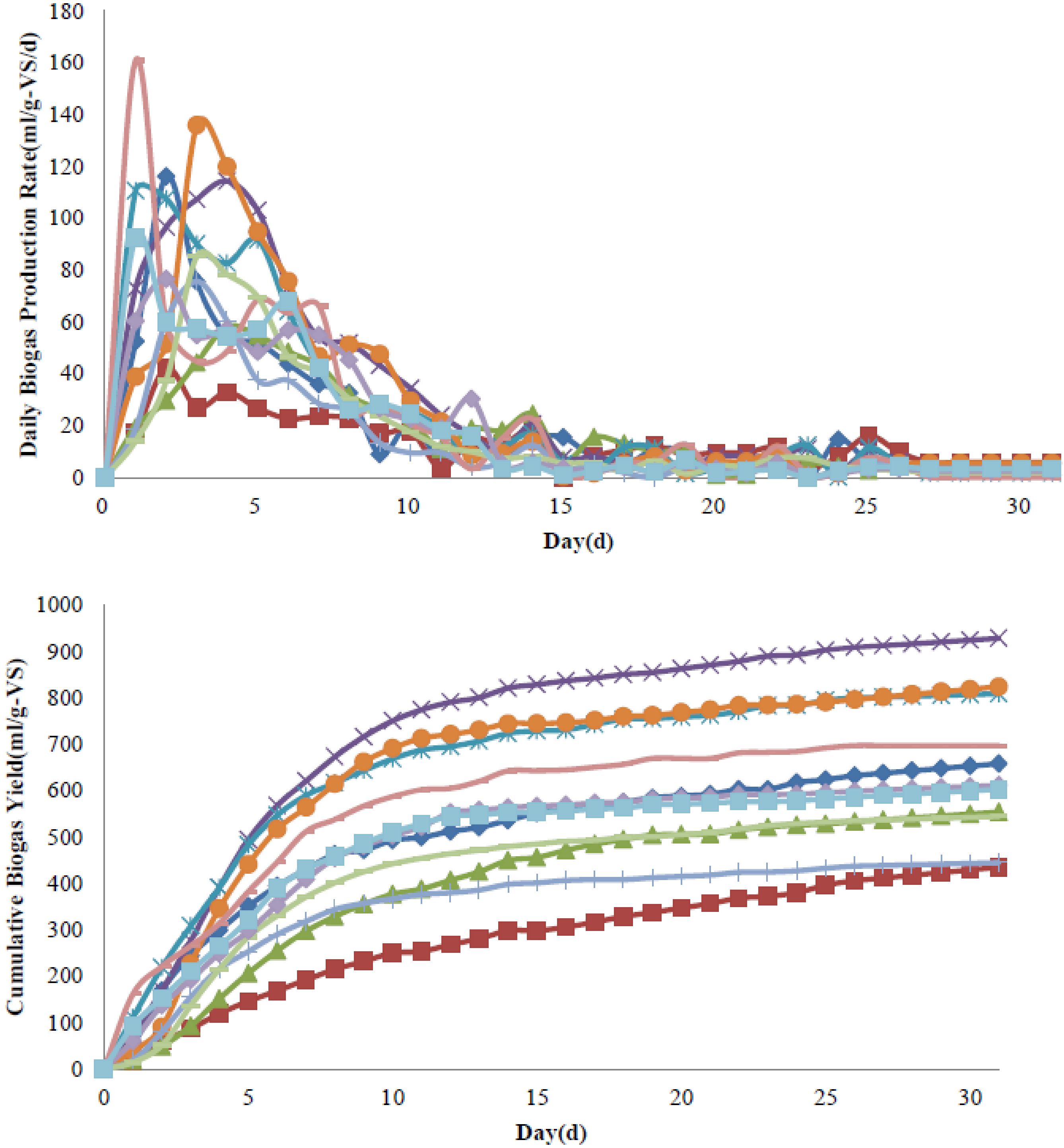
m_{vsl} = Mass of volatile solids loaded at the beginning of treatment (g)

4.3.2.4 Experimental Results and Discussion

At the beginning, cumulative biogas yield increased rapidly and then began to taper off after approximately 12 days of digestion. After 30 days of digestion, the daily biogas production volume was less than five mL per day. The experiment was allowed to continue for three more days to ensure that no additional biogas would be produced, and then the experiment was concluded. The CH_4 content of the biogas produced from various feedstock ranged from 60—75 percent.

The daily and cumulative VS-based biogas yields are shown in Figure 18, below. The ultimate biogas yield at the end of the experiment ranged from 445—929 ml/g for the various feedstocks tested. The biogas production started immediately after inoculation, indicating good bacterial health. Mixed food waste and cardboard, restaurant waste, tomato waste, and cereal tailings had the highest biogas production rates from the beginning. The daily biogas production rates for these feedstocks peaked in the first five days.

Figure 18: Daily (Top) and Cumulative (Bottom) Biogas Yield

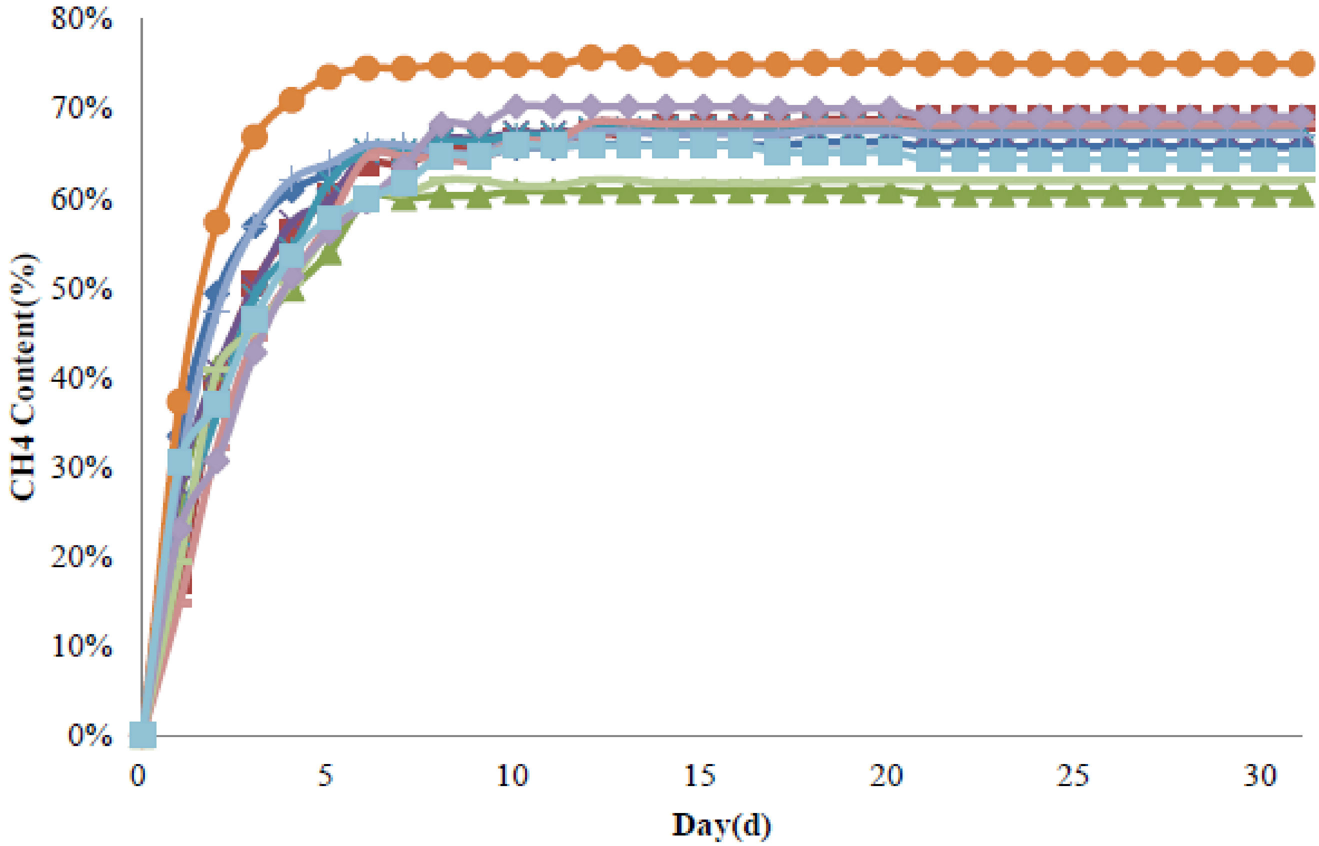


Source: Clean World Partners, LLC

The cumulative biogas yield increased with digestion time and achieved stability after 10—15 days of digestion. Restaurant waste, supermarket waste, and tomato waste had the three highest ultimate biogas yields. These feedstocks also had the highest VS/TS ratios. Tomato pomace and chicken manure had the lowest ultimate biogas yields. Notably, these were even lower than cardboard. The low biogas yield of chicken manure may have been due to losses of digestible material during the chicken manure maturation process.

The CH_4 content of all samples rapidly increased in the first five to seven days and stabilized by day six to eight, as shown in Figure 19, below. The ultimate CH_4 contents of the samples ranged from 60—75 percent on a volumetric basis. Rice straw and cardboard had the lowest CH_4 content while egg liquid had the highest. The remaining samples had CH_4 contents of 65—70 percent.

Figure 19: CH_4 Content of Biogas



Source: Clean World Partners, LLC

The final results of the batch digestibility test are presented in the table below. As shown, the pH was stable for all samples by the end of the experiment indicating that the initial loading was not so high as to lead to excessive acidification. Furthermore, VS reduction correlated with biogas yield as expected, with 90—93 percent VS reduction of those substrates with the highest biogas yields.

Based on previous batch digestion tests at thermophilic temperature, cannery waste produced a biogas and CH_4 yield of 641 and 391 mL/g, respectively. For the 3:1 ratio mix (TS-basis), the weighted average biogas yield would be 617 mL/g, which is within 1 percent of the actual yield. The weighted average biogas yield would be 592 mL/g for the 1:1 ratio mix, which is within 2 percent of the actual yield. Full results from the batch anaerobic digestion are shown in Table 6, below.

Table 6: Results from Batch Anaerobic Digestion of Biomass Feedstock After 33 Days of Thermophilic (122°F [50°C]) Digestion

Sample	Biogas Yield* (ml/g)	CH_4 Yield* (ml/g)	Initial pH	Final pH	TS Reduction	VS Reduction
Agricultural Ranch						
Tomato waste	658.1	400.9	7.86	7.41	34.9%	62.3%
Tomato pomace	434.8	275.6	7.93	7.53	11.9%	32.5%
Fresh rice straw	553.2	315.0	8.03	7.22	49.0%	72.1%
Waste Hauling Company						
Restaurant waste	928.5	544.9	7.96	7.19	54.8%	75.4%
Supermarket						
Fruit & vegetable waste	808.5	440.6	7.75	7.22	68.6%	89.9%
Egg Ranch						
Fresh egg liquid	823.7	602.1	8.0	7.50	58.3%	78.9%
Mature chicken manure	444.5	282.1	8.1	7.53	29.3%	45.2%
Food Producer						
Cereal tailings	697	346.1	7.92	7.05	71.3%	92.6%
Packaging Plant						
Cardboard	544	304.2	7.88	7.61	49.2%	67.0%
Codigestion**						
3:1 Ratio	611.6	333.3	7.94	7.38	60.8%	90.5%
1:1 Ratio	602.4	323.3	7.86	7.30	63.5%	89.1%

* Volumetric gas yields were calculated on a VS-basis and standardized to 273 K, 101.3 kPa.

** Codigestion indicates a combination of food waste and cardboard as the feedstock, mixed at the indicated ratio of masses of TS from food waste and cardboard, respectively.

Source: Clean World Partners, LLC

4.3.2.5 Pilot Scale Continuous Anaerobic Digestion Study

In addition to the batch digestibility study, a 150 gallon continuous digester was built and run on the 3:1 ratio codigestion feedstock mix for several months (Figure 20). The objective of the continuous digester test was to confirm the biogas yield that was determined during the batch test and to prove that an HRD digester similar to that which would be built at full-scale could be run continuously on this substrate. The proposed full-scale project designed to digest a 3:1

mix of food waste and cardboard was sized 600 times larger than the lab-scale digester. However, the lab-scale system was sized to facilitate loading and provide relevant but not overly large quantities of liquid and solid residuals. From startup to current steady-state operating conditions, the feed rate increased from three to nine lbs./day of the food waste/cardboard mixture.

Figure 20: Lab-scale Continuous HRD Digester System

Source: Clean World Partners, LLC

4.3.2.6 Pilot Digester Design, Construction, and Operation

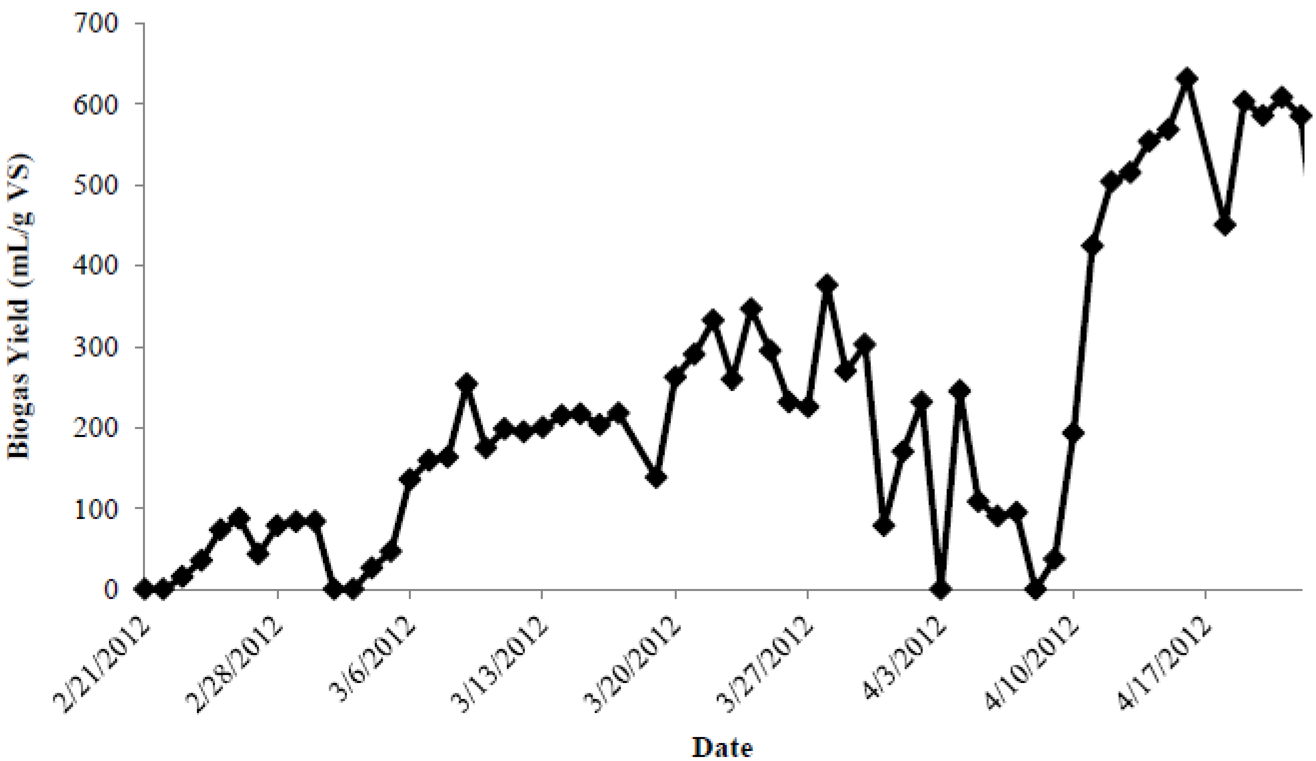
The digester comprised three reactors, each constructed from a resealable 50-gallon steel drum fitted with a one-and-a-half-inch inlet and outlet port, one three-inch sampling port, and a three-inch feed tube plus a quarter-inch barbed gas collection fitting inserted through the lid. The feed tube was constructed of ABS plastic that extended down half the height of the reactor in order to form a liquid lock to prevent air infiltration while allowing for manual feeding of thick substrates. A coil of half-inch plastic tubing was wrapped around the inside of the reactors for circulating hot water to maintain the reactors' temperatures at 125—130°F (51.7—54.4°C) (thermophilic). A 30-gallon water heater was wired with a digital thermostat and dual positive displacement pumps to provide the hot water. The reactors were mixed mechanically on an intermittent timer. Insulation was wrapped around the reactors and exposed hot water tubing to limit heat losses. The system was leak proofed and heat tested prior to use. Biogas flow rate was measured using a wet tip gas meter with a counter and data logger. Reactor temperature was measured by inserting a thermometer into a 6" thermal well installed in the side of each reactor. Reactor pH was monitored by testing the pH of daily liquid samples using a portable pH probe. Ammonia concentration was monitored weekly using a colorimetric Nessler method.

Feedstock was created by mixing the proper proportions of cannery waste with cardboard that had been hammer milled through a five-fourths-inch screen. Premixed feedstock was refrigerated prior to use. The MC of the feed mixture was 75 percent, which was identical to the prediction based on a weighted average of the individual components. Initially, the digester was loaded at an organic loading rate of 1.0 g/(L d), and the organic loading rate was increased exponentially such that it would double every three weeks. The HRT of the system was fixed at 20 days. If the flow rate of liquid out of the digester due to displacement by incoming feedstock was too low to sustain the desired HRT, liquid was recirculated from the third tank back to the first at the necessary rate.

4.3.2.7 Continuous Digester Operation Results and Discussion

The results of the continuous study on biogas yield are shown in Figure 21, below. Initially, biogas volumes were lower than expected, but gradually the yield increased and began to stabilize near the anticipated biogas yield from the batch digestion study. The experiment is ongoing and future plans include increasing the organic loading rate further as well as shifting the ratio of food waste to cardboard from 3:1 to 1:1.

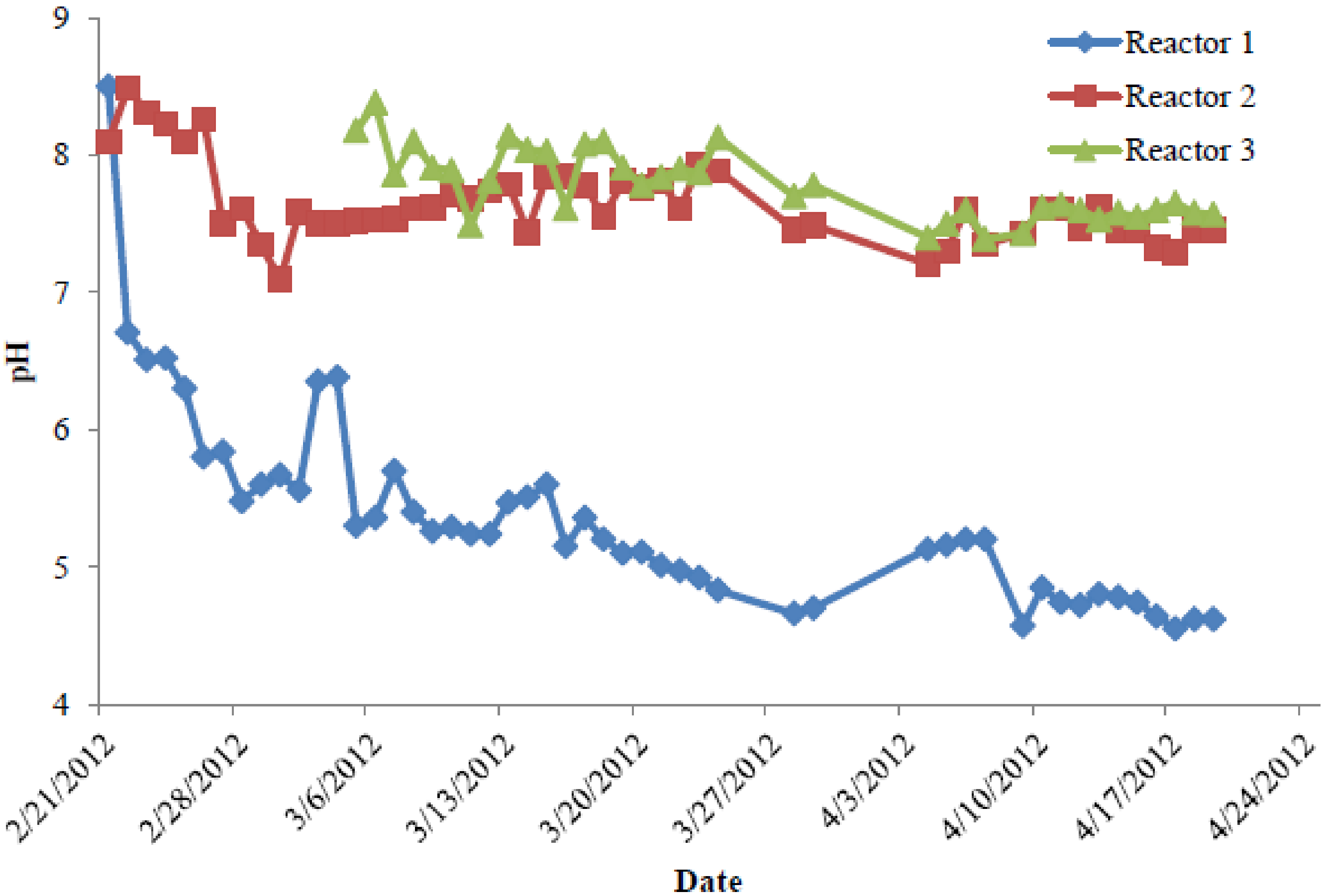
Figure 21: Biogas Yield for the Lab-scale HRD Digester Continuously Fed a 3:1 Mix of Food Waste to Cardboard



Source: Clean World Partners, LLC

The pH of the three reactors has remained relatively stable throughout the experiment (Figure 22). The second two reactors in the series stabilized at 7.3—7.6 while the first reactor (hydrolysis phase) stabilized at 4.6. During the initial startup period, sodium carbonate was added to the second reactor as a pH buffer in response to brief declines in pH.

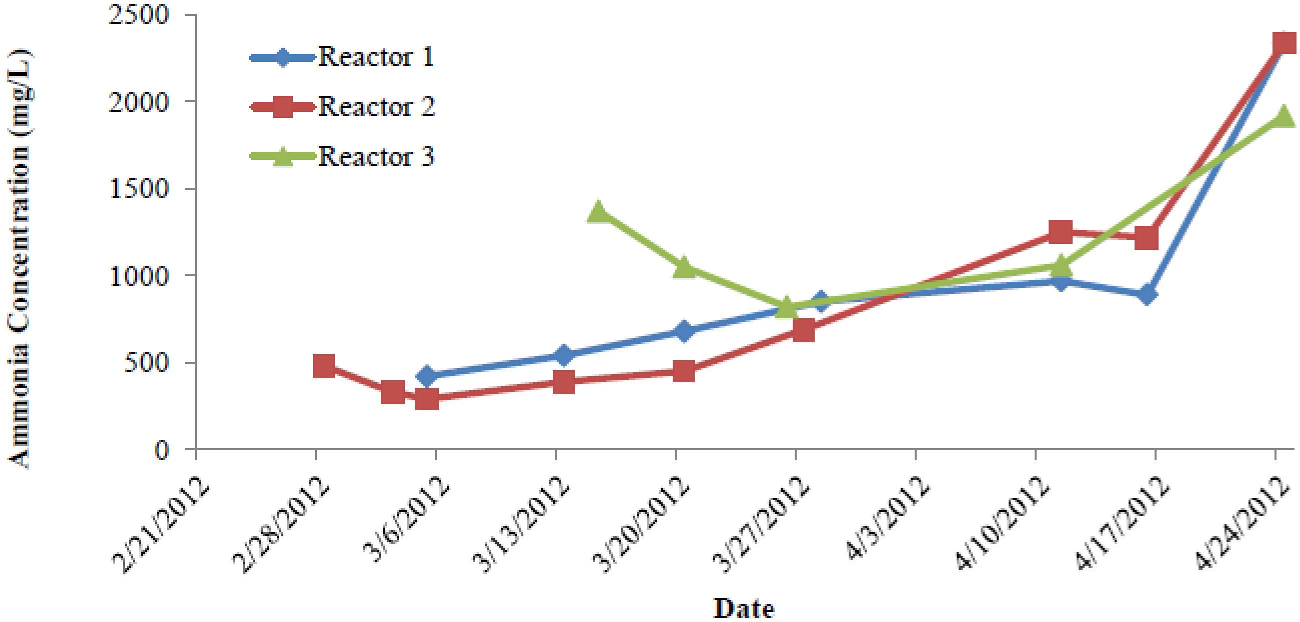
Figure 22: pH of the Three Reactors in the Lab-scale HRD System



Source: Clean World Partners, LLC

The ammonia concentration in the three reactors was measured once per week, as shown in Figure 23, below. Ammonia concentrations greater than 3,000 mg/L can become detrimental to reactor health. Therefore, the ammonia concentration in the system will be monitored closely and may eventually need to be remediated.

Figure 23: Ammonia Concentration of the Three Reactors in the Lab-scale HRD System



Source: Clean World Partners, LLC

The high biogas yield, stable pH, and low ammonia concentration indicate that the reactor was healthy, stable, and productive at the desired operating conditions. This implies that full-scale operation will be successful under similar conditions.

4.3.2.8 Laboratory Studies on Digester Residuals Processing

In addition to digester operation, research was also conducted on the residual solids and liquids discharged from the continuous lab-scale reactor. The lab-scale HRD digester produced 1—1.5 gallons per day of liquid effluent and 1—1.5 pounds per day of residual solids under the steady-state operating conditions. The solids were extracted from the digester by screening the liquid transferred from the second to the third reactor through a 20 mesh nylon sieve and squeezing out water to generate a press cake with 60—65 percent MC. The liquid effluent was removed from the third reactor daily at a volume equal to that of the introduced feedstock. The solids and liquids were refrigerated within 15 minutes of extraction until being further processed.

4.3.2.9 Solid Residuals Processing and Analysis

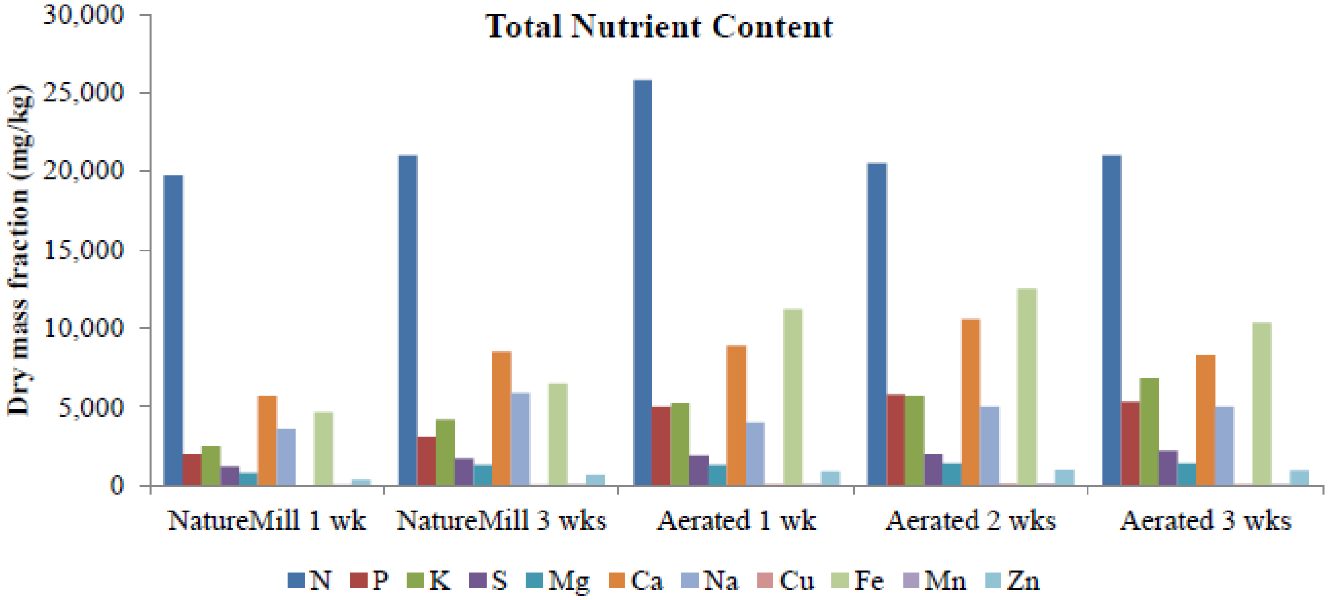
The solids were composted in a lab-scale continuously mixed aerated composting system (NatureMill, Inc., San Francisco, California). After one and three weeks of composting, samples were removed and analyzed at Sunland Analytical Laboratories. The composting system is shown in Figure 24, below.

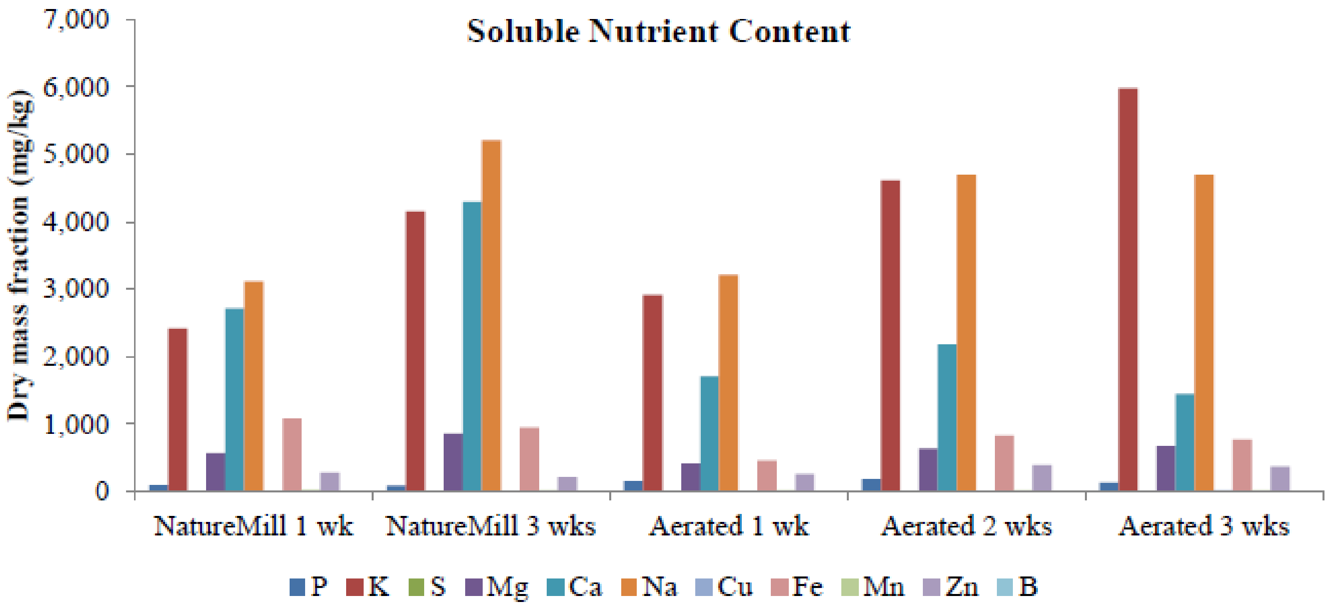
Figure 24: Lab-scale Composter (NatureMill) Before (Left) and After (Right) Three Weeks of Composting of Digester Solids

Photo Credit: Clean World Partners, LLC

Additional samples were delivered to an off-site composting facility that aerated the materials for up to three weeks. Samples were collected after one, two, and three weeks and submitted to Sunland for analysis. The results of the analyses are shown in Figure 25, below. The compost had high N content, very little of which was nitrate (one to two mg/kg). The compost was also high in the remaining essential nutrients and micronutrients. The materials did, however, have relatively high (3,000—5,000 mg/kg) sodium concentrations that could pose problems. However, the sodium was 85—95 percent soluble, and could possibly therefore be leached from the compost. Potassium was also primarily soluble, and would therefore need to be fixed or precipitated after leaching. Iron concentrations were also higher than expected (5,000—12,000 mg/kg). It is unclear why iron concentrations were so high, since the feedstock iron concentrations were only 250—500 mg/kg. It seems likely that it could be due to rust from the reactor walls. However, this requires further investigation.

Figure 25: Total (Top) and Soluble (Bottom) Nutrient Analysis Results for Digester Solids Composted in a Lab-scale Composter (NatureMill) and at an Off-site Composting Facility (Aerated) for One, Two, and Three Weeks





Source: Clean World Partners, LLC

4.3.2.10 Liquid Effluent Processing and Analysis

In addition to solids composting, liquid effluents were filtered as well. A bench-scale demonstration membrane filtration system (Koch Industries, Inc.) was utilized with a 100,000 Dalton molecular weight cutoff microfiltration membrane. Five liters of digester effluent were loaded into the filter, as shown in Figure 26, below. The filter was allowed to run continuously for 14 hours, reducing the effluent volume by 85 percent. –

Figure 26: Lab-scale Demo Membrane Filtration Unit Loaded with Digester Effluent

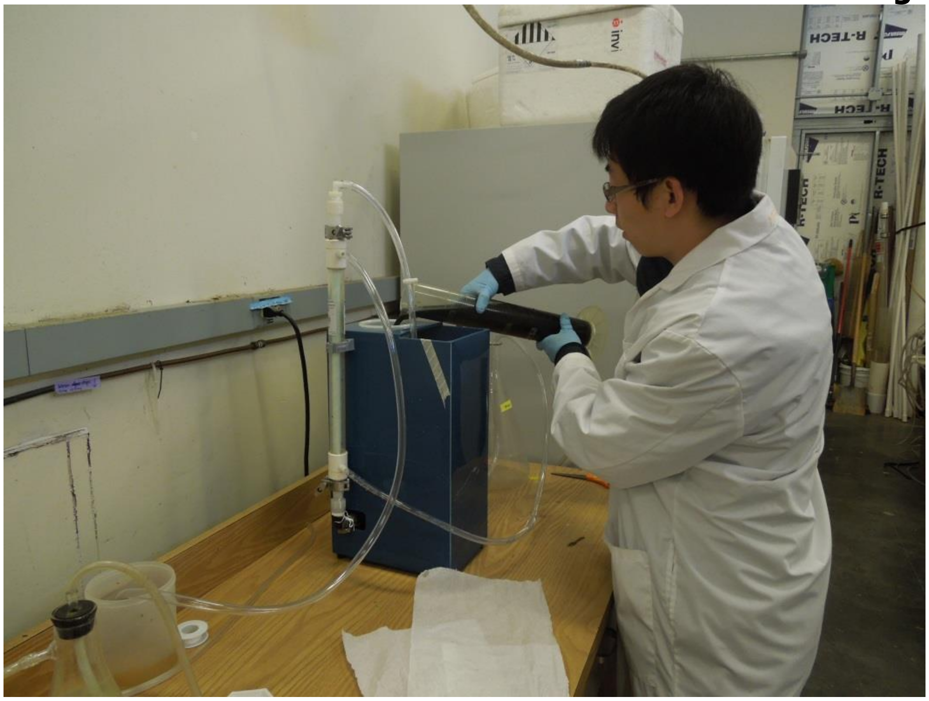


Photo credit: Clean World Partners, LLC

The suspended solids and oxygen demand of the permeate were significantly lower after filtration. TSS was reduced from 5.2 g/L to less than one g/L, and COD was reduced by 93 percent. The permeate was transparent compared with the opaque raw effluent, as shown in Figure 27, below. Experiments are also underway to determine whether more porous membranes could be utilized to the same effect while increasing the flux rate and membrane life.

Figure 27: Results of Membrane Filtration with Raw Effluent Before Filtration (Left) and Permeate After Filtration (Right)

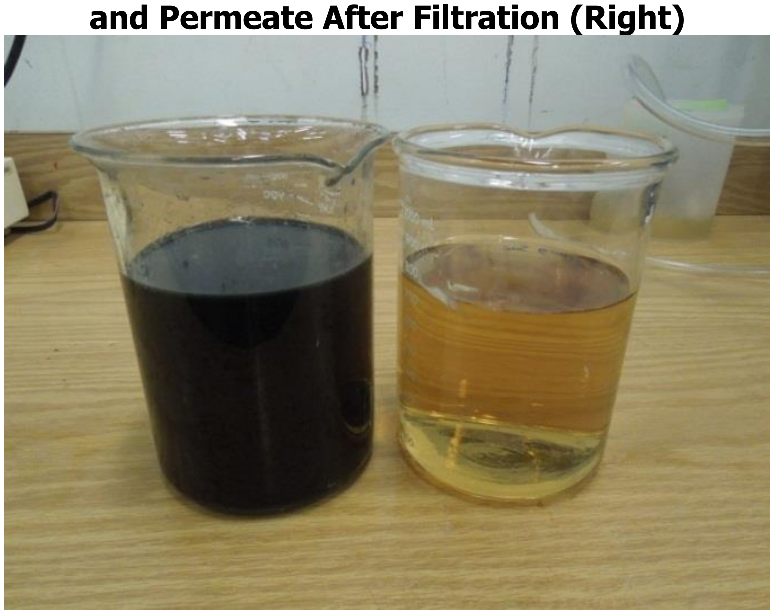


Photo credit: Clean World Partners, LLC

4.3.2.11 Determination of Critical Design Parameters for the Anaerobic Digestion System

The results of the batch and continuous anaerobic digestion trials as well as the lab-scale effluent treatment experiments, were used to determine the critical design parameters for the full-scale anaerobic digestion systems. The key parameters are:

- Maximum organic loading rate
- Expected biogas yield
- Expected CH_4 content
- Mass balance of sulfur
- Mass balance and conversion of N to ammonia
- N, P, K of digestate
- Expected micronutrient and salt concentration of digester effluent
- Reactor size

These parameters were used to populate a model that allowed for the calculation of anaerobic digester performance and mass/energy balances. The process model was developed over several years in conjunction with UC Davis researchers. Is assumes sustained steady-state conditions. The feedstock characteristics, composition, biogas yields, and CH_4 potentials determined at the lab-scale were used to estimate the steady-state digester condition.

Equipment performance efficiencies were determined in consultation with engineers, manufacturers, and industry experts. Parts of the model have been validated in pilot-scale anaerobic digestion studies, and a lab-scale continuous digester was run for several months to confirm that steady-state biogas yields matched the batch-study yields.

The model was not designed to account for unforeseeable events or to track dynamic changes in performance level. Therefore, the model would tend to be more accurate over longer time scales and may not account for day-to-day fluctuations. For the purposes of long-term planning, the model is expected to be accurate within the standard error of measurement.

CHAPTER 5: Feedstock Management and Protocols

5.1 Key Findings and Conclusions

In Task 5, CWP prepared and submitted a Feedstock Resource Assessment to support sustainable feedstock supply requirements for anaerobic digestion and codigestion possibilities at the proposed SBR1 facility. Additionally, CWP prepared a Feedstock Procurement Program Summary Report that presented an implementation program for procurement of sustainable feedstocks such as food wastes and other organic wastes.

5.2 Summary of Activities Performed

In Task 5, CWP performed the following tasks:

- Submitted a Feedstock Resource Assessment Report that quantified key physical and chemical characteristics of the feedstock streams (Task 5.1.1)
- Submitted a Feedstock Procurement Program Summary Report (Task 5.1.2)

5.3 Description and Results

The Task 5 subtasks are described below.

5.3.1 Feedstock Resource Assessment

The goal of the Feedstock Resource Assessment was to perform a refined and site-specific feedstock resource assessment (analysis of the gross, technical, and economic potentials for feedstocks) to help assure a sustainable feedstock supply. The feedstock resource assessment include the following materials: agricultural residues, food waste, fruit and vegetable wastes, preconsumer food processing waste, dairy manure, municipal green waste, and other organic wastes suitable for anaerobic digestion.

There are three categories of projects being studied:

- Projects designed to convert waste residue streams to energy and useful byproducts utilizing anaerobic digestion systems that will be located on-site to manage waste streams that are specific to the site.
- Projects designed as community waste collection systems where several waste streams are consolidated and converted to energy simultaneously at a central location.
- Projects for organizations with waste streams that are available for diversion but which are not interested in owning and operating an on-site digester, in which case the feasibility of taking their waste off-site to a nearby anaerobic digestion system was analyzed.

For this report feedstock resource assessments were conducted for two potential on-site anaerobic digestion projects: a food processor with highly liquid waste streams and a food processor with highly solid waste streams. For the second category of projects (community collection programs), CWP analyzed the anaerobic digestion feedstock resources available for a municipal food waste collection program and a biodiesel project. To represent companies that are interested in sending their waste off-site to another anaerobic digestion system, a grocery store chain and a food processor plant were included in the resource assessment.

5.3.1.1 Availability of Digester Feedstock in California

Food waste is the largest constituent of the national waste stream by weight, mostly due to its high MC. There have been several major studies on the feedstock availability in the state of California published by the CEC and in *Bioresource Technology*. According to the Biomass in California report, California produces nearly 100 million dry tons of biomass every year from three primary sources: agricultural, forestry, and municipal wastes. Of this total waste, 30—40 million tons have been determined to be available for diversion to digesters for the production of electricity, vehicle fuels, and other renewable products. The waste available for diversion would consist of 40 percent from forestry, 30 percent from agriculture, and 30 percent from municipal waste.

The California Environmental Protection Agency (Cal/EPA)'s website shows the feedstock availability by feedstock type for each county in California. Since most the projects in this feasibility study are located in or around Sacramento County, research was done to determine the amount of feedstock available for diversion in Sacramento County. For the county of Sacramento, there is an estimated 120,691 tons of available food waste per year, which makes up 18.2 percent of the waste stream for the county. While food waste is the highest priority for digester feedstock due to its high energy content, other waste streams such as paper (73,818 tons per year), leaves and grass (37,115 tons per year), manures (3,276 tons per year), and agricultural residues (39 tons per year) are also good feedstocks that are available for digestion in Sacramento County.

One study by Cascadia consulting group analyzed an assortment of different sites in Los Angeles, Sacramento, San Diego, and San Francisco to identify the food waste sources that had the largest quantities of food waste available for diversion. By weight, 73—75 percent of the waste streams from fast-food restaurants, full service restaurants, and food stores were estimated to be composed of food waste, making these facilities good targets for organic waste diversion. The study also identified nondurable goods wholesale distributors, large hotels, retail stores, shopping malls, public venues and events, and large office buildings as sites with significant waste streams for diversion.

5.3.1.2 Findings from Site Visits to Feedstock Sources

Multiple site visits were performed at prospective sites during this feasibility study (Table 7). Two of the sites in the feasibility study had waste streams that involved the collection of feedstocks from off-site sources, while the others had on-site waste streams that would be managed with a single anaerobic digestion system designed for that specific material.

Table 7: Site Visit Summary

Prospective site	Potential feedstocks	Collection method	Collection frequency	Anaerobic digestion location
Municipal food waste collection company (source separated)	Restaurant waste Food processing waste	Garbage trucks	Weekly	On-site at transfer station
Canola crush/oil extraction and biodiesel production facility	Rice straw Animal manure Biodiesel waste Vegetable processing waste	Harrows	Constant during collection season	On-site
Food processing plant with highly solid waste	Food Waste (90% solids)	Bins	Daily	On-site
Food processing plant with highly liquid waste	Food Waste (15% solids)	Tank Trucks	Daily	On-site

Source: Clean World Partners, LLC

5.3.1.3 Waste Collection and Consolidated Treatment Projects

The **Municipal Food Waste Collection Company** is currently collecting 2.5 TPD of source separated food waste and composting it at a garden in the Sacramento area. If a digester is constructed at the transfer station site, the food waste collection program will be expanded to 25 TPD of mixed greens and source separated food waste.

The second project involving waste collection revolves around colocating an anaerobic digestion facility with a **Canola Crush/Oil Extraction and Biodiesel Production Facility** currently under development. This project aims to utilize biogas from the anaerobic digestion facility to produce the heat and electricity required by the canola crush and biodiesel facility, while simultaneously providing solutions for agricultural waste disposal issues in the vicinity. In addition, the liquid and solid effluents from the digester could be applied to the adjacent land or given back to the farmers who provide the feedstocks, thereby assuring that some of the crop nutrients return to the fields.

Rice straw, cattle manure, poultry manure, tomato processing waste, and biodiesel processing waste (glycerin) have all been proposed as potential feedstocks available to the digester. These materials could be blended in proportions determined to help balance the carbon-to-N ratio, which would avoid the need to provide additives to the digester. Rice straw is the most abundant resource in the area with over 1,200 dry tons produced per year on the farm hosting the biodiesel project alone. Farmers currently dispose of rice straw to avoid tilling too much of it into the soil which upsets the balance of nutrients in the soil. Rice straw can be digested to extract some energy via anaerobic digestion, but without pretreatment the degree of degradation is low. Higher degradation rates can be achieved by presoaking rice straw in alkaline or acid solutions, but the impact of associated salts must be mitigated. Initially, the rice straw could be digested without pretreatment, while pretreatment technologies are developed for future application. In addition, the N content of rice straw is too low to support the growth of healthy anaerobic microorganisms in a continuous digester without applying nitrogenous chemicals. For this reason, animal manures have been suggested for codigestion at this facility.

Cattle and poultry manures are produced at nearby farms in excess of 10,000 tons per year. These manures are currently composted and land applied. Digesting the manure in an anaerobic digestion facility would provide N for digesting carbonaceous feedstocks, produce energy in the form of biogas, and the residual solids (including all of the N, phosphorus, potassium, and other minerals) would still be available for land application.

Other carbonaceous feedstocks available for anaerobic digestion include tomato processing waste and waste glycerol from the biodiesel production facility. Both of these feedstocks are more highly degradable than rice straw and thus would produce more energy on a dry-mass basis. Tomato processors in the area currently produce 8,000 tons per year of waste consisting of under and over ripe or damaged tomatoes as well as tomato vines and leaves. The production season lasts 80 days; therefore, 6,000 tons per year of the waste (about 1.5 million gallons) would have to be stored and metered to the digester at an average rate of 22 TPD. The tomatoes could be ensilaged as a form of storage as they are currently for use as animal feed.

Biodiesel production generates waste consisting primarily of glycerol mixed with some residual catalyst (methanol), reactants (oil and sodium hydroxide), and product (biodiesel). All of these can be converted to energy in an anaerobic digestion system with very high degradability. However, the salt (sodium) and lack of N can pose problems for the digester. As with rice straw, animal manure can be codigested with the glycerol to provide N. To limit the impact of the salt, the amount of glycerol may need to be limited. On a mass basis, for every ton of biodiesel produced, 10 percent as much waste glycerin is generated (100 kg). However, the density of biodiesel is 70 percent that of glycerin; therefore, a one-million gallon per year biodiesel facility will produce 70,000 gallons per year of glycerin. Although glycerin can be utilized by the chemical industry, purifying the biodiesel waste to generate industrial-grade glycerin may be costly. Digesting the waste on-site would generate energy and eliminate the need to transport the material.

5.3.1.4 Food Processing Plants

Site visits were performed at two food processing plants in the Sacramento area that are considering installing a digester on site to meet sustainability standards. The first food processor has a highly liquid (15 percent solids) food waste that is currently being sent to a pig farm. The processor pays a tipping fee for the waste to be transported and accepted by the farm. This site also has a problem with high concentrations of solids in their waste water. A digester at this site could operate on both the waste water stream and the food waste stream of the processing plant to provide a solution to both problems. The bacteria in the digester would consume some of the biological oxygen demand (BOD) and could have the potential to reduce the concentration of solids in the liquid effluent from the digester. Using waste water as the water source for the digester is also advantageous because it reduces or eliminates the need to use fresh water.

The second food processor has three highly solid (90 percent solids) waste streams of food waste, which is currently going to a cattle farm. The waste is currently sold at different price levels for the three waste streams because they differ in quality for use as cattle feed. This project has a homogeneous waste stream with low risk of contaminants, which makes the preprocessing of the feedstock very simple and low cost. The food waste would be sent through a grinder and mixed with water before entering the digester, which requires low cost equipment. The low MC of this food waste also makes storage possible since it will not break down quickly or have odor issues.

5.3.1.5 Offsite Feedstock Producers

Sources of feedstock to be brought in to the municipal food waste project include a grocery store and a food manufacturer, each of which are discussed below.

The **Grocery Store Chain in the Sacramento Region** operates approximately 150 supermarkets in the Northern California and Nevada markets ranging from the Central Valley to Redding and Santa Cruz to Sparks, Nevada. The company distributes the grocery products to each store daily out of their distribution center located in north Sacramento.

Each store generates between 33—400 lbs. of vegetable waste daily. This waste is packaged in plastic bags and totes that are loaded at the store by forklift onto the truck that delivered products to the store. The trucks haul this waste back to the distribution center, where it is unloaded at a collection area and then onto a 25-ton trailer for daily pick up. This waste is currently picked up by a pig farmer, who takes the waste to the farm for use in their operation.

In addition to the vegetable waste, the company also generates an equal amount of meat waste and a smaller amount of packaged goods waste that is given to food banks as the expiration date approaches. The meat waste is currently being picked up by a rendering company at each store. With successful implementation of an anaerobic digestion technology, the grocery chain may be interested in back hauling the meat waste for use as well.

The **Food Manufacturer Located in the Central Valley of California** creates soup, salsa, and tomato related products at their Northern California location. There are seven different manufacturing lines. Each line has a waste water line that collects the waste from the production process. These seven lines collect in one holding tank, where the waste is screened with ¼ inch sieves. This waste is picked up daily and is taken to landfill or compost operations depending on the MC. Currently, the company is collecting between two and three tons a day of this waste.

In addition, through the company's quality control efforts, a significant amount of product is determined to be unsuitable for sale. This already-packaged waste is put on pallets, loaded on trucks, and then taken to landfills. Currently, the company is averaging between seven and eight tons a day of this waste, but is making significant strides in improving their manufacturing processes, which is lowering this type of waste.

Other Companies for Offsite Feedstock

In 2009, SMUD produced a Food Waste and Liquid Food Processing Waste Survey and Analysis Report, which investigated local companies that would be potentially good participants in a feedstock program. The study identified 31 companies and ranked them based on technical and economic potential. California tax enterprise zones provide tax incentives for jobs created in those areas. There are currently 48 areas in California designated as enterprise tax zones and if jobs are created from anaerobic digestion systems in that area, tax credits could be applicable.

5.3.1.6 Waste Collection and Consolidated Treatment Projects

For the **Municipal Food Waste Collection Project**, the feedstocks will all be collected from the Sacramento Region which, at full project development, will include the counties of Sacramento, San Joaquin, Yolo, Placer, Sutter, and El Dorado. On an interim basis, the collection area is generally Sacramento County and West Sacramento.

The potential customer is a waste hauling company which operates a postconsumer food collection program from restaurants and other institutions such as hotels and hospitals. This program could be expanded by including waste from larger institutions like food processors and grocery chain distribution centers. The waste collection company currently collects source-separated food waste from the city of Sacramento with the farthest feedstock source located about 15 miles from the digester.

For the **Canola Crush/Oil Extraction and Biodiesel Production Project**, the bulk of the feedstock is rice straw, which is collected from the farm on site of the digester. Most of the straw will be collected from farms owned by investors of the biodiesel plant, while the remaining straw will be collected from farms within a half mile of the biodiesel farm. Rice straw is currently baled on the field and placed onto a harrow for transfer to the digester, this process currently costs $30—$35 per ton to bring the straw from the field to the digester location. Tomato waste is also currently brought to the biodiesel farm for use as animal feed from two nearby tomato processing plants , located about six miles from the digester. The farm is currently paying $5 per ton to cover transportation costs from the processing plants to the farm. If the tomato waste were brought to the digester in quantities greater than can be used at once, the waste would have to be stored in a silage pit until needed. Cow manure is collected from a feed lot located on the farm that hosts the biodiesel plant and chicken manure is collected from chicken farms within 10 miles of the digester. The economic incentives for digesting rice straw include the following:

- Eliminates the need to flood the fields to decompose the rice straw ($17/acre).
- Eliminates the need to grind rice straw and till it into soil with tractors (less wear and tear on tractors, reduces fuel usage and GHG emissions, saves $33—$58/acre).
- Solves the problem of excess rice straw overwhelming the nutrients in soil.
- Can generate electricity from biogas.
- Can generate liquid and solid fertilizer products.

Food Processor Projects

Food processors are often paid for their food waste or have their waste hauled free because the food waste has value as animal feed. For the food processor project with a high solid waste stream, the processor is currently selling its waste for cattle feed at $40—$170 per ton based on the quality of the waste stream. This makes this project a particularly difficult economic challenge because the waste streams currently have a value that is difficult to match by the value of the electricity that could be produced. This processor is currently challenged to meet a strict diversion plan goal for which sending food waste to a cattle farm does not qualify. The benefit of meeting the diversion plan goals and the value of the electricity produced by the project would need to be very high to make this project economically feasible.

Digester Locations with On-site Feedstock Sources

For the other projects being analyzed by CWP, the feedstocks will be collected from on-site sources. During site visits, CWP engineers identified prime locations for the digester where transportation of feedstock and water would be minimized. The end use of the biogas also affects the location of the digester. In a project where the biogas will be converted to electricity, the feasibility of interconnecting to the grid was considered in siting the digester system. Proximity to heat demand may also be important for combined heat and power applications. In a project where the biogas is being refined into CNG, the CNG can either be injected into existing NG pipelines or it can be injected directly into vehicles equipped to burn CNG as transportation fuel. For the latter, the system should be located in a space with enough land for the fueling station footprint and in a location that is accessible to vehicles for fueling. For the former, the digester should be located as close to a NG injection point as possible to limit the high cost of laying additional pipeline (approximately $1,000 per linear foot). Space constraints must also be considered when designing the anaerobic digestion system. Low rate systems and feedstocks that require long retention times call for larger tanks or additional tanks, which will result in a larger footprint for the overall system. Space requirements for front-end processing of the incoming waste also need to be considered relative to the complexity of handling the materials. Disposal or further processing of liquid effluent and solid residuals from the digester system also play a role in determining the ideal location. All of these considerations must be weighed before picking a site for the digester.

5.3.1.7 Collection Fees for Feedstocks

For the municipal food waste collection project, the service area for feedstock other than Raley's and Campbell's soup will be all of Sacramento County and possibly the city of West Sacramento. Most of the surrounding counties and cities have exclusive agreements in place that will not allow us haul this material for a fee. If we haul for free we could most likely haul this feedstock but it would not be economical unless the material had a high enough value as a feedstock to offset transportation costs. The collection fees for this project will be based upon the tip fees at the digester and a franchise fee of 8—12 percent will be added.

For the biodiesel farm project, the collection fees are approximately $30/ton of rice straw. The rice straw will be collected from the closest radius to the digester to save on transportation costs.

For projects in which CWP picks up waste from the site and delivers it to a nearby anaerobic digestion site, collection fees will be determined by the cost that the company is currently paying for its waste disposal, the distance that the waste travels to reach the digester, and the preprocessing necessary. After analyzing these factors for the grocery store chain and the food processor plant, CWP determined that $35/ton of waste would be an economically feasible collection fee for those feedstocks.

5.3.2 Feedstock Procurement Program

The economic and regulatory feasibility studies conducted assumed that the SBR1 project would be able to consistently secure sufficient feedstock to maximize the designed capacity of the system. Doing so would produce enough biogas and residuals to ensure consistently high revenues for the project, while minimizing the quantity of waste being hauled to landfills and stored on site. The project partner, Atlas Disposal, has offered to work towards providing the feedstock needed.

The goal of the feedstock assessment is to determine the availability of digester feedstocks and develop a plan to access and deliver the appropriate quantities consistently throughout the life of the project, from startup of the 25-TPD Phase I system, through the scale-up to a 100-TPD Phase II system and onward into the future.

A detailed plan for securing feedstocks and anticipating issues is important for preventing shortfalls and minimizing project risk. The following discussion outlines the issues associated with procuring digester feedstocks and identifies potential solutions.

5.3.2.1 Feedstock Source Management

From the Cal/EPA’s website, the annual amount of food waste feedstock available for diversion in Sacramento County is estimated at 120,691 tons. This is 18.2 percent of the total MSW stream in the county. Since the Sacramento area currently lacks organic waste processing facilities, and those that can accept large volumes are at least 45 miles away, the SBR1 facility will accept waste from multiple collection companies. The waste will be weighed on scales located at the entrance of the facility and then taken to a material holding station. The material will be stored in the most optimum containers depending upon loading. The site will be able to accommodate both solid and liquid waste streams.

5.3.2.2 Collection, Transportation, and Storage

Project partner Atlas Disposal provides over 5,000 commercial businesses in the greater Sacramento area with custom recycling and diversion programs. These services include source separated recycling, mixed recycling, construction and demolition debris recycling, electronic waste recycling, and food waste recycling. The services provided were designed to meet the specific needs of the businesses or complexes being served. SBR1 will allow Atlas Disposal to expand its food waste recycling program and access new customers.

The top ten generators of food waste in Sacramento are restaurants, hospitals, managed care facilities, grocery stores, distribution centers, hotels, conference centers, food processors, schools, and correctional facilities. Atlas Disposal services roughly one-third of these Sacramento-region contracts today. In 2009, Atlas Disposal entered into a partnership with the Green Restaurant Alliance of Sacramento, a local nonprofit, to provide on-site technical assistance to help commercial customers separate materials for collection. Atlas and the Green Restaurant Alliance of Sacramento developed a collection program that allowed local restaurants to divert their organic wastes from landfills to composting operations. Since there are no other food waste diversion programs in the region today, the program has been extremely successful and has been expanding rapidly. Atlas Disposal currently collects pre- and postconsumer food waste. Materials are source separated and collected in 60-gallon carts. Materials include traditional food scraps such as fruits, vegetables, meat, dairy, and eggs, as well as other organic materials normally discarded after consumption including soiled paper, cardboard, compostable utensils and trays, and coffee grounds and filters.

The program is currently collecting 2.5 TPD of source-separated food waste from restaurants and other food establishments in Sacramento County. This waste is taken to an area composting operation and the end product is used in a farm operation in the Sacramento area. In order to grow the collection effort to 25 TPD, the collection will expand to the following waste sources:

- Restaurant residuals collected by Atlas Disposal
- Food processing waste from regional processing facilities (e.g., grocery store chains, hospitals, event centers, sporting facilities, hotels, and other large meeting facilities)
- Green waste from municipal collection systems

The feedstock "waste shed" for the municipal food and green waste collection company will be the Sacramento region. The waste shed will encompass a 50-mile radius around the digester, thereby ensuring that the digester will be the closest food waste recycling center for all of its waste providers. In the future, this project is planned to be scaled-up to 100 TPD. This will be accomplished by increasing the waste collection in the current waste shed before expanding the waste shed's radius farther from the digester. CWP will work with Atlas Disposal to implement planning software such as Microsoft Streets & Trips to map collection addresses and develop efficient collection routes. CWP and Atlas Disposal have already begun to establish new collection contracts for the SBR1 project.

5.3.2.3 Seasonality

Human consumption of food is relatively consistent throughout the year, but crop production rates follow the changing seasons. Therefore, wastes that are generated at the point of consumption (grocery stores, restaurants, cafeterias) are not typically seasonal (although their composition may be). However, organic wastes generated at the point of production (crop farms, postharvest crop processors, residential green waste collectors) may only be available during and shortly after the harvest. This poses a challenge because it creates a seasonal increase in collection activity, as well as in the amount loaded into the digester. Many seasonal feedstocks will likely have similar production seasons, creating a large overall surge in collection during that time.

One solution to this issue is to oversize the digester to be able to accept both the normal waste collection feedstock, as well as the seasonal, and to have extra trucks available to pick up the seasonal waste. The downside to this approach is that the digester will be running at less than capacity when the seasonal waste is not available, unless another waste source can be found for the opposite season. Running a digester under capacity severely affects its economic viability since the capital costs are unchanged but the revenues are reduced.

A second solution is to load the digester with the minimum quantity of waste available year-round and send the excess waste to other operations such as composting or landfill. This keeps the digester facility running at full capacity year round, but it limits the size of the system.

A third solution to this problem is to store the seasonal waste and feed it into the digester slowly in order to maintain a consistent amount of feedstock. Some agricultural wastes can be ensilaged for storage. Packaged food processing residuals such as off-spec cans, bottles, and bins could be stored in their original packaging on site with the packaging preserving the waste. Digesters are much more tolerant than humans and animals to partially decomposed food waste.

For the SBR1 project, the majority of the expected feedstocks—restaurant and grocery store wastes—are not seasonal). However, seasonal issues must be considered if the waste collection effort expands to include residential green waste or agricultural residues.

5.3.2.4 Customer Fluctuations

When a customer leaves or moves from the waste shed for the digester, a challenge arises with replacing their feedstock. Either a new customer must be recruited or the existing customers' waste diversion needs to be increased. This could affect truck routes and scheduling. A customer joining the waste shed for the digester creates a challenge of making a truck available for pick up and room in the digester for the increase of waste.

One solution for dealing with the challenge of customer fluctuations is to design the digester system to be as flexible as possible in accommodating a wide range of feedstock types. The digester can accommodate feedstock shortages without altering the base design, although biogas production will decrease if feedstock volume decreases. Biogas processing systems can be turned down to different extents depending on the system. Digesters have a maximum loading rate that cannot be exceeded without physically expanding the system. However, this maximum is a moving target. The CWP digesters are designed with some additional capacity, but the practical maximum is unknown. Similarly, biogas processing systems are designed with a maximum flow capacity that can be extended slightly. The CWP digester system will be designed to accommodate some fluctuation in feedstock quantity and much greater fluctuation in quality (i.e., moisture, fiber, and protein content), but very large, sudden changes in feedstock volumes will affect the system. Therefore, it will be important to have a variety of contracts, both large and small, so that any given loss or addition to the feedstock would not materially impact the operations of the digester system.

5.3.2.5 Variability in Waste Stream

Variability in the waste stream can pose a challenge when it entails more contamination, because it requires more preprocessing work. Bacteria can also become accustomed to digesting a particular feedstock and will not be able to efficiently break down another type if it is switched quickly. For example, if bacteria is used to digesting a low-protein feedstock such as grass trimmings, and is suddenly fed meat scraps, the digestion could be inhibited. Therefore, heterogeneous feedstocks are preferable for the digester. This also ensures that all of the proper micronutrients are present.

For the SBR1 project, CWP and Atlas will make sure contracts are established with a wide variety of feedstock providers, resulting in heterogeneous feedstocks. This is inherently designed into the hauler's collection model by contracting with large and small customers. The feedstock variability would further increase if crop and yard wastes are incorporated. Green waste could also be sent to area landfills for use as alternative daily cover if more digestible and energy rich feedstocks become abundant.

5.3.2.6 Route

Picking up feedstocks can pose a challenge because transportation costs are significant. This becomes especially considerable when the quantity of feedstock at a single location is small. A model will be developed to analyze the quantity and energy content of the feedstock versus the cost of pickup. Customer interest in participating in a digestion program should also be considered because if the customer is willing to pay a higher tipping fee to have their waste picked up, then including that feedstock may be feasible despite its distance from the digester and the energy content alone.

One solution to this issue is to make sure that the project partners prioritize waste for digestion. Since food waste provides the highest energy content, the restaurant and food processing collection system will be the highest priority. Other wastes like agricultural and collected green waste can be collected and brought to the site. When demand allows, this waste can also enter the digester system and, when it is not available, used as alternative daily cover at area landfills.

5.3.2.7 Competition

Competition can be a difficult challenge to overcome in the collection of feedstock. Landfill fees have not risen significantly in California, making it difficult to compete with traditional landfilling. This challenge can be met by keeping operating costs on the digesters as low as possible. The digester should also be marketed as a more environmentally friendly and renewable way to dispose of waste, which customers could use to promote their sustainability efforts. A customer may be willing to pay a premium to dispose of waste in a digester rather than a landfill if doing so can be used as a marketing promotion to increase business or help meet sustainability requirements.

Another competitive challenge will be other digestion projects that may be developed after this project is completed (including other CWP systems). A solution to this challenge is to ensure that customer contracts are established in a manner that would not adversely affect the project if customers choose to move their waste to another anaerobic digestion project which may be developed. These contracts would be longer in period and would overlap so that a large number of customers could not leave the project at one time. A pricing strategy will also be implemented that is competitive in the market to current conditions. CWP and Atlas Disposal have developed a pricing strategy that is equal to area composting and landfill operations. Any additional projects that may be developed later will need to compete in the market and make sure that their rates can compete. This project will have significant market differentiation as the first fully commercial digester located in the Sacramento region. Project finance for additional projects will have a much higher threshold to overcome due to this differentiation and current waste contracts.

A solution to this challenge will be to design a modular facility that can be expanded easily to meet further demand. The project location is currently permitted to treat over 300 TPD. The current digester construction plan is to develop this project in phases and scale up the system size. The design includes a mechanical system that can handle up to 100 TPD of waste with tank volume that equals 25 tons a day in Phase I. Phase II will scale up the facility (after demand is proven) to 100 TPD by adding additional tank volume. If demand further allows, CWP has designed modular system skids that could be implemented and installed, along with additional tanks, operating in a parallel manner to the original project.

5.3.2.8 Securing Long-term Contracts

Research performed in 2005 by the CEC noted that "potential developers find difficulty in securing long-term contracts for biomass, especially from public lands agencies and in areas with fragmented federal, state and local ownership patterns." [i] This problem is being addressed by partnering with a company that already has contractual relationships and is providing organics management services. Additionally, waste companies like this partner are accustomed to long-term contractual relationships to ensure their collection capital investments are protected. This strategic partnership allows the hauling partner to expand its current route services and scale up its business. Contracts would be entered into by the hauling partner, which will in turn contract with the project partnership to manage the waste and pay a tipping fee. The hauling partner will be responsible for billing the customer for tipping and collection transportation fees as well as all customer service activities. The partner currently is providing all of these services as a part of its business plan and is extending additional offerings not currently available in the region.

Feedstock commitment letters of intent have been collected by several food processors in the Sacramento area. In order to keep customer information private, these letters will not be included in this report but will be available to the CEC if requested.

CHAPTER 6: Technical and Process Flow Requirements

6.1 Key Findings and Conclusions

In Task 6, CWP developed and submitted preoperational design specifications for a 25-TPD commercial Anaerobic Digester plant based on the physical and chemical characteristics of the biomass streams as determined in prior research and plans. Critically, CWP optimized the system design to improve overall system performance and the performance of the anaerobic digestion process. Utilizing research from previous tasks, CWP substantially increased the quality of the residuals recovered from the digester effluent.

6.2 Summary of Activities Performed

In Task 6, CWP performed the following tasks:

- Developed the pre-engineering feasibility and preoperational design of a 25-TPD commercial Anaerobic Phased Solids Digester plant based on the physical and chemical characteristics of the biomass streams (Task 6.1).
- Reviewed and completed preliminary design of the processes for digestate treatment to achieve effective separation of solids and nutrients from the water and produce compost, concentrated liquid fertilizer, and clean water (Task 6.2).
- Reviewed digestion test results, reviewed and completed preliminary design and feasibility of the gas cleanup system, and defined the specifications and preliminary design of the compression, storage, and delivery systems for conditioning the cleaned biomethane gas (Task 6.3).
- Provided the pre-engineering and preoperational design requirements for the auxiliary power needed for feedstock handling and processing, digester heating, residual recovery and filtration, biogas cleanup, and compression of purified biogas for CNG delivery for use as a vehicle fuel (Task 6.4).
- Assembled subsystem designs into a comprehensive, integrated predesign package suitable for final engineering, design, construction, and procurement (Task 6.5).

6.3 Description and Results

The Task 6 subtasks are described below.

6.3.1 UC Davis Digester Design

The goal of Task 6.1 is to provide the pre-engineering feasibility and the preoperational design of a 25-TPD commercial Anaerobic Digester plant based on the physical and chemical characteristics of the biomass streams as determined in prior tasks.

CWP's design methodology takes Dr. Zhang's proven UC Davis technologies and applies packaging and standardization features that allow the systems to be modularized, prefabricated, and tested in a controlled environment before delivery to a customer site. There are several advantages to this approach:

- Standardization of design and commonality of parts leads to lower system costs and improved reliability and serviceability.
- 80 percent reduction in custom system engineering.
- Fabrication in a controlled "factory" environment with all trades "in-house."
- Shop labor rates vs. field labor rates and expenses along with more robust tools and fixtures in the shop environment reduce costs.
- Fully prewired and tested modules (or skids) that are ready for field plug and play at the customer site, resulting in installation and start-up times 75 percent shorter than traditional field constructed designs.

6.3.1.1 CWP Features and Added Intellectual Property

During the process of productizing this technology, CWP has introduced additional subtle changes that also facilitate low cost operations, high reliability, and a design that can be fabricated to specification close to the customer site at a prequalified electro-mechanical partner's site (CWP's Virtual Factory of Excellent Partners). Many of these changes include CWP intellectual property that are confidential and cannot be included in a detailed discussion. In summary, the improved features include:

- Combined process hydraulic functions (load/mix/transfer/unload).
- Reevaluation and optimization of all materials of construction.
- Built-in standard process component and instrumentation redundancy.
- Improved tank design, insulation, and integral heat transfer devices.
- Fully-integrated controls, instrumentation, human-machine interface, data collection, and offsite monitoring capabilities.
- "Designed in" standard heat recovery and energy saving features.
- Multiple technologies and partners and options for front-end material handling as well as back-end gas processing, power generation, and residuals processing.

6.3.1.2 HRD-digester Preliminary Engineering Design Specifications

As noted earlier, CWP has endeavored to productize a standard product wherever possible to simplify the hardware of the anaerobic digestion system. The second part of developing an application-specific design is to determine the process parameters that define the process conditions, recipes, and sequences that are appropriate for each customer application. While most of the details of this process involve confidential algorithms and formulas, they are generically described in the following sections.

6.3.1.3 Front-end Process Design

Based on both feedstock type and customer preference, the front-end is a partner-supplied module that introduces feedstock into the anaerobic digestion system. There is an array of options that can be used and the design is based on a number of parameters:

- Size, wetness, and other variation of the feedstock properties
- Contamination and the need to sort, size, and separate materials
- Customer site constraints (e.g., site area restrictions, odor control, interface with existing systems, manual vs. automation considerations)
- Other customer considerations (e.g., budget, aesthetics, expandability, owner-operator vs. third party)

CWP has developed and is continually expanding the options applicable to the design of front-end processes. Most of these unit operations are well understood and the focus is on partners and processes that will provide the highest reliability for the end user. A CWP applications specialist or engineer works with the customer to decide upon the optimal process design.

6.3.1.4 Anaerobic Digestion System Modeling and Design Based on Feedstock

Usually the first step in a specific system design is defining feedstock material properties and variation and inputting them into a proprietary simulation model developed by CWP research and development. The results are a number of parameters that include:

- Process material balance and energy balance
  - Biogas production, quality, and characteristics
  - System heat requirements and potential heat recovery
  - System power requirement and potential power output
  - Process estimates for byproducts and residuals
- Quantity of process tanks and dimensions of each
- System spatial footprint
- Additive and input requirements for system operability

In order to provide a constant reference for this design analysis, the following design parameters resulted from the process model used:

- 100 TPD of a mixed food and green waste feedstock (70 percent MC)
- Total system capacity of 900,000 gallons in three reactors
- Mean biogas production of 300 SCFM, assuming continuous loading at maximum designed loading rate and steady-state conditions
- Liquid effluent processing of 20,000 gallons per day
- Removal of solids of 30 TPD
- Biogas converted to transportation-grade renewable CNG (4,000 psi)
- Mean annual ambient temperature of 60°F (15.6°C)
- Operating digester temperature of 130°F (54.4°C)

6.3.1.5 Biogas Refining

The disposition of the biogas as a transportation fuel, electricity, or heat is a customer preference. For purposes of this grant, the focus is on transportation fuels. Detailed descriptions of the biogas refining equipment needed and potential vendors are provided in the subsequent sections of this report.

6.3.1.6 Power Generation Design

Although the biogas produced by the digester for this analysis was assumed to be converted to transportation fuel, some of the biogas could be utilized to provide the electricity and heat needed by the digester system and its supporting unit processes. References in this report are made to power and heat generation in regards to management of these parasitic system loads. A number of options are available and the design will be defined for each specific application in the subsequent sections.

6.3.1.7 Back-end Process Design

Design of the backend processes is similar to the front-end in that it involves one or more key partners integrated with CWP's equipment and material flow. The design is based on:

- Anaerobic digestion system's specific effluent properties.
- Markets for the liquid and solid byproducts.
- Customer's preference or interest in handling the solid and liquid byproducts.

Once again an array of options is available depending upon the specific needs. A CWP applications specialist or engineer will assist in determining the best combination of options to complete the design.

6.3.1.8 Ongoing Customer Support and System Monitoring

While service and support is outside the scope of this section, it is worth noting that CWP's business model is based upon continuous process monitoring and customer support. This model results in a flexible system where feedstock mixes and operation configurations can be fine-tuned and updated to maximize system efficiency and eliminate operating errors, effectively updating the original design.

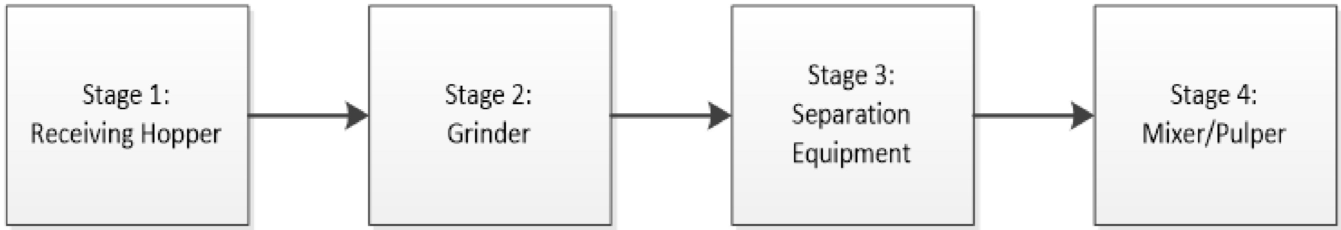
6.3.1.9 Review and Selection of Equipment Vendors and Alternates

This section lists a sampling of equipment vendors and alternates for the various sections of the design. In the cases of proprietary relationships, the vendor and/or trade names have been omitted to protect the privacy of the participants.

6.3.1.10 Front-end Equipment

The front-end equipment can vary greatly depending on the size of project as well as the variability of feedstock. The main goal of the processing equipment is to ensure that the digesters are receiving the organic fraction of the feedstock, free from metals, glass, and other unwanted materials, in a state that is appropriate for encouraging rapid degradation of the material (i.e., reduced particle size and proper MC). For a generic feedstock requiring particle size reduction and removal of contaminants, the front-end equipment will consist of four unit processes for receiving waste, reducing the particle size, removing contaminants, and preparing the material for transfer to the digester (Figure 28).

Figure 28: Front-end Flow Chart



Source: Clean World Partners, LLC

It is important to note that the order of the grinder and separation equipment (Stages 2 and 3) can be switched, and that the arrows between the stages represent either conveyor belts or hydraulic pumps to move the material along. The only stage that does not consume power is the receiving hopper but immediately thereafter conveyors or pumps are used to move the material. It is also possible to install a "moving floor" hopper, but for the purpose of this report we will focus on power demand from Stages 2, 3, and 4. Several technologies have been investigated for preparation and handling of 100 TPD of mixed solid wastes containing significant levels of contamination with inorganic materials. A sampling of that work is summarized here.

DODA Preprocessing Option

Doda® supplies equipment for separating organic material from inorganic material. The company is based in Italy and does most of its business on the European continent. Doda's product line includes equipment that could provide all four stages needed for front-end processing (see Figure 36). The first stage of the DODA system is the separation unit, which separates nonorganic content from the feedstock. The feedstock is deposited directly into the loading hopper of the machinery, and through a process of screens and augers the nonorganic material or contaminants are separated out. The unit is powered by a 75 kW electric motor and can handle processing of up to 120 TPD in eight hours. The organic fraction of the feedstock is then transported via conveyor belts to a grinder that prepares the feedstock for the digestion tanks. Once the feedstock has the desired particle size, water is introduced to the system and the resulting slurry is pumped through a chopper pump to the anaerobic digestion tanks. One of the attractive features of using this vendor's system is that the equipment is scaled to meet the requirements of the project. In many cases the material handling capabilities of other suppliers far exceeds the maximum throughput of the projects. As a result, the total electrical load of the system is lower than its competitors and the footprint of the overall system is decreased. On the other hand, if the project were to scale to a higher throughput there would be limitations based on the loading equipment.

Komptech Preprocessing Option

Komptech is another company based in Europe that manufactures front-end processing equipment, but it has offices and a distribution network in the United States. The Komptech system can easily process 100 TPD and leaves much room for scalability for future growth. Unlike the DODA system, the Komptech solution begins by shredding the feedstock as the first stage of processing. The shredder unit utilizes a 242 kW electric motor to process the material, which could easily handle processing 100 tons in four hours of operation. The next stage of the process, includes separation machinery, which uses a pressure blower to lift the light fraction contaminants off the conveyor system, and also separates the heavy fraction out of the feedstock with magnetic head pulleys. The last stage of this design includes a mixing tank to introduce water to the feedstock for ease of transportability to the digester tanks. An advantage of this system is that the equipment can be delivered with the necessary conveyor belts to move the material throughout each stage of the process, which would decrease integration costs. Having a dealer network in the U.S. allows a closer line of communication with both technical support and repair services. Altogether, the system could consume around 315 kW of electricity, but the hours of operation would be reduced to four hours a day. The Komptech system is more expensive than other solutions, but can also handle processing more feedstock as the project may grow in the future, and thus the increase in biogas created could possibly decrease the rate of return on capital investment.

6.3.1.11 Anaerobic Digestion System (CWP)

The anaerobic digestion systems include the following subcomponents. The tanks, controls, and heating will be on a single modular skid that is designed so that it can be used for a 10- to 100-TPD system by changing the size of the tanks as well as a few key subcomponents:

- Tanks – multiple generic suppliers
- Controls (instrumentation, actuators, variable frequency drives) – proprietary partner
- Fluid handling (pumps, valves, nozzles) – various proprietary suppliers
- Heating (boiler, pumps, thermal control valves) – various generic suppliers
- Gas handling and safety (refining, flare, over/under pressure relief) – various proprietary partners
- System electro-mechanical integrator – proprietary partner

6.3.1.12 Biogas Refining

Some biogas refining must be done regardless of the end use of the biogas. At a minimum, the hydrogen sulfide (H_2S) must be removed before the gas can utilized or even flared due to air board regulations. For electrical generation equipment or CNG creation for transportation fuels or pipeline injection, further refining must be performed on the biogas. This information is analyzed in detail in the interim report for Section 6.3 of the grant. The possible components of a gas refining process include:

- H_2S removal
- Water removal
- CO_2 removal
- Siloxane and VOC removal
- Organic sulfur removal
- Particulate matter removal

Biogas refining and processing specifications will vary depending on the end use of the biogas. Applications such as flaring the biogas or using it in a boiler will reduce the need for extensive biogas refining, while creating CNG for transportation fuel or other more sensitive end uses will require stringent biogas refining. For more detailed information on the biogas refining required for transportation fuel and pipeline injection, see interim report for Section 6.3. For further analysis on the biogas refining necessary for use in an electrical generation system to off-set the parasitic load, see interim report 6.4.

6.3.1.13 Power Generation

Power generation equipment specifications will vary based on the technology chosen to offset the parasitic load. Considerations taken when choosing an electrical generation technology will be based on the following criteria:

- Availability and suitability of equipment sizes
- Capital cost
- Cost of complementary equipment required (e.g., for biogas conditioning)
- Installation cost
- Operations and maintenance costs
- Turn-down ratio
- Electrical conversion efficiency
- Availability and efficiency of heat recovery (cogeneration)
- Availability of federal, state, and local financial and regulatory incentives
- Customer interest in specific technologies
- Emissions profile and environmental impact
- Ability and ease of obtaining permits
- Length of market experience and track record

6.3.1.14 Back-end Processing

Back-end processing consists of separating the solid and liquid effluent and turning it into value-added products, including liquid and solid fertilizers. The technologies used for back-end processing are analyzed in the interim report for Section 6.2.

6.3.1.15 RFP/RFQ System Specific Bid Specification Details

This section summarizes a partial list of parameters to be included in equipment RFP/RFQ packages. While CWP is closely involved in defining and monitoring this process, the actual vendor qualification and procurement will be executed with one of our principal partners. The last subsection covers generic RPF/RFQ concerns.

Front-end Specification Details

- 100 TPD processed during six to seven hours of an eight hour shift (15—20 tons per hour)
- Mixed food and green waste of less than 12 inches to be introduced into anaerobic digestion system chopper hopper pump at less than one inch mixed with water.
- Size, shape, and density separation capabilities

Anaerobic Digestion System Specification Details

- Tanks or vessels
  - Built per code and foundation details referenced on supplied engineering drawings.
  - Materials to be CS/SS/Concrete or other proven system with corrosion resistance at pH 3—9 and in presence of H_2S.
  - Integrated heat exchange coils to be SS tubing with welded or swaged fittings.
  - Insulation polyurethane foam or other standard insulating material and finished with weatherproof siding or CWP approved epoxy system (top and sides). Color per customer to be determined (TBD).
  - Tank head space to be tested to +6psig pressure and -0.50psig vacuum. Leak tested to less than [TBD] l/min air at +3.0 psig
  - Tank roof fixed steel dome fitted with flame arrestor and over/under pressure relief set at +2.4 psig and -0.05 psig.
  - Bio-media or other "column packing" materials as specified
- Process pallets and controls – CWP proprietary based on Anaerobic Phased Solids technology
  - Controls and instrumentation
    - pH 3—9 with integrated rinsing system to prevent fouling and removable electrodes for regular manual calibration
    - Gas flow meters: thermal mass flow meters calibrated in 60:40 mix of CH_4:CO_2 with software compensation for gas composition variations
    - Pressure sensors for level sensing (35' water column) and headspace pressure monitoring (-0.5—6 psig)
    - Temperature sensors calibrated for linear measurement at 60—160°F
    - Gas composition
      - CH_4/CO_2/O_2: combustible LEL 0—80 percent
      - H_2S: 10—10,000 ppm plus Draeger sensors for safety monitoring
      - Siloxane (optional): ppb level sensitivity
      - H_2 (optional, may be included in combustible LEL)
    - Water composition
      - Volatile fatty acids (acetate: 0—5,000 mg/L, propionate: 0—1,000 mg/L)
      - Ammonia: 100—10,000 mg/L
      - Alkalinity: 1,000—50,000 mg/L CaCO3
      - Suspended Solids: 100—50,000 mg/L (lower if used for effluent from dewatering)

        - Feedstock quality monitoring
            - TS & VS (5—35 percent w.b.)
        - Software
            - PLC
            - Human-machine interface
            - Data Acquisition
            - Remote Monitoring
    - Pumps
    - Valves and actuators
    - Materials of construction
    - Finishes

6.3.1.16 Biogas Processing Specification Details

- 300 SCFM biogas refined to end-use specifications 24 hours per day.
- Biogas conditioning system able to turn-down to 50 percent of maximum rated output.
- Gas refining skid will divert biogas through H_2S removal system and then to flare if the refining system is unable to operate.

6.3.1.17 Power Generation Specification Details

- Power generation equipment will provide enough electricity to offset the parasitic load of the entire anaerobic digestion system.
- Power generation equipment will be able to turn-down to 50 percent.
- Heat recovery unit included in the proposal for the power generation equipment.
- Installation package includes interconnection to grid.

6.3.1.18 Back-end Specification Details

- The back-end of the anaerobic digestion system will separate the solids from the liquid effluent either mechanically, thermally, or chemically.
- The back-end system will blend in the additives necessary to create the value-added products.

6.3.1.19 Generic Equipment Specification Details

- Complete site prep, installation details specification, required and optional ancillary equipment, and quote including permitting package to be submitted before PO is assigned.
- System price to include supervision of delivery, rigging, installation, and start-up of system.
- All system components to be warrantied (parts and labor) for a minimum of 18 months after start-up and acceptance.
- Recommended spare and consumables to be priced and provided with proposals.

- Full documentation including drawings, operation, service manuals, and parts lists, etc. to be provided in electronic format (e.g., PDF).
- Servicing agreement including operations and maintenance cost.
- Payment terms: (To be negotiated). Minimum of 20 percent retention to be held until acceptance sign-off.
- Performance Bonus/Penalty – TBD along with delivery schedule.
- Equipment to be powered via efficient electric source with single point connection (i.e., 480VAC/60HZ/3PH). Average, peak, and typical power requirements to be specified.
- Equipment will send status and error communications (TBD) to anaerobic digestion central control and human-machine interface.
- Service and spares parts availability to be provided to ensure MTTR of one day or less for all minor faults and three days or less for all major faults requiring the replacement of a single failed component not due to abuse or negligence.

6.3.2 Residual Processing and Filtration Summary Report

The goals of Task 6.2 are to review and complete the preliminary design of the processes for digestate treatment to achieve effective separation of solids and nutrients from the water and produce compost, concentrated liquid fertilizer, and clean water as valuable products.

6.3.2.1 Overview and Background on Residual Processing and Filtration

Processing of the effluent from the digester is critical in the creation of valuable products and clean water. Effluent from the digester may be converted into a valuable product, composted, disposed of at a land fill, or treated to enter the wastewater stream. The quality of the effluent will vary greatly from project to project, based on the feedstock entering the digester. In cases where the feedstock is primarily food waste, there will be low amounts of solids in the mostly liquid effluent (0.5—2 percent by weight) much of which will consist of potential crop nutrients (e.g., N, P, K, Ca, Mg). Contrastingly, in projects with less digestible feedstock such as rice straw or cardboard, there could be 10—15 percent solids in the digester effluent prior to solid/liquid separation. In addition, the effluent streams may have high BOD and ammonia levels that could necessitate treatment prior to beneficial use or disposal.

6.3.2.2 Front-end Processes that Have an Impact on Residual Processing and Filtration

Presorting the feedstock to remove inert contaminants is a desirable strategy to optimize energy creation as well as increase the potential for valuable effluent. The challenge as waste streams become more blended with source-separated food and green waste is that contaminants often enter food and green waste bins and these contaminants can be difficult to sort from the desired organic waste. Also, wood and other cellulosic materials are often permitted by municipal collection agencies, and these materials are more difficult and much slower for the digesters to break down. Mixing organic materials that are quick to digest with other materials that are slower to digest, results in a larger fraction of solids in the residual effluent from the digester. The most challenging waste stream, from an organics separation perspective, is a MSW stream in which every kind of waste is mixed together. However, this is the least challenging stream from the perspective of the customers and the collection agency. Separating organic waste from a mixed waste stream is labor and/or equipment and energy intensive and often results in a low organic recovery rate. A cost/benefit analysis can be used to determine whether the cost reductions associated with simplified public education and collection justify the costs incurred in organic separation technology. However, even source-separated organic waste streams inevitably become contaminated to some level with undesirable materials.

It is important to have an understanding of how different feedstock can affect the components and thus the value of the effluent. For example, if mixing a more N-rich feedstock with the current feedstock could increase the N content of the effluent, making it a more premium fertilizer product, then it would be advantageous to mix the feedstocks in the proportion that would maximize the efficiency of the digester as well as the value of the effluent.

6.3.2.3 Potential Products of Residual Processing and Filtration

Compost and Soil Amendments

Solid residuals from the digester have the potential to be high-quality soil-amendment products. The composition of the residuals will vary greatly based on the feedstock entering the digester, and in most cases the residuals will need to be concentrated or have nutrients added to increase their value. In projects where manure is used as a feedstock, pathogen testing and destruction may be required for the effluent to be suitable for use on land used to grow food crops. Depending upon the volatility of the residual material from the digester, the effluent may need additional aeration and maturation time (from a few days to several weeks) in a traditional composting operation. The overall time required to convert organic waste to useable compost via anaerobic digestion followed by aeration, however, is typically a fraction of the time required for aerated composting alone.

Dilute Fertilizer

Creating dilute fertilizer from the digester effluent will require the least amount of treatment after digestion. The effluent simply needs gross suspended solids removal, possibly minimal aeration to reduce residual BOD, and some additives may be mixed with the effluent to increase its value. Dilute fertilizer is only economical when sold in close proximity to the digester in order to reduce transportation costs because it generally has a much lower selling price per ton than concentrated fertilizer.

Concentrated Fertilizer

Concentrating the nutrients in liquid effluent to produce concentrated fertilizer requires additional processing, such as moisture removal and nutrient additions, but it will make the product economical to sell to a wider range of customers. Various technologies are being considered and tested that could concentrate the digester liquid effluent in the range of 2:1 to 10:1. In addition to concentrated fertilizer, the concentration processes may create a potentially large permeate stream that will consist primarily of water with different qualities depending on the processes used. Several uses for the liquid permeate are being explored.

Residual Water

Grey water coming out of the concentrated fertilizer process must be treated to city standards to enter the sewer system. Constituents expected to require removal include excess BODs, N (as ammonia, nitrates and/or nitrites), and excess suspended solids. Although pH is expected to be neutral, it too would have to be monitored and possibly adjusted prior to disposal. The anaerobic digestion process often leaves wastewater cleaner than when it entered the digester and extracts useful water from solids that may otherwise end up in landfills, but the water coming from the digester would still be expected to meet the necessary standards for discharge to sanitary sewer.

In some projects, the water coming out of the concentrated fertilizer process may be a valuable product that could be land applied directly, with any residual nutrients making it desirable for irrigation applications. However, the water may require odor mitigation if too many residual volatile compounds remain, especially when the permeate is used on land in residential areas.

Since the water coming off the digester is hot (125—135°F [51.7—54.4°C]) and the feedstock entering the digester must be heated to approximately 135°F (57.2°C), for feedstocks that require dilution, recycling the effluent water back into the digester can save on heating costs and reduce water usage for the project. Certain dissolvable elements (e.g., Na) may need to be monitored in order to ensure that they stay below allowable limits, and the fraction of the permeate that can be recycled may need to be limited to prevent the build-up of excessive mineral concentrations in the digestion process.

For an anaerobic digestion project adjacent to processes that require low-grade water, it may be beneficial to utilize the effluent water in those processes, thereby reducing the unnecessary consumption of clean water. The permeate from the fertilizer concentration process may provide a good influent to concurrent processes that require water but may be tolerant of the low levels of BOD and other contaminants present in the permeate stream produced by the anaerobic digestion system.

6.3.2.4 Challenges of Predicting Product Quantities, Qualities, and Values of Anaerobic Digestion Byproducts

Feedstock Variation

There are many challenges in predicting the product quantities and values of anaerobic digestion byproducts. First, for some sites, particularly agricultural projects, the volume of feedstock available is not consistent year round. The type of feedstocks available can also vary from month to month as different crops produce waste at different seasons. An anaerobic digestion system works most efficiently when the volume and type of feedstock is constant and the system is scaled for those values. Lack of certainty in the amount and type of feedstock can change the rate of digestion or even prevent the bacteria from being able to break down the feedstock. For example, in a digester which is fed rice straw and chicken manure, if the chicken manure were to no longer be included in the feedstock, the bacteria would have an overload of carbon and not enough N to continue the digestion process. This can be mitigated by introducing a N additive but it could increase the cost of operations and alter the digester effluent. Similarly, variability in volumes of influent wastewater, product mixes in food processing operations employing anaerobic digestion systems, and seasonality of waste production also introduce challenges to the stability of operations. One method of managing fluctuations in feedstock flow rates and qualities is to include storage systems and blending tanks in the overall system design.

Effects of Storage of Feedstock and Byproducts

The type and size of the storage system must be evaluated on a site-to-site basis depending on the type, quantity, and seasonality of the feedstock to be stored. For systems treating varying flow rates of feedstock with high-water content, the day-to-day variability can be buffered with a storage tank sized to hold the difference between the average daily flow rate and the maximum daily volume received. Differences in compositional quality from several incoming streams can be reduced by incorporating a small blending tank for mixing the streams. Seasonally produced materials such as agricultural and food processing residues may be stored by ensiling the materials, which encourages the production of natural lactic acid that helps to preserve the material and prevents excessive degradation and odor production. The ensilage process may require some moisture control to ensure efficient fermentation for lactic acid production. In addition, silage piles may need to be covered to prevent rain from leaching out useful organics and altering the MC.

Seasonally produced feedstocks with very high MCs may be stored in large hydrolysis tanks, but these tanks will produce gas that may need to be filtered to remove VOCs and odorous compounds. The size of the storage tank may be limited by physical dimensions for very short production seasons with very high overall volumes of waste produced.

Fertilizers created through anaerobic digestion processes face similar seasonality issues as they generally can only be used during growing seasons, which vary by region. For instance, liquid fertilizers created through the process tend to be quick release fertilizers meaning they are dissolved quickly when nutrients are needed. When crops are not ready, there must be methods of storing that maintain the stability of the product until it can properly applied, increasing costs of distribution and for the customer.

Having a firm understanding of how the feedstock entering the digester affects the potential value of the effluent products in critical is designing the most economically attractive anaerobic digestion system. Although each project will vary greatly depending on its size and feedstock, the trends between feedstock, process, and effluent will be tracked and analyzed by CWP to enable predictions of effluent values. This knowledge will be placed into a database and will allow for more accurate economic analysis for future projects.

6.3.2.5 Management of Gross Solids and Fibers

Large solid particulates and fibers can be an impediment to digestion. These large particles can clog filters and interfere with other downstream unit processes. Fortunately, they are easily separated with a range of available technologies. When collected and dewatered, these gross solids become a valuable product or feedstock for a value-added process such as composting, vermiculture, and others.

A **filter press** is a series of filters that are loaded with effluent and then forced together with a hydraulic press. Filtra Systems manufactures the Verti-Press EF Filter, which has a diaphragm capable of compressing cakes to 94 percent solids. The Filtra Systems filter press is fully automated with few moving parts and uses water as the operating fluid, minimizing the need for compressed air. Filter presses operate in batch mode and require considerable capital and operating expenses. Generally speaking, their efficiency is quite good and they are tolerant to great swings in process conditions.

In a **belt filter**, effluent is fed into the machine by a hopper onto belts between two filter cloths, which are then fed through rollers that squeeze water from the effluent. After the final set of rollers, the filter cloths are separated and the solid cake is removed. Siemens makes a Compact Belt Filter machine, which has low capital costs and requires a small footprint, as well as a Static Radical Wedge belt filter, which is available with one or two meter belts to accommodate different ranges in process flow requirements. The latter machine also features a dual belt drive system that ensures equal pressure is applied to each belt. Belt filters operate as continuous processes and have efficiencies comparable to filter presses. Capital costs are generally lower, as belt filters require less supporting equipment.

A **screw press** is a slow-moving, continuously turning mechanical device that separates solids from liquids by forcing water through screens surrounding a progressively smaller volume. Fukoku Kogyo Company designs and manufactures screw presses from four inches to 30 feet long, depending on the desired flow rate of material through the press. These systems are upgradeable (via internal steam injection or other thermal processes) to produce class A biosolids and have simple, unattended operation.

The **rotary press** works by rotating effluent between two parallel screens, allowing the filtrate to pass through the screens while the sludge continues through the channel, resulting in a very dry cake. The company Fornier specializes in rotary presses that have a low footprint, continuous operations, and high cake dryness. A rotary press can be used for dewatering, but has the disadvantage of requiring a polymer to separate the solids off the screens. Polymers need to be replaced as they are consumed and can be considered a contaminant in the effluent.

Centrifuge processes can be designed to dewater slurry mixtures with very high efficiency. Some systems even have the ability to separate solids less than one micron in diameter from liquid slurry. A centrifuge works by spinning effluent in a bowl with propeller blades that accelerate the liquid upwards at full rotational speed. The particles that are heavier than the liquid then separate and are deposited on the perimeter of the bowl, forming a dry cake in batches. The liner of the centrifuge needs to be removed when full. The liquid passes through a hole at the center of the bowl.

US Centrifuge Systems manufactures many types of centrifuge systems including manual cleaning and self-cleaning models. It also make horizontal decanter centrifuges, which have an especially small footprint and are easily adjusted for different amounts and types of effluent. Capital costs are generally high, yet operations can be highly automated.

6.3.2.6 Management of Suspended and Dissolved Solids

After removing gross solids, small particulates (0.1—100 microns in size) can remain. Because of their small size, they tend to remain suspended in the liquid effluent. For some projects, these suspended solids must be removed either to meet wastewater standards or in preparation for further downstream processing. The concentrated solids can be combined with the gross solids removed previously or they can be disposed of.

Much of the digester's liquid effluent consists of dissolved solids (i.e., nutrients and salts) that will not be removed by the same techniques used to remove the suspended solids. Many of these dissolved components, such as ammonia, calcium, potassium, magnesium, and phosphates, have value. In general, anaerobic digestion systems reduce the concentrations of many wastewater contaminants, such as BOD, sulfates, and coliform bacteria. However, some of the stable, soluble components such as salts and minerals become concentrated as the volatile solids leave the system as biogas and water vapor. Processes can be used to concentrate these desirable constituents in order to increase the value and marketability of the effluent liquid. Both the removal of undesirable elements, as well as the concentration of desirable factors can be achieved with mechanical, thermal and/or chemical processes.

Mechanical/Physical Separation Processes

Some of the simplest forms of concentration involve the mechanical separation of substances by either particle size or particle density. Large holding tanks (settling tanks or clarifiers) used with or without flocking agents allow time for particles to settle from the liquid by gravity separation. This is typically the least expensive method for removing suspended solids. However, settling may require long retention times that necessitate large footprints and the smallest suspended solids will not settle no matter how long the retention time.

Filtration (including coarse and fine screening) is a faster method of reducing TSS levels in effluent water. Different sized filters can be used in series to progressively remove smaller and smaller particles. The simplest filter is a bag filter in which the liquid is pumped through a filter housing containing a replaceable mesh bag. Bag filters are generally recommended for removing particles 1—100 micrometers (um) in size. In contrast, cross-flow membrane filters can remove suspended particulates of 0.1—10 um from liquid effluent streams in a continuous process. The tangential flow of the effluent prevents the membrane from clogging completely and allows the effluent to be recirculated through the membrane. Cross-flow membranes come in extremely fine sizes.

Ultrafiltration membranes (0.1—0.03 um), use semi-permeable synthetic membranes and high pressures to pass very small dissolved chemicals and water through the membrane. Itasca makes an ultrafiltration system that is capable of removing contaminants larger than 0.03 um at a flow rate of 600gpm. This generates a permeate stream of sufficiently high quality to allow it to be classified as "purified water."

Nanofiltration is a cross-flow filtration technology which ranges somewhere between ultrafiltration and reverse osmosis (RO). The nominal pore size of the membrane is typically about one nanometer. Nanofilter membranes are typically rated by molecular weight cutoff rather than nominal pore size. The molecular weight cutoff is typically less than 1,000 atomic mass units. The transmembrane pressure (pressure drop across the membrane) required for nanofiltration is lower (up to three MPa) than the one used for RO, reducing the operating cost significantly. However, nanofiltration membranes are still subject to scaling and fouling and often modifiers such as antiscalants are required for use. Koch Membrane Systems designs and manufactures a nano filtration system that is available in spiral or flat sheet membrane configurations.

Reverse osmosis is a method of water purification that removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. Desalinization RO systems are often scaled to handle 1,000—500,000+ gallons of water per day. These systems require rapid water flow across the surface of the membrane to keep it from plugging. The incoming water should be free of all suspended solids and pretreated for softening to reduce the frequency with which the membranes must be replaced. RO systems require higher pressure and flow rates than other filtration systems (overcoming osmotic pressures can exceed 600—1000+ psi for seawater) and therefore consume more energy per gallon of water processed. The efficiency of RO membranes can vary between manufacturers, and there is typically a trade-off between separation efficiency and permeate production volume.

Thermal Processes (Phase Change)

In contrast to filtration processes that selectively remove particles based on their size or density, thermal separation removes the water along with any components that evaporate at lower temperatures than water. Most suspended and dissolved solids are left in the concentrate. The water vapor can be vented to the atmosphere or re-condensed to the liquid state. Evaporators can boil off water at different temperatures depending on the pressure in the evaporator.

Atmospheric pressure evaporators are ideal for effluent with high solids content. They are relatively low cost and achieve very high separation rates. Samsco designs atmospheric evaporators with several models to scale to the size or dewatering needed and the tanks have no welded pieces so they have no leaks and low maintenance. Electrically powered wastewater evaporators use electrical coils to heat the slurry to evaporate off the water while allowing the solids to settle on the bottom. Because of their relatively low efficiency they are best suited for low volume applications. Electric evaporators also cannot take advantage of the abundant waste heat available at the digester that often goes unused. Similar to electric evaporators in operation, modern gas fired evaporators typically have lower energy costs and also achieve very high separation efficiencies. Since they burn a combustible fuel, they require an exhaust, additional safety systems, and are subject to environmental regulations. However, the biogas from anaerobic digestion could be used to fuel a gas fired evaporator which would be a very efficient use of the energy in the biogas.

In projects where waste heat is available in significant quantities, waste heat evaporators can be a very efficient method to dewater the effluent. These evaporators use waste energy off the power generation equipment as the energy source to vaporize the effluent. The process consists of a circulation pump, a fluidized bed heat exchanger, and an evaporation vessel.

Several of these systems can be repeated in series as needed to vaporize all of the water. Organics Group PLC designs waste heat evaporators to suit the customer's needs.

When insufficient heat is available for atmospheric evaporation, the amount of heat required can be reduced by creating a vacuum in the evaporation chamber. Evaporating under vacuum via indirect heat allows the system to return waste heat streams without mixing them with the process. Vacuum conditions can be achieved using vacuum pumps, blowers, or ejectors. Samsco manufactures a vacuum distillation system called the Samsco Wastesaver with a fully automatic, skid mounted design.

6.3.2.7 Design Specs for Residual Unit Processes

The specific unit processes for Residual Processing and Filtration in this section are directly dependent on the properties and the characteristics of the specific process streams and the feedstocks at the front end on the anaerobic digestion process. The design specs will vary considerably but have several generic requirements that need to be determined before equipment and processes can be defined and implemented. First and foremost of these is a thorough characterization of the process stream including:

- Gross solids exiting the anaerobic digestion system
- Daily volume and peak period production if applicable
- Variations in process stream temperature
- Total solids
- Suspended solids
- Dissolved solids
- pH
- Viscosity

Filtration

- Size distribution (particle shape)
- Chemical composition
- Ionic concentrations
- Conductivity
- Viscosity
- Variability of feedstock (hourly, daily, seasonal, etc.)
- Specific heat
- Phase diagram (liquid vs. gas) vs. pressure

Upon the characterization of the process stream and its variability, an appropriate process stream can be designed, tested, and implemented. Most of the capital equipment companies surveyed (Table 8) will assist with such analysis and many will provide custom solutions tailored to a specific set of conditions and properties.

Table 8: Equipment Vendor Survey Results

Comparison of Process Equipment Technologies	**Filter Press**	**Belt Filter**	**Screw Press**
Capital Cost Range	MED- HI	MED	MED-HI
Operating Cost Range	MED	MED	LOW-MED
Maintenance	MED-HI	MED-HI	LOW-MED
Capacity	HI	MED-HI	LOW-HI
Physical Size	L	L	M-L
Continuous or Batch	B	C	C
Energy Consumption	MED	LOW	MED
Air Emission Control	N/A	N/A	N/A
Odor Containment	POOR-GOOD	FAIR-GOOD	GOOD
Selectivity & % Recovery	GOOD	GOOD	GOOD
Permeate Quality (further processing required?)	GOOD	GOOD	FAIR-GOOD
Waste Energy Utilization	N/A	N/A	N/A
Process "Sensitivity" Risk (Change in process conditions resulting in a disproportionate change in process output)	MED	MED	LO
Process "Fragility" Risk (Change in a process resulting in equipment damage and/or increased maintenance)	MED	LO	MED

Comparison of Process Equipment Technologies	**Rotary Press**	**Centrifuge**	**Settling Tanks**
Capital Cost Range	MED	HI	HI
Operating Cost Range	LOW-MED	HI	LOW
Maintenance	LOW-MED	MED	MED
Capacity	LOW-MED	MED	HI
Physical Size	M	M	L
Continuous or Batch	C	C	C
Energy Consumption	LOW-MED	MED-HI	LOW
Air Emission Control	N/A	N/A	LOW-MED
Odor Containment	GOOD	GOOD	POOR-FAIR

<u>**Comparison of Process Equipment Technologies**</u>	**Rotary Press**	**Centrifuge**	**Settling Tanks**
Selectivity & % Recovery	GOOD	GOOD	GOOD
Permeate Quality (further processing required?)	FAIR-GOOD	GOOD	FAIR
Waste Energy Utilization	N/A	N/A	N/A
Process "Sensitivity" Risk (Change in process conditions resulting in a disproportionate change in process output)	MED	LO	LO-MED
Process "Fragility" Risk (Change in a process resulting in equipment damage and/or increased maintenance)	LO	MED	LO-MED

<u>**Comparison of Process Equipment Technologies**</u>	**Ultra, Nano, RO Filtration**	**Thermal Evap. (Electric)**	**Thermal Evap. (Gas)**
Capital Cost Range	MED-HI	MED	HI
Operating Cost Range	MED-HI	MED	MED
Maintenance	MED	LOW-MED	LO-MED
Capacity	LOW-MED	MED	MED
Physical Size	M	M-L	M-L
Continuous or Batch	C	B/C	B/C
Energy Consumption	HI	HI	MED-HI
Air Emission Control	N/A	N/A	YES
Odor Containment	GOOD	FAIR-GOOD	FAIR-GOOD
Selectivity & % Recovery	GOOD	N/A	N/A
Permeate Quality (further processing required?)	EXCELLENT	N/A	N/A
Waste Energy Utilization	N/A	Possible	Possible
Process "Sensitivity" Risk (Change in process conditions resulting in a disproportionate change in process output)	HI	LO	LO
Process "Fragility" Risk (Change in a process resulting in equipment damage and/or increased maintenance)	MED	LO	LO

Source: Clean World Partners, LLC

6.3.3 Biomethane Refining, Conditioning and Delivery System

In Task 6.3, CWP reviewed digestion test results, completed preliminary design and feasibility of the gas cleanup system, and defined the specifications and preliminary design of the compression, storage, and delivery systems for conditioning biomethane gas for use as a transportation fuel.

Biomethane refining, conditioning, and delivery are the steps necessary to turn the raw biogas collected from the digesters into a viable and valuable transportation fuel. The first step in this process, biogas refining, entails the removal of all contaminants from the biogas—typically CO_2, H_2S, and possibly siloxanes—to the extent that the biomethane complies with SAE J 1616 and Engine Manufacturers' fuel specifications standards for vehicle fuels. Next, the biomethane is conditioned to the appropriate state for storage prior to fueling. This process includes drying and cooling the gas and then finally compressing it to the pressure designated by the storage container. The biomethane can then be transferred either to on-site gas storage or to a gas transport module for transportation to an existing fueling station. Fueling stations can be either stationary or portable. This report describes the specifications for refining, conditioning, and delivery of biomethane based on a 10-TPD project with generic food waste feedstock for the gas-generating anaerobic digestion system.

The biogas conditioning system should be scaled for a biomethane flow rate of 30 SCFM for a 10-TPD system up to 300 SCFM for a 100-TPD system with a composition of approximately 55—65 percent CH_4, 35—45 percent CO_2, 0—2 percent H_2, and 500—1500 ppm H_2S. For feedstocks contaminated with siloxanes (man-made chemicals used in some cosmetics and cleaning products that easily volatilize into the gas phase and fuse to surfaces when burned) even trace quantities in the biogas (greater than 4—10 ppb) must be removed. As described previously, removal should be performed after the other contaminants are removed. The inlet and outlet gas pipes for the anaerobic digestion system are expected to have a two-inch inner diameter. The land use for a system producing transportation fuels will be a minimum of 11,250 square feet for a 10-TPD system and 80,000 square feet for a 100-TPD system.

6.3.3.1 Input Specifications

The biogas input stream will consist of approximately 55—65 percent CH_4, 35—45 percent CO_2, 0—2 percent H_2, 500—1,500 ppm H_2S, and will be 100 percent saturated with moisture upon exiting the anaerobic digestion system. In feedstocks where siloxanes are present, such as MSW or wastewater, there could be a risk of siloxanes in the biogas stream.

6.3.3.2 Output Specifications

The biomethane output stream should comply with SAE J 1616 and Engine Manufacturers' fuel specifications standards.

6.3.3.3 Biogas Conditioning Technologies

There are several methods of conditioning biogas to transportation fuel quality RNG. All of these methods, except pressure water scrubbing, require the H_2S and water to be removed prior to CO_2 absorption, and then the biomethane is dried and cooled after the CO_2 is absorbed.

In general, biogas conditioning involves the following steps:

1) H_2S removal is performed first and H_2S concentration should be reduced to the lowest practical level.
2) The biogas is dried and chilled.
3) CO_2 is removed.
    a. CO_2 and H_2S may be removed simultaneously with certain technologies such as pressure water scrubbing, although some prior H_2S removal may be required due to the limited amount of H_2S that can be absorbed during pressure swing absorption.
    b. H_2S and CO_2 removal are performed before siloxane removal because H_2S and CO_2 foul the very expensive medium that captures siloxanes.
4) Siloxane removal (if necessary) is performed in the treatment process.
5) The biomethane is chilled and dried to less than 5 percent MC.
6) The biomethane is compressed to the appropriate pressure (typically 3000—5000 psi) for storage in a high pressure gas storage system.

Numerous technologies are available for CO_2 removal. The ideal technology for SBR1 is one which minimizes cost (both initial and ongoing) at the scale expected for the digester system. The technologies must be rated on their ability to scale as well as to be turned down and to handle fluctuating flows. Several of these technologies are described below, followed by Table 9, which summarizes their pros and cons.

6.3.3.4 Amine Scrubbing

Amine scrubbing is a process that sends the biogas into an amine scrubber composed of washing columns packed with fillings. The aqueous amine solution flows opposite the biogas flow and absorbs the CO_2 in the biogas. CH_4 flows to the end of the column for extraction with a CH_4 loss rate of less than 1 percent. The CH_4 remaining is then dried and cooled. Drawbacks to this method are that a large amount of energy is required for regeneration of the fillings and safety concerns of having concentrated H_2S gas in the columns.

6.3.3.5 Pressure Swing Absorption

Pressure swing absorption is a method in which activated carbon or carbon molecular sieves absorb the CO_2 in the biogas, and the CH_4 flows to the end of the absorber for extraction. One drawback to this method is that the carbon sieves must be replaced when they are full of CO_2. For this reason, several carbon molecular sieves should connect in a series to increase the quality of the gas. CH_4 loss for this system is between 2—5 percent.

6.3.3.6 Pressure Water Scrubbing

The pressure water scrubbing method passes biogas through a water column in the opposite direction of the water flow. The pressure dissolves the CO_2 and H_2 molecules into the water and pushes the clean gas to the end of the column. Once the CH_4 is extracted, the pressure is reduced and the CO_2 bubbles out of the solution. The CH_4 loss for the system is approximately

2—4 percent. This system has the ability to extract H_2S and CO_2 simultaneously and it is a less expensive option when water is available on site.

6.3.3.7 Selexol Scrubbing

The selexol scrubbing process is similar to that of pressure water scrubbing, except that selexol replaces water as the CO_2 absorbing solution. The benefit of this system is that CH_4 dissolves better in selexol than water. CH_4 losses for this system are between 1—4 percent.

6.3.3.8 Membrane Permeation

Membrane permeation is a method that utilizes the differences in particle sizes to allow certain molecules to pass through a membrane, while trapping others. This method is best used for biogases where only one or two gases are being removed because a membrane cannot be both highly permeable and highly selective. Advantages of this system include that membranes are highly reliable and easily operated.

Table 9: Gas Conditioning Method Comparison

Method	Summary	Pros	Cons
Amine Scrubbing	Biogas is sent into an amine scrubber composed of washing columns packed with fillings.	High removal rates of H_2S and CO_2	Requires a large amount of energy for regeneration of the fillings. Safety concerns of having concentrated H_2S gas in the columns.
Pressure Swing Absorption	Activated carbon or carbon molecular sieves absorb the CO_2 in the biogas and the CH_4 flows to the end of the absorber for extraction.	Low power demand Low level of emissions	Carbon sieves must be replaced when they are full of CO_2.
Pressure Water Scrubbing	The pressure dissolves the CO_2 and H_2 molecules into the water and pushes the clean gas to the end of the column. Once the CH_4 is extracted, the pressure is reduced and the CO_2 bubbles out of the solution.	Ability to extract H_2S and CO_2 simultaneously. Inexpensive when water is available on site. Neutralization of corrosive gasses.	Requires a large amount of water. pH must be carefully monitored for H_2S removal.
Selexol Scrubbing	Similar to pressure water scrubbing, except that selexol replaces water as the CO_2 absorbing solution.	CH_4 dissolves better in selexol than water.	Properties of selexol such as attraction to water vapor complicate the process.
Membrane Permeation	Uses the differences in particle sizes to allow certain molecules to	Low energy requirements	Membranes cannot efficiently separate many different gasses.

Method	Summary	Pros	Cons
	pass through a membrane, while trapping others.	Simple process Highly reliable	

Source: Clean World Partners, LLC

6.3.3.9 Potential Suppliers for the Biogas Refining System

Guild Associates makes a biogas refining system with Molecular Gate's absorption technology for a project with a minimum gas production rate of 100 SCFM. Guild is the manufacturer of the equipment and supplies it to a company called Ameresco, which engineers, constructs, owns, and maintains the NG pipelines. Guild systems use pressure swing absorption technology with a CH_4 recovery rate of about 90 percent. The system works on a variety of waste streams and removes H_2S and siloxanes in one step as the water vapor and CO_2 are removed from the biogas.

SouthTex Treaters manufactures an amine gas treatment plant with amine scrubbing technology and a continuous process in which CO_2, H_2S, and H_2 impurities are absorbed from the biogas under high pressure and moderate temperature conditions. Amine provides regeneration skids with gas train and glycol regeneration units that can be used when there is excess water, H_2S, and CO_2.

Cornerstone's biogas upgrading system can be scaled for gas production streams at 10, 25, and 50 SCFM. The conditioning system removes water, H_2S, CO_2, and other volatiles, then cleans and conditions the gas to create transportation fuel-quality biomethane.

Xebec Biogas manufactures pressure swing adsorption biogas refining systems that use pressure swing absorption technology to separate CH_4 from other components such as CO_2, H_2S, H_2, O_2, and N_2. Gas is pressurized to 90—100 psi for adsorption of CH_4 and then depressurized to recover the CH_4. The degree of separation depends on the number of cycles of pressurizing and depressurizing, and the energy consumption depends on the efficiency of the compressors used. Xebec Biogas upgrading plants are best designed for gas production systems over 200 SCFM. The system is packaged as a compact skid with all the necessary equipment to condition biogas to biomethane that meets pipeline or transportation fuel specifications. These systems also offer heat recovery from the upstream process.

Acrion makes biogas upgrading systems that remove impurities in a two-step process, best suited for larger biogas streams. First the H_2S is removed and then a CO_2 wash removes the CO_2 and VOCs and dries and compresses the biomethane. In gas conditioning systems in the hundreds or thousands of SCFM range, where the CO_2 is in a large enough quantity to be economically worth capturing, it can also be recovered.

Unison manufactures a skid for gas refining, including H_2S and siloxane removal, moisture removal, and chilling to transportation and pipeline quality CNG. Unison is a new company to refining biogas to transportation quality, but is best suited for small projects with gas production under 100 SCFM.

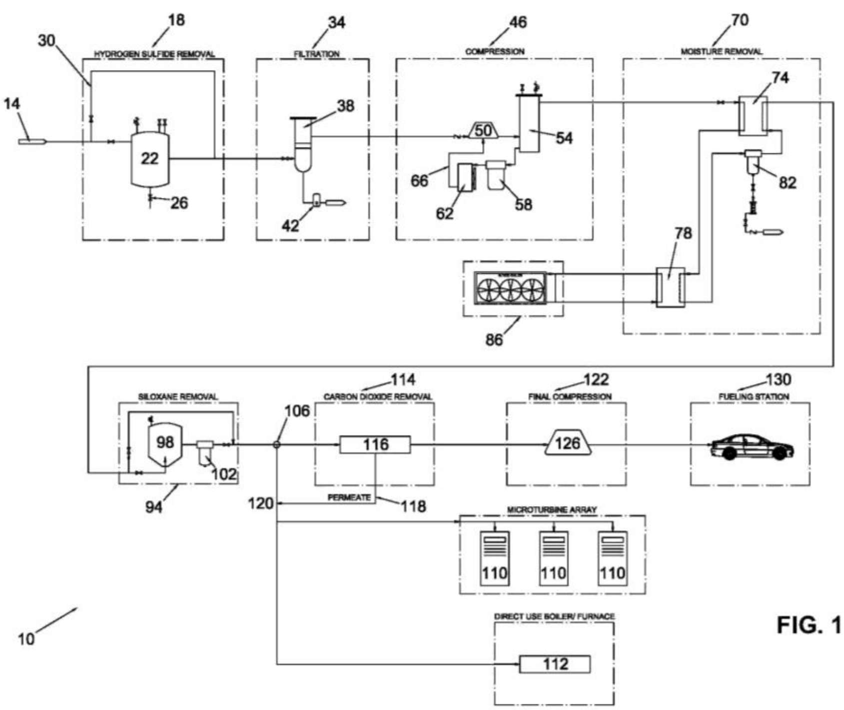
CWP is working with several gas conditioning companies to ensure the appropriate integration and optimization of the systems with CWP's anaerobic digestion system. Future pilot scale testing will allow the confirmation that the gas conditioning systems do work appropriately with the anaerobic digestion systems.

To model material balances for the process of the biogas leaving the digester to entering vehicles as CNG, CWP will use the analysis and specifications provided by the company supplying the biogas refining and fueling stations. Further process modeling for integration with anaerobic digestion systems may be performed by CWP as deemed necessary depending on future applications.

6.3.4 Preferred Providers of Technology and Support

CWP has identified a preferred company to work with for biogas cleanup: Cornerstone LLC. This company has provided information on the design package, photos of current projects and site layout plans, which are shown in Figures 29 and 30, below.

Figure 29: Cornerstone Gas Conditioning and Vehicle Fueling Site Layout Plan



Source: Clean World Partners, LLC

Figure 30: Cornerstone CNG Station

Photo credit: Clean World Partners, LLC

6.3.4.1 Gas Transport Options

CWP has researched several manufactures of gas storage including stationary gas storage domes and portable gas transport modules. A photo of the Cornerstone gas conditioning skid is shown in Figure 31, below. The three optimal storage trailer technologies are described thereafter.

Figure 31: Cornerstone Gas Conditioning Skid with Fueling Station

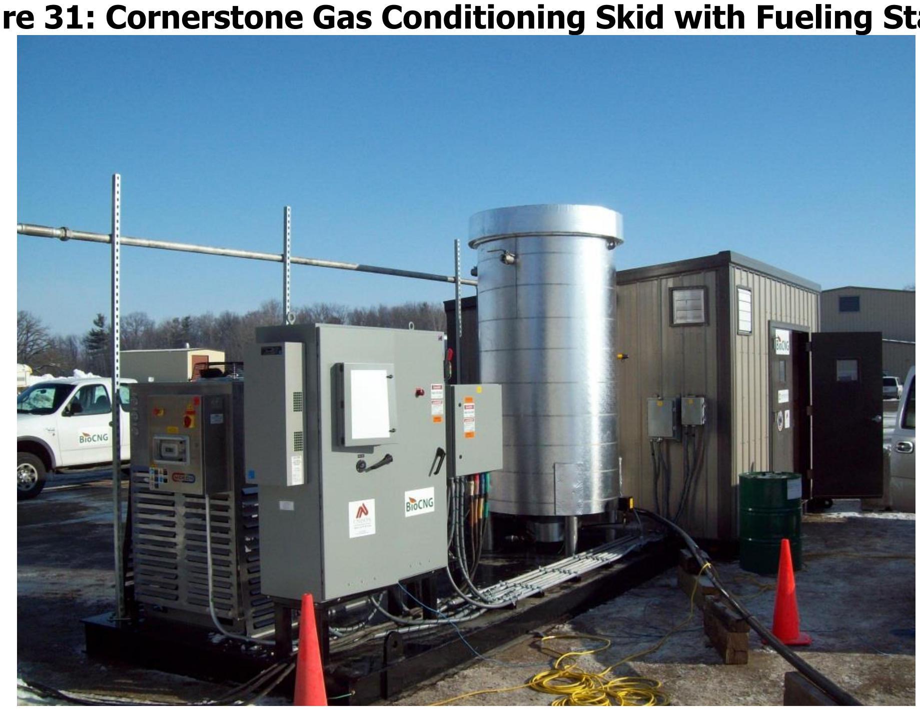


Photo credit: Clean World Partners, LLC

The **Pinnacle Gas Transport Modules** typically hold nine cylinders that can each hold up to 13,000 standard cubic feet of CH_4. The gas transport modules are DOT-compliant for transport by any method. The Pinnacle Gas transport module would provide enough gas storage for nine days of gas production for a 10-TPD anaerobic digestion system or one day for a 100-TPD system.

The **Lincoln Deposits Titan Gas Transport Modules** are composed of four tanks for mass transport of CNG with a total CNG storage capacity of 88,860 standard cubic feet at a max pressure of 4,714 psi. Their high strength and nonsteel TUFFSHELL® design is well-proven, with over 90,000 fuel containers with this technology currently used worldwide.

The **Marlin Tube Trailer** can hold from 5—166 thousand cubic feet (Mcf) of CNG at 3,000 psi. Marlin has a fleet of dedicated tube trailers for CNG and is best suited for temporary transfer of CNG for projects with a duration of less than one year.

6.3.4.2 Safe and Efficient Loading of CNG

The NG will be odorized by a professional NG odorizer company after it is refined. Four possible odorizer companies are Natural Gas Odorants, Preco, Odor-Eyes, and King Tool Company. Natural Gas Odorants provides liquid injection and vaporization systems that odorize NG. Preco created the Pulse Bypass Odorization System, which is suitable for lower gas volume applications. The system has an adjustable volume pulse bottle, an odorant tank, and a day tank with odorant level and temperature gauge packaged together on a single skid. Odor-Eyes Technologies, Inc., offers both injection and pulse-bypass odorization systems. It also manufactures gas odor monitors and transmitters. King Tool Company manufactures two different types of gas odorizers, a bypass type odorizer for larger CNG streams and a small-tap odorizer for smaller CNG streams (less than 8.3 SCFM). The bypass type is available in six sizes and the small-tap odorizer is available in four sizes.

Once the NG is odorized and pumped into a gas transport module, it is connected to a fueling station with an NGV 2 profile, which is a NG vehicle connection that has been certified by the Federal Tier 2. This connection is approved for fast fuel and time fuel applications and has a high flow capacity. The fueling station can either be an existing fueling station, to which the gas transport module would be conveyed, or a portable fueling station, which would be brought to the site or to the vehicle fleet. Stabuli NGV is one company that manufactures approved refueling connections, including the NGV 2 profile connection. For metering of the CNG, an appropriate flow meter will be needed. Micro Motion specializes in manufacturing the CNG050 Coriolis Meter for NG, with over 50,000 meters installed worldwide, mostly at CNG fueling stations. Krohne also manufactures flow meters for NG which are economical, high performance, general purpose flow measurement solutions.

Table 10 provides a comparison of the gas conditioning and storage suppliers.

Table 10: Gas Conditioning and Storage Supplier Comparison

Gas Refining	Technology	Pro	Con	10 TPD	25 TPD	100 TPD
Guild Associates, Inc.	Pressure Swing Absorption	Single step biogas upgrading process	Only suitable for large systems	Not suitable	Scalable but not ideal	Ideal
SouthTex Treaters	Amine Scrubbing	Some low cost refurbished equipment available	Only suitable for large systems	Not suitable	Scalable but not ideal	Ideal
Cornerstone		Designed for small gas production, provides fueling stations for $160,000		Ideal	Ideal	Ideal
Acrion	CO_2 Wash	Can recover the CO_2 from the process	Only suitable for large systems	Not suitable	scalable but not ideal	Ideal
Unison		Single skid system	New to transportation quality refining	Ideal	Ideal	Ideal
Xebec	Pressure Swing Absorption	Compact skid with upstream heat recovery	Expensive	Scalable but not ideal	Ideal	Ideal
Gas Storage		**Pro**	**Con**	**10 TPD**	**25 TPD**	**100 TPD**
Marlin Tube Trailer		Large storage capacity (up to 166 Mcf of CNG)	Only for temporary transfer	Ideal	Ideal	Ideal
Pinnacle Gas Transport Module		DOT-compliant for travel	Expensive and two required	Ideal	Ideal	Wouldn't store a full day of CNG
Lincoln Deposits Gas Transport Module		DOT-compliant for travel	expensive and three required	Ideal	Ideal	Wouldn't store a full day of CNG

Source: Clean World Partners, LLC

6.3.5 Design of Auxiliary Systems for Providing Parasitic Heat and Power Requirements

The purpose of Task 6.4 is to provide the pre-engineering and preoperational design requirements for the auxiliary power needed by the system.

Auxiliary energy (i.e., power and heat) is needed for feedstock handling and processing, digester heating, residual recovery and filtration, biogas cleanup, and compression of purified biogas for CNG delivery for use as an alternative fuel. Collectively, these internal system energy demands are often referred to as the system's "parasitic load."

The electricity needed for powering the digester system can come from the utility grid in situations where the digester has access to interconnection. However, there may be sites and situations in which interconnection is either not possible or not desirable. Studies have shown that it may be financially advantageous in some cases for a digester producing transportation fuel to divert some of its biogas to electricity production for providing parasitic power. There are also some biogas cleaning technologies that produce an exhaust stream containing enough CH_4 to justify auxiliary power recovery from the exhaust gas, in which case the auxiliary power may be a byproduct of the transportation fuel.

Heat can also be recovered from the exhaust or cooling systems of most electrical generation devices for use in providing the digester's thermal load. Additional heat needed as backup or during startup may be provided from direct combustion of biogas or other flammable fluids (e.g., NG, propane, or heating oil). Some digester systems may also be sited in close proximity to ready sources of waste heat, in which case there would be no need to design primary heating systems. However, backup heat may be needed even in these cases.

For this reason, the potential for producing the digester's parasitic power from biogas will be explored.

6.3.5.1 Parasitic Load for the SBR1 Anaerobic Digester System

A parasitic load is a common expression for the power or energy consumed in a system that otherwise creates energy whether it is electrical, heat, or fuel. The net energy production of a system can be expressed as the difference between the energy created and the energy required to operate the system. Parasitic load is typically the fraction of the power produced that is required to run the digester. For anaerobic digesters producing only electricity, the parasitic load typically does not include the heat required. Such systems often report parasitic loads in the range of 10—20 percent of the electricity produced. For this analysis, all of the parasitic energy used, both electrical and thermal, was considered.

The following unit processes were considered in determining the electrical consumption of the digester system:

- Front-end material handling units
- Control systems and instrumentation
- Pumps, valve actuators, and other active fluid handling systems
- Gas processing, refining, and compression units

- Power generators, boilers, and/or heaters
- Back-end material handling, dewatering, water purification systems

The following forms of heat were considered in determining the thermal load of the digester system:

- Hot water for tank heating
- Steam or hot water for preheating new material additions
- Steam or hot water for drying solid and liquid effluents

6.3.5.2 Mass/Energy Balance Basis for the Design Analysis

The auxiliary power requirements for the 100-TPD SBR1 digester project were estimated based on the projected operating time and power rating for each of the above mentioned unit processes required for running the digester system (assuming a 50:50 mix of food and green wastes at 70 percent MC). The results of the analysis (Tables 11 and 12) lead to an estimated power requirement of 4,000—5,500 kWh per day. This equates to 167—229 kW, assuming 24 hours per day of electricity generation. If the auxiliary electrical generation system is larger than the actual parasitic load demand then the excess power may be available to the customer to run other processes on site or to feed back into the grid, assuming the system is connected and permitted for this.

Table 11: Electrical Energy Requirements (kWh/d) 100-TPD Anaerobic Digestion System

Subsystem	Total kW Load	Min. h/d	Max. h/d	Min. kWh/d	Max. kWh/d
Front-end (loading)	210	4	8	840	1640
Controls and instruments	2	24	24	48	48
Fluid handling	70	3	4	210	280
Gas processing	60	24	24	1440	1440
Fueling station	50	24	24	1200	1200
Back-end (effluent)	25	12	24	300	600
TOTALS	417	N/A	N/A	4038	5508

Source: Clean World Partners, LLC

Table 12: Thermal Energy Requirements* (MBH) 100-TPD Anaerobic Digestion System

System	Quantity	10°F (-12°C) Average	40°F (4.4°C) Average	60°F (15.6°C) Average	80°F (26.7°C) Average
Influent heating	100 TPD	1000**	970	750	540

System	Quantity	10°F (-12°C) Average	40°F (4.4°C) Average	60°F (15.6°C) Average	80°F (26.7°C) Average
Single tank	300,000 gal	230	170	130	100
Full system	900,000 gal	690	510	390	300
TOTALS		1690	1,480	1,140	840

* Assumes one-inch polyurethane foam covering all reactor surfaces. Moderate winds (five mph average).

** Maximum heat demand for 100 TPD at freezing point (32°F [0°C]) assuming frozen feed will not be loaded into the system.

Source: Clean World Partners, LLC

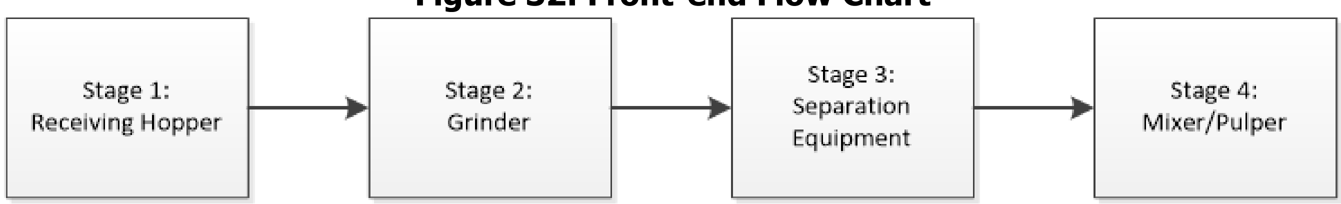
6.3.5.3 Review of Sub-systems that Require Power

The sub-systems of the anaerobic digestion system that require power include front-end processing, controls and instrumentation, fluid handling, gas processing, power generation, and back-end processing.

6.3.5.3.1 Front-end Processing

The front-end processing equipment can range in power consumption depending on the material being loaded and what approach is taken to processing it prior to loading it into the digester. The main goal of the processing equipment is to ensure that the digesters are receiving the organic fraction of the feedstock, free from metals, glass and other unwanted materials, in a state that is appropriate for encouraging rapid degradation of the material (i.e. reduced particle size and proper MC). For a generic feedstock requiring particle size reduction and removal of contaminants, the front-end equipment will consist of four unit processes for receiving waste, reducing the particle size, removing contaminants, and preparing the material for transfer to the digester (Figure 32).

Figure 32: Front-end Flow Chart



Source: Clean World Partners, LLC

It is important to note that the order of the grinder and separation equipment (Stages 2 and 3) can be switched, and that the arrows between the stages may represent conveyor belts, gravity feed, or hydraulic pumps to move the material along. The only stage that does not consume power is the receiving hopper, but immediately thereafter conveyors or pumps are used to move the material. It is also possible to install a "moving floor" hopper, but for the purpose of this report we will focus on power demand from Stages 2, 3, and 4. Several technologies have been investigated for preparation and handling of 100 TPD of mixed solid wastes containing significant levels of contamination with inorganic materials. To handle the necessary load to process organic food and green waste, the solutions investigated ranged from 105—315 kW in energy consumption. The hours of operation differ among the solutions based on the difference in throughput capabilities. For instance, a 315 kW system can process 100 tons of material in four hours. On the other hand, a 105 kW solution would need to be operated twice as long to achieve the same results. For the purpose of this report, an average load of 210 kW over eight hours per day was used.

6.3.5.3.2 Anaerobic Digestion System Electrical Consumption

The digester's control package monitors all the sensors and conditions in the system. It also supervises and actuates the transfer of fluids from tank to tank by triggering valves and pumps as programmed. The data collection system logs the states of sensors, pumps, valves, and programs on a continuous basis. It then stores the data locally and transfers it to an offsite server where it can be accessed from any secure internet browser by CWP technicians for real time monitoring and control. The control system will also monitor the third-party-supplied front- and back-end processing equipment. This functionality will require ongoing electrical power and backup power to mitigate the effect of power outages. It is estimated that the control system will require at least two PLC-integrated computer systems with enough power to actuate solenoids and power sensors. It is predicted that the control system would consume 2.0 kW of electricity on a continuous basis, regardless of the quantity of waste loaded or biogas produced. Therefore, the controls and instrumentation will consume 48 kWh per day or 0.48 kWh per ton of waste processed.

The fluid handling systems will mix the contents of the reactors and transfer liquid between reactors as well as effluent out of the digester system. Reactors require regular mixing in order to provide sufficient distribution of microorganisms through the slurry within the reactor. Mixing also provides an opportunity for additional particle size reduction when the mixing pump incorporates a chopper. Typically, each reactor is mixed for one hour every six hours with a 23 kW chopper pump. Since the pump would be expected to operate at 75 percent of its rated capacity, it is estimated that mixing will consume about 210 kWh per day.

As solids disintegrate in the first-stage reactors, the resulting liquid with dissolved organics must be transferred to the second-stage reactor for conversion to biogas. This leachate transfer process also occurs approximately four times per day and requires about one hour per transfer, utilizing the same pump used for mixing the second-stage reactor. Thus, liquid transfer would be expected to consume about 70 kWh per day. Together with the mixing pumps, the fluid handling system will consume a total of 280 kWh per day, or 2.80 kWh per ton of waste treated.

During feeding, liquid effluent will be removed from the digester to maintain volume balance within the system. Occasionally, solids will also be removed from the system via screw press. These systems will be accounted for and described as part of the back-end processing system.

6.3.5.3.3 Biogas Processing Electrical Consumption

The gas processing sub-system will vary depending on the technology used to convert biogas to energy. For microturbines and IC engines, the biogas must have the H_2S and moisture removed, and the gas must be compressed to a minimum of five psig for microturbines and

1.9 psig for IC engines. Biogas is expected to be produced at a flow rate of 300 SCMF. Compression of this flow rate to five psi should require a 7 kW blower/compressor operating continuously, which would consume 168 kWh per day or 1.7 kWh per ton of waste.

To create compressed RNG for transportation fuel or pipeline injection, the above processing must be performed prior to CO_2 removal and polishing to remove any trace siloxanes. However, the inlet pressure for CO_2 removal is typically 100 psig for systems using molecular sieves. This requires a 60 kW compressor operating continuously. The storage and fueling pressure for CNG is 3000—4000 psig, which requires an additional 50 kW compressor, for a total power demand for the transportation fueling option of 110 kW operating continuously. These systems consume 2,640 kWh per day or 26.4 kWh per ton of waste treated.

For fuel cell applications, all of the processing for CNG must be performed, although the inlet pressure for a fuel cell is 15—20 psig. In addition, a polishing step is required to remove any VOCs and organic sulfides, as any detectable level of these contaminants will shorten the life of the fuel cell, although this step would not be expected to add significantly to the power demand for the gas conditioning unit. A 20 kW compressor would need to be operated continuously to condition biogas for a fuel cell, which would consume 480 kWh per day or 4.8 kWh per ton of waste treated. These values were not included in the parasitic load calculations but are included for completeness.

6.3.5.3.4 Back-end Processing Electrical Consumption

Fluid handling systems will process the liquid effluent from the digester to create value-added products such as liquid fertilizer. CWP is working with consultants to create proprietary processes that create the fertilizer product, which will be branded and sold to local farms. A 25 kW load at 24 hours per day was assumed for this process in the model. This estimate is based on consuming 600 kWh per day or 6 kWh per ton of waste treated.

6.3.5.3.5 Heat Recovery Systems Electrical Consumption

Engine generators and turbines for electrical production do not consume any electricity other than during the initial start-up. Fuel cells continuously consume a portion of the biogas for reforming biogas to H_2, but they do not consume any electricity.

The digester heating system will consume some electricity in order to circulate the working fluid (typically water) through the heat exchangers in the reactors and the electrical generators' heat recovery units or a boiler. Due to the friction in the transfer lines, significant back pressures can build up in these systems, necessitating larger pumps than expected: up to 20 kW, based on initial calculations. However, these pumps typically operate at about half of their rated capacity for 6—12 hours per day, consuming 120—240 kWh per day or 1.2—2.4 kWh per ton of waste treated. These values were included in the values assigned to fluid handling.

6.3.5.4 Review of Technology Options for Electricity Generation

Several options were analyzed for electrical generation fueled by biogas. Each option's electricity production capacity, capital cost range, operating cost range, and permit challenges considered in the analysis. Some of the technologies include the option to recover heat for maintaining reactor temperatures, which could reduce or eliminate the need for additional heat from boilers. If the waste heat recovered is too hot for the digesters (microbes cannot be exposed to temperatures in excess of 160°F [71.7°C]) or in greater quantity than can be used, a radiator may be necessary to dispose of excess heat. The biogas-to-electricity conversion technologies evaluated include turbines, IC engines, and fuel cells.

6.3.5.4.1 Microturbines

Microturbines generate electricity similarly to IC engines, except instead of turning the generator rotor with an Otto or Diesel-cycle engine, they use small Brayton-cycle turbines fueled with biogas. Most microturbines come in 30, 65, and 200 kW models (larger models composed of strings of 200 kW units are also available). The most readily available model is the 65 kW microturbine. For a 100-TPD anaerobic digestion system, a package of two or three 65 kW microturbines with heat recovery water jackets could provide the electricity for the parasitic load. A single 200 kW microturbine could also be used but would not have the same flexibility to turn down that three 65 kW microturbine would have. If the customer desired more electricity to run other operations, additional microturbines could be packaged or larger models could be used. Each 65 kW microturbine with a water jacket has a parasitic load of 7.5 kW, which runs the internal compressor and intercooler jacket pumps.

A significant advantage to this system is the ability to turn down the microturbines if the biogas production slows for any reason. For example, a package of three 65 kW microturbines could be turned down to 17 percent capacity if two of the units were turned off and the remaining one was run at 50 percent (each unit is capable of being turned down by up to 50 percent). Capstone microturbines also meet California Air Resources Board (ARB) emission standards as long as the H_2S content of the biogas is reduced to below 300 ppm before entering the microturbine (this reduces the sulfur oxide [SOx] emissions to allowable levels).

Drawbacks to microturbines include the need for conditioning biogas prior to conversion. Microturbines require biogas to be dry (less than five lbs water per thousand SCF) and pressurized to five psi, with an H_2S concentration below 300 ppm. The unit processes needed for this can cost twice as much as the microturbine itself. However, for the current application, biogas will be conditioned and compressed for transportation fuel anyway, making the microturbine a viable option. Microturbines also have slightly lower conversion efficiencies (about 28 percent) than other electrical generation technologies such as fuel cells.

One emerging technology is a combination of a microturbine with a thermal oxidizer. The oxidizer is designed to oxidize volatile compounds (CH_4, VOCs, and H_2S) in the exhaust and allows for the use of biogas with a very low CH_4 content (as little as 5 percent CH_4) while producing very low emissions (less than one ppm NOx and SOx). Although a 250 kW model is currently being marketed by one company, none have been installed and the technology has yet to be proven in the market. The emissions profile of this technology would make it permissible in severe nonattainment areas with extreme NOx and SOx emission restrictions.

6.3.5.4.2 Combined Heat and Power Modules

Combined heat and power systems are based on an IC engine technology. IC engines are used around the world for low-capacity (up to several thousand kilowatts) electrical generation because they are well understood, relatively low cost, and scalable. However, California's strict emissions regulations make IC engines difficult to permit, especially in severe nonattainment areas. To meet ARB emissions requirements, many IC engines are being fitted with exhaust processing equipment, which raises costs and may lengthen the permitting process, especially for new emissions control technologies. However, the industry is responding to these constraints making IC engines that meet ARB standards increasingly available. One of these units was recently installed in Concord, California, and did not face any significant challenges in permitting.

The engine is packaged in an enclosed combined heat and power unit that has ultra-low emissions and an 86 percent overall efficiency (including 52 percent thermal and 34 percent electrical energy recovery). This system is available in sizes ranging from 65 kW to 2 MW, with the most commonly sold units being 157 kW and 250 kW. The smaller typical system would be an ideal size to provide the electricity for the parasitic load of the anaerobic digestion system and the heat recovered could be used to heat the digester for our reference 100-TPD facility.

6.3.5.4.3 Fuel Cells

The fuel cells considered in this report are solid-oxide fuel cells with integrated reformers that allow them to accept CH_4 (or NG) as a fuel source. They range in size from 300 kW to 2.4 MW and are all typically larger than the parasitic load for a 100-TPD anaerobic digestion system. However, they can be turned down by as much as 50 percent, and since the biogas would be cleaned to meet transportation fuel standards, little additional gas cleaning would be required. Furthermore, the gas could be compressed and stored on-site, making it possible to match supply with peak demand using control systems. Alternatively, any excess electricity may be net-metered to the grid, and biogas can be blended with conventional NG if insufficient biogas is available. Fuel cells currently have more expensive capital and operating costs than other electrical conversion technologies. However, current federal and state incentives may offset a large portion of their capital cost. Fuel cells also currently have high operating and maintenance costs, typically \$0.04—\$0.05 per kWh. This cost includes the need for fuel cells to be rebuilt every five years. Fuel cells have very clean emissions profiles, well within current ARB standards.

6.3.5.5 Auxiliary Heating Systems

In general, the energy in biogas that is not captured as electricity is converted to heat, regardless of the conversion technology. Combustion based systems (i.e., engines and turbines) vent the waste heat through their exhaust systems. Fuel cells convert H_2 to electricity in an exothermic process that generates heat; they require a high-temperature reformer to convert CH_4 to H_2, thus generating significant quantities of waste heat. The ability to capture this waste heat for use in the digester depends on the efficiency of the heat exchanger and the design of the heat recovery system. The digester requires water at 160°F (71.1°C), while most of the waste heat is produced at 250—300°F (121.1—148.9°C). Due to the large temperature gradient, very high heat recovery rates can be achieved (70—80 percent of the available waste heat), but they require high flow rates of transfer fluid, typically water. This necessitates large diameter heat exchangers to avoid excessive back pressure in the circulation systems, with the concurrent need for relatively large pumps. These heat recovery systems may consume 2—5 kW of electricity.

In some cases, additional heat may be required in excess of that recovered from the electrical conversion equipment or in situations in which grid electricity is used rather than self-generated electricity. Boiler systems designed to operate using low-energy fuel such as biogas are commercially available. These systems can achieve extremely high thermal conversion efficiencies (80—95 percent) and generate low emissions without need for expensive emissions control units. H_2S in the biogas should be removed prior to combustion in order to limit SOx output.

6.3.5.6 Electrical and Heat Design for the 100-TPD System

For the 100-TPD system's electrical demand, microturbine technology was used. A package of three 65 kW microturbines were sufficient to generate the average amount of electricity needed to offset the parasitic load of the anaerobic digestion system. This solution was selected due to the high turn-down ratio, minimal gas conditioning requirement (especially relative to fuel cells), and ability to meet ARB standards, thereby expediting the permitting process. Microturbines also cost less than most other electricity generation technologies.

The heating system design for the 100-TPD system consists of heat recovery water jackets for the three microturbines. The hot water recovered from these units will be used for heating the digester tanks. The total parasitic power load of the anaerobic digestion system is expected to range from 121—213 kW, so the three microturbines (totaling 195 kW) will provide all or most of the parasitic load. With this solution, 795 MBH of heat will be recovered, which is nearly enough heat to offset the entire heat demand of the anaerobic digestion system. Additional heat will be provided via a NG-fired boiler.

6.3.5.7 Permitting Requirements for Auxiliary Power Generation

Permitting requirements for power generation systems depend on the size and location of the system. The following agencies currently regulate electrical generation for on-site use:

- Local enforcement agencies (LEA)
- California Public Utilities Commission (CPUC)
- United States Environmental Protection Agency (U.S. EPA)
- Department of Energy (DOE)
- California Air Resources Board (ARB)

If electricity is utilized on-site only without grid interconnection, the equipment must meet safety and health standards set by the above agencies for Sacramento, California.

For projects in which the electricity produced will be connected with the local utility's grid, Interconnection Requirements Rule and Regulation 21 (https://www.smud.org/en/Business-Solutions-and-Rebates/Interconnection-Information) applies for net metering.

Any electrical generating unit operated in California will produce air emissions and therefore has to meet ARB standards (Table 13). In addition to utilizing technologies that achieve these standards, monitoring equipment and protocols will be included in the final design in order to meet state and federal reporting requirements.

Table 13: Air Pollution Concentrations

Pollutant	Averaging time	Concentration
Ozone	One hour	0.09 ppm (180 μg/m³)
	Eight hours	0.07 ppm (137 μg/m³)
Respirable particulate matter (PM2.5)	24 hours	50 μg/m³
	Annual arithmetic mean	20 μg/m³
Fine particulate matter (FM2.5)	24 hours	No separate state standard
	Annual arithmetic mean	12 μg/m
Carbon monoxide (CO)	Eight hours	9 ppm (10 mg/m³)
	One hour	20 ppm (23 mg/m³)
	Eight hours (Lake Tahoe)	36 ppm (7 mg/m)
Nitrogen dioxide (NO2)	Annual arithmetic mean	0.03 ppm (57 μg/m³)
	One hour	0.18 ppm (339 μg/m³)
Sulfur dioxide (SO2)	24 hours	0.04 ppm (105 μg/m³)
	Three hours	—
	One hour	0.25 ppm (655 μg/m³)
Lead	30 days	1.5 μg/m³
	Calendar quarter	—
	Rolling three-month	—
Sulfates	24 hours	25 μg/m³
Hydrogen sulfide	One hour	0.03 ppm (42 μg/m³)
Vinyl chloride	24 hours	0.01 ppm (26 μg/m³)

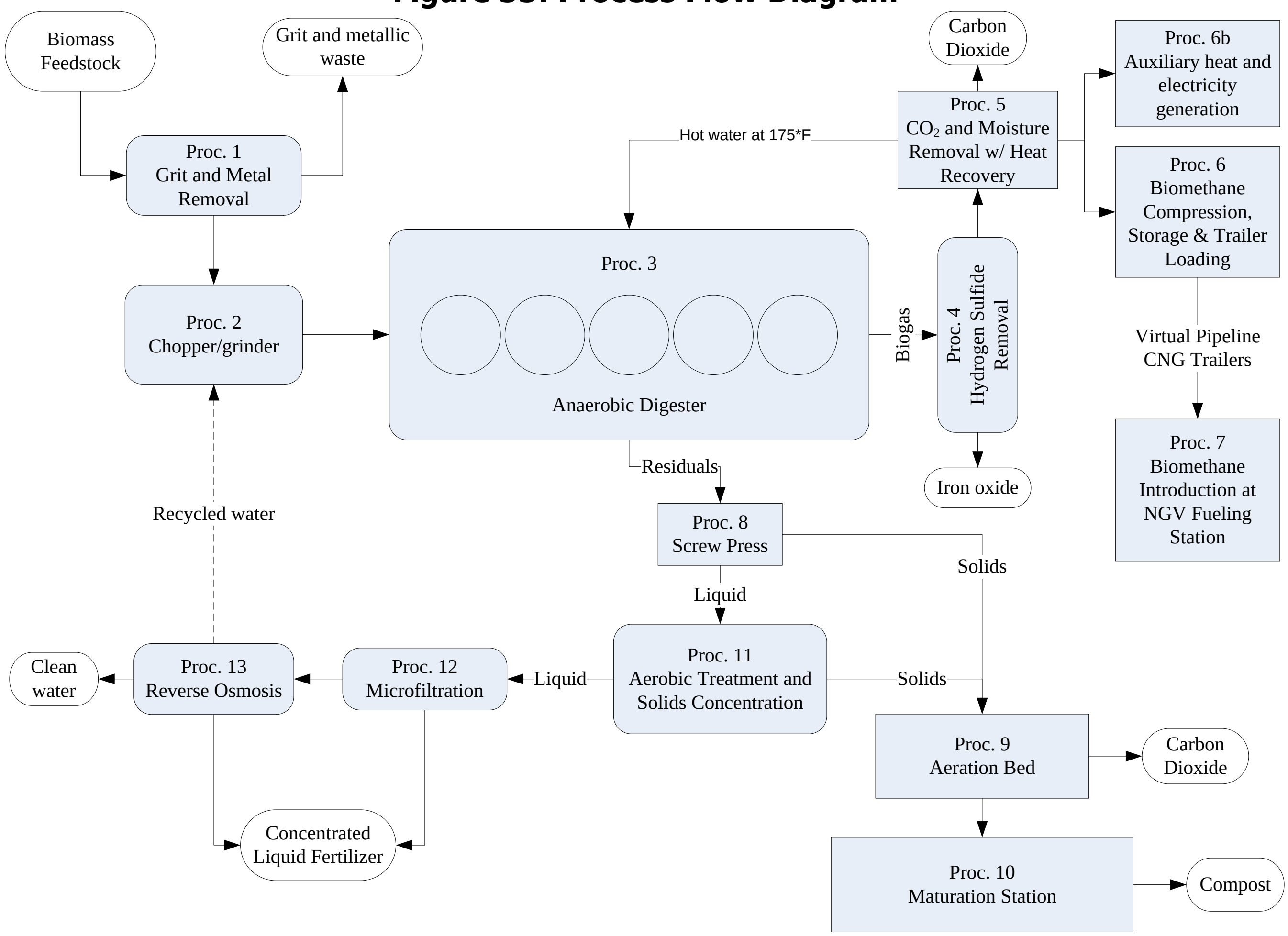
Source: Clean World Partners, LLC

6.3.6 System Process Flow and Layout

The goal of Task 6.5 is to assemble subsystem designs into a comprehensive integrated predesign package suitable for final engineering, design, construction, and procurement.

At Task 6.3.6, CWP completed preliminary reports and deliverables for sections. Within each individual section an attempt was made to integrate the specific section with the processes both preceding and following that section. This included consideration of material balance, energy balance, and physical connections, as well as overall coordination of utilities and material flow throughout the plant design. There are two deliverables for this section: the Task 6.5 summary report and the preliminary site layout and utilities drawings. This report will summarize the system process flow, including the initial and more current flows, as well as proposed control system flows and methodologies, thereby satisfying the first deliverable. The system layout process and instrumentation diagram, design package summary (including mass and energy balances), and site layout and utilities drawings are submitted in this updated version of the report. Figure 33 diagrams the process flow.

Figure 33: Process Flow Diagram



Source: Clean World Partners, LLC

6.3.6.1 Initial and Updated Flow Diagrams

The system process flow has changed from an early conceptual diagram to a functional flow that is being used to examine all aspects of the project—planning, budgeting, project management, construction, documentation, training, and operation. All elements of the original flow are in the functional flow, but are clustered in more meaningful units. In some cases the arrangement has been dictated by mass or energy considerations; in others, specific partners' products have required rearrangement of the units into dedicated subsystems (Figure 34).

Figure 34: Functionality and Unit Operations

Functional Section	Specific Unit Operations	Critical Design Criteria	Comments
SS Site Specific Section	Plan, Permit, Inspect, Local Engineering, Civil, Grading Utilities, Service Connections Foundation, Security, Lighting	Location, AHJ's, Neighbors Proximity to Utilities Proximity to Waterways Business Factors, ROI	GC Partner Critical Customer Interest Proximity to Byproduct Use
FE "Front End" Section	Material Transport, Containers Transfer, Conveying, Storage Size Reduction, Crush, Grind Sort, Size, Recycle, Dispose	Feedstock Source & Type Quality and Consistency Seasonal/Cyclical Variation Contamination Risk	FE Partners Critical Proven Processes Scalability & Flexibility
AD Anaerobic Digestion Section	Blend, Slurry, Transfer, Heat Process Monitor & Control Decant, Transfer, Collect Gas Recycle, Transfer to BE	CWP Core Technologies Productization, Lean Build Control Automation, Data Technical Feedback Value	CWP Long Term Support Recipe Monitor & Updating CR and NVA Analysis
GP Gas Processing Section	H2S Removal, H2O Removal CO2 Removal, H2O Removal Siloxane Removal, Adsorption Compression, Storage, Xfer	GP to GU Integration Min, Max, Turndown Facts Environmental Limits Time of Use & Storage	GP Partners Critical Proven Processes Scalability & Flexibility
GU Gas Utilization Section	Boiler, Furnace, CHP Unit IC Engine, Microturbine Fuel Cell, CNG Transport Fuel Direct Injection as CNG	Supply vs. Demand Study Min, Max, Turndown Facts Backup Provision Grid Connect Capability	GU Partners Critical Uptime & MTBF, MTTR Scalability & Flexibility
BE "Back End" Section	Screen/Filter Solids Compost Concentrate Liquid (uF, RO) Dispose Solids of Low Value Recycle, Drain Surplus Liquid	Characterize Byproducts Particle Size, Chemistry Pilot Test, Stability, Quality Mix, Blend, Certify, Market	FE Customer Applications Proven Processes Scalability & Flexibility

Source: Clean World Partners, LLC

The result of this rearrangement is standardization in the planning, estimating, and business modeling of the system. While the more traditional flowchart has details of value to process engineers and in the analysis of energy and mass balances, the functional grouping aids the organization of standard options, features, and business analysis of each project and system.

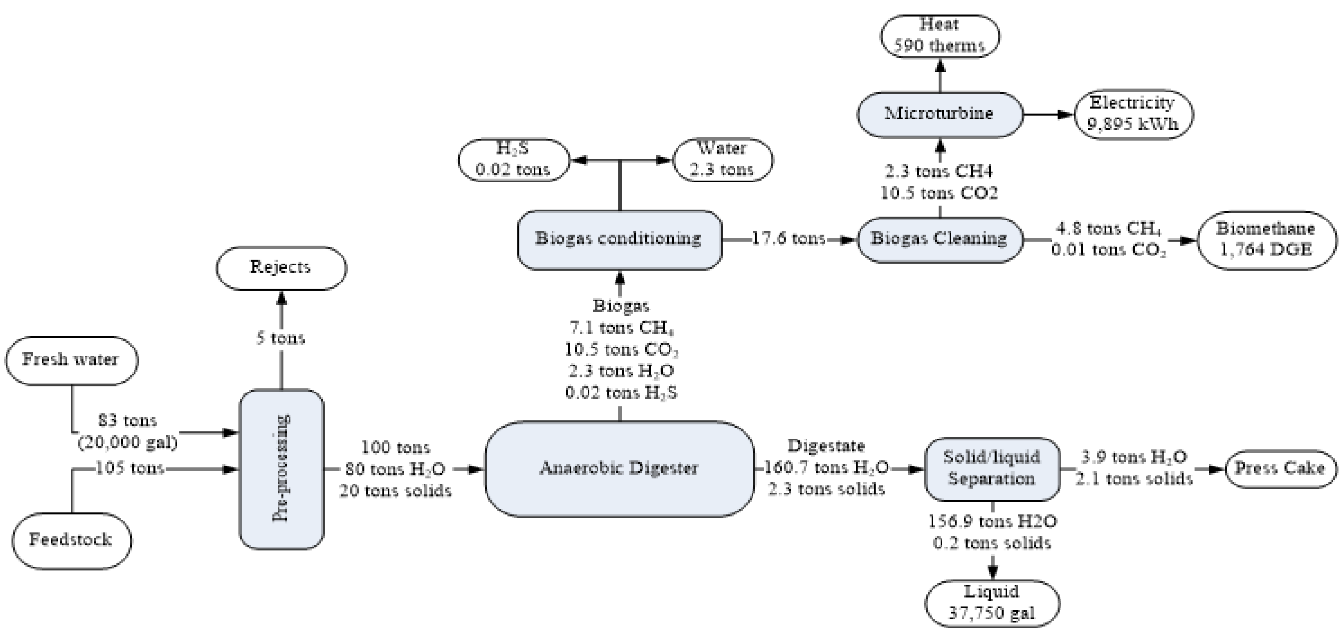
6.3.6.2 Calculation of Mass and Energy Balance

Mass balance refers to the flow of material (such as solids, water, and specific compounds) into and out of the system's unit processes and conversions of the material between different forms and phases. Energy balance refers to an analysis of consumption versus production of energy, including flow of energy between forms during conversion (from chemical energy to heat and/or electricity). For SBR1, the system boundary includes preprocessing, anaerobic digestion, solid/liquid separation, and biogas energy conversion. All other processes outside the system boundary (e.g., composting, liquid fertilizer production, and power transfer) were not included in the mass and energy balance calculations. Material inputs included source-separated organics collected from municipal restaurants and water for dilution of ammonia in the digester. Outflows included rejected materials during preprocessing, biogas and solid/liquid slurry during anaerobic digestion, liquid and solid fractions from solid/liquid separation, and exhaust gases produced during biogas energy conversion.

6.3.6.2.1 Mass Balance

For the system as defined, the total mass input must equal total mass output as a whole, as well as across each individual unit process. In addition to the overall mass balance, the TS and water balance were also calculated (Figure 35). For the digestate, solid/liquid separation was modeled assuming that the equipment used (a screw press) recovered 90 percent of the solids, generating a press cake with 65 percent MC. The resulting mass balance was calculated to determine the volume of the liquid fraction. To reduce the water consumption of the digester, it may be advisable to remove ammonia from the liquid stream and recycle it as dilution water. The press cake will require additional aeration and possibly addition of a bulking agent (wood chips or paper) before it can be land applied or sold as organic compost.

Figure 35: Mass Balance for Proposed 100-TPD Digester



Source: Clean World Partners, LLC

Based on the assumed biogas yield, 92 percent of the volatile solids in the feedstock will be converted to CH_4 and CO_2. The gas will be saturated with water vapor at the reactor temperature (135°F [57.2°C]). H_2S concentration in the gas was assumed at 900 ppm, based on the sulfur content of the feedstock. Other trace gaseous elements were considered negligible for this analysis. The biogas conditioning unit was assumed to consist of an iron sponge, activated carbon filter, and glycol chiller for gas drying. These would be expected to remove over 99 percent of the water vapor and H_2S in the biogas. Any residual concentration would be negligible and was not included in the mass balance. The biogas cleaning unit consists of a membrane separation that recovers 67 percent of the CH_4 and rejects 99 percent of the CO_2. The recovered gas, biomethane, can be used as transportation fuel where it would have the energy equivalent of 17.64 gallons of diesel fuel per ton of feedstock loaded into the digester. Gas additives such as odorants were not included in this analysis.

The exhaust gas from the biogas cleaning system was assumed to be used to run a microturbine for electricity and heat generation. Air input to the combustion or thermal oxidation process was not included in the mass balance, thus the exhaust stream from the microturbine was also omitted. However, it can be assumed that greater than 99 percent of the CH_4 would be oxidized to CO_2, and using the appropriate technology, very little oxides of N would be produced. Also, because the H_2S was removed, no oxides of sulfur would be produced. The energy balance of the system depends on the rate of loading and the power ratings of the equipment used.

6.3.6.2.2 Energy Balance

For the purposes of calculating an energy balance for the system, the loading rate for the digester was assumed to average 100 TPD consistently throughout the year. The energy content of the biogas produced was calculated based on the assumed CH_4 content of 65 percent by volume and the lower heating value of CH_4 (1,010 Btu/scf). Diesel fuel has a lower heating value of 129,500 Btu/gal. Based on these assumptions, the system will produce the following energy products on a daily basis:

- 1,764 DGEs of biomethane
- 9,895 kWh of renewable electricity
- 590 therms per day of useable heat

The electricity production capacity assumes the generator has a thermodynamic efficiency of 30 percent, leaving 70 percent of the energy produced as heat, which is recovered with a net heat transfer efficiency of 75 percent.

The electrical demand for the digester system was determined based on the power rating and operating time for the various unit processes that required electricity (Table 14). The total electrical demand of 8,249 kWh/d could be satisfied with 83 percent of the electricity produced from the biogas cleaning exhaust.

Table 14: Electrical Demand for Primary Unit Operations

Operations	Description	Average Power Usage (kW)	Daily Operating Time (hrs.)	Normalized Electrical Demand
Preprocessing and Loading Equipment	100-TPD DODA ® grinder/separator with chopper pump	75	7	525 kWh/d 5.25 kWh/ton
Digester Mixing, Transfer, and Controls	900,000 gal high-rate, two-stage anaerobic digester	16	24	331 kWh/d 18 W/kgal
Effluent Processing System	Screw-press and centrifuge	20	4	145 kWh/d 3.3 Wh/gal
Biogas Conditioning Skid	Glycol chiller and compressor for drying and cleaning 300 SCFM biogas	150	24	3,937 kWh/d 8.0 Wh/scf Biogas
Biomethane Storage and Delivery	4,000 psig compressor	110	24	3,215 kWh/d 15 Wh/scf Biomethane
Total				8,249 kWh/d

Source: Clean World Partners, LLC

In addition, the thermal demand was calculated assuming two-inch thick polyurethane foam insulation and an overall heat transfer coefficient of 1.76 Btu per hour-ft^2-°F. Assuming the average annual temperature was 60°F (15.6°C), the annual average thermal demand was calculated to be 314 therms per day, including heat needed to raise the temperature of the feedstock (assuming it had the thermal properties of water). Based on these calculations, 53 percent of the recovered heat could provide the thermal load. However, the heat will be produced at a relatively constant rate while the thermal demand will vary with ambient temperature. Assuming the feedstock is protected from freezing, the generator heat recovered could maintain the digester temperature even on a sub-zero day.

6.3.6.3 Proposed Control System Flow and Methodology

The critical parts of any system are the controls, which consist of a number of inputs or sensors (both digital and analog), and the software that conditions and draws relationships from the data resulting in predictable desired outputs. In the case of the CWP proprietary designed anaerobic digestion system the inputs may include:

- Operator discrete inputs (e.g. ON, OFF)
- Human-machine interface recipes and set points
- Temperature, pressure, valve position (open/closed), tank level, pH, and other inputs derived from field sensors
- Subsystem permissives from other interconnected processes (e.g. system ready, system running, system waiting, and acknowledgment)
- Warnings and alarm status digital communications

These inputs are processed by the various PLC software modules and result in outputs that may include:

- Starting and stopping of pumps, valves, boilers, and other equipment
- Triggering of indicator lights, horns, or other visual and/or audible indicators
- Changes in system permissives to other interconnected processes (e.g. system ready, system running, system waiting, and acknowledgment)
- Initialization of warnings and alarm status digital communications
- Collection and logging of data points
- Delivery of system pages, texts, emails, and other mobile communications

In order to control, monitor, and maintain the system both locally and remotely, the following control system features are being considered:

- Human-machine interface selection and development
    - System status and basic processes
    - Recipe modules and standard recipes
    - Safety v interlock functions
        - Warnings
        - Alarms
        - Faults
        - Error Codes
    - I/O and equipment listing maintenance screens (timers and counters)
    - Instrumentation setup and calibration
- Data collection, format, sampling frequency, and local storage
- Data cloud secure storage (multisystem capability)
- Offsite access
    - Monitoring
    - Control
    - Data Review
- Security and access control (multilevel)
- Documentation

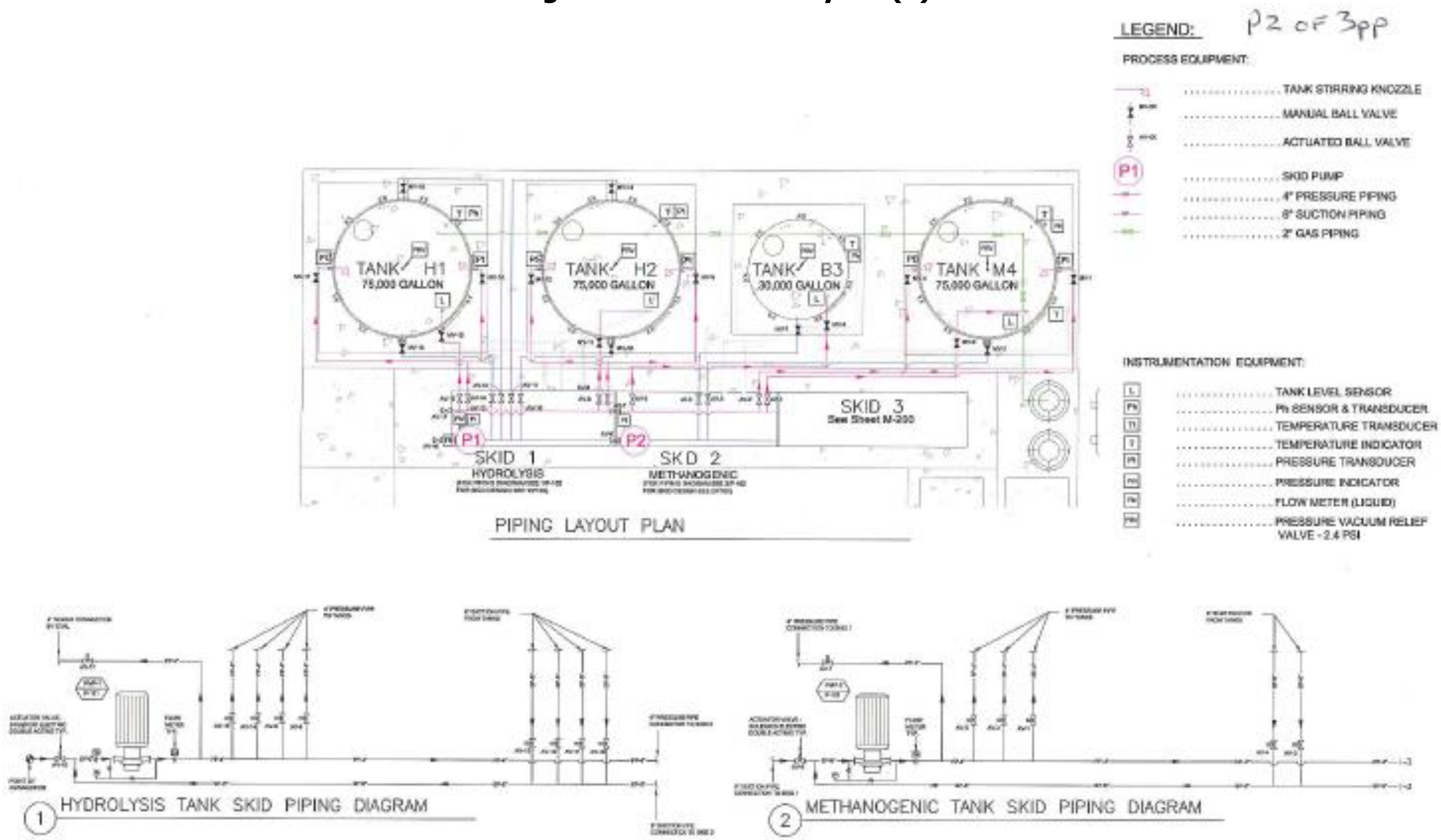
6.4 Site Plan Layout and Technical Drawings

Figure 36 offers an overhead, satellite photograph of the site plan layout. Figure 37 diagrams various tanks and skids associated to the layout. And Figure 38 features technical drawings of the site plan and plant layouts.

Figure 36: Site Plan Layout

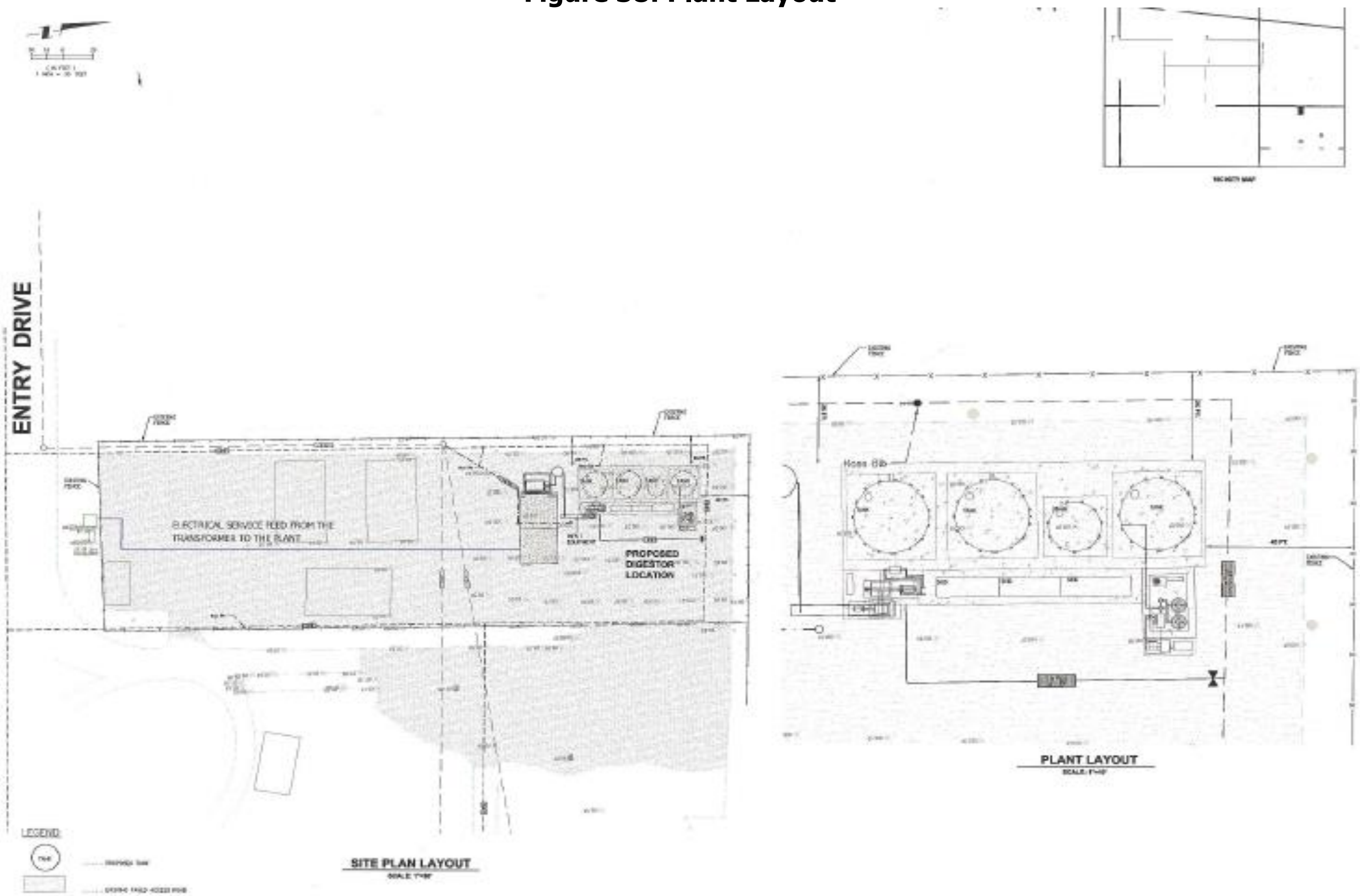
Source: Clean World Partners, LLC

Figure 37: Site Plan Layout (2)



Source: Clean World Partners, LLC

Figure 38: Plant Layout



Source: Clean World Partners, LLC

GLOSSARY

AMERICAN RIVER PACKAGING (ARP) – Project location for this agreement. Cardboard manufacturing company in Natomas, California.

BRITISH THERMAL UNIT (Btu) – The standard measure of heat energy. It takes one Btu to raise the temperature of one pound of water by one degree Fahrenheit at sea level. MMBtu stands for one million Btu.

CALIFORNIA AIR RESOURCES BOARD (ARB) – The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA ALTERNATIVE ENERGY AND ADVANCED TRANSPORTATION FINANCING AUTHORITY (CAEATFA) – Program within the California Treasurer's Office that works with public and private partners to provide innovative and effective financing solutions for California's industries.[1]

CALIFORNIA DEPARTMENT OF RESOURCES RECYCLING AND REVOVERY (CalRecycle) – Department within the California Environmental Protection Agency (Cal/EPA). Administers and provides oversight for all of California's state-managed non-hazardous waste handling and recycling programs.[2]

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY (Cal/EPA) – A state cabinet-level agency created in 1991 to unify California's environmental authority.[3]

CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA - pronounced See' quah) – Enacted in 1970 and amended through 1983, established state policy to maintain a high-quality environment in California and set up regulations to inhibit degradation of the environment.

CARBON DIOXIDE (CO_2) – A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO_2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent).

CARBON DIOXIDE EQUIVALENT (CO2e) - A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

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1 California State Treasurer (https://www.treasurer.ca.gov/index.asp)

2 CalRecycle (https://www.calrecycle.ca.gov/)

3 Cal/EPA (https://calepa.ca.gov/)

CARBON INTENSITY (CI) – The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

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

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

ENVIRONMENTAL IMPACT REPORT (EIR) – Refers to the assessment of all possible impacts that a land development or construction project may cause on the environment in a particular area. It includes population, traffic, schools, fire protection, endangered species, archeological artifacts, and community beauty.

FIXED SOLIDS (FS) – The residue left in the vessel after a sample is ignited (heated to dryness at 550EC).[4]

GIGAWATT-HOUR (GWh) – One million kilowatt-hours of electric power. California's electric utilities generated a total of about 302,072 gigawatt-hours in 2007.

GREENHOUSE GASES (GHG) – Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

HYDROGEN (H_2) – A colorless, odorless, highly flammable gas, the chemical element of atomic number 1.

INTERNAL COMBUSTION (IC) – Relates to internal combustion engine, in which the combustion that generates heat takes place inside the engine proper instead of in a furnace.[5]

KILOGRAM (kg) – The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1000 cubic centimeters of water at the temperature of its maximum density.

KILOWATT (kW) – One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

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4 U.S. EPA (https://www.epa.gov/)

5 Merriam Webster (https://www.merriam-webster.com/dictionary/internal%20combustion%20engine)

KILOWATT-HOUR (kWh) – The most commonly-used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumes 534 kWh in an average month.

LITER (L) – A metric unit of capacity equal to one cubic decimeter.

LIQEUFIED NATURAL GAS (LNG) – A natural gas that has been cooled to a liquid state (about -260°F [-162.2°C]) for shipping and storage. The volume of natural gas in its liquid state is about 600 times smaller than its volume in its gaseous state. This process makes it possible to transport natural gas to places pipelines do not reach.[6]

LOCAL ENFORCEMENT AGENCY (LEA) – Local enforcement agencies are designated by the governing body of a county or city and, upon certification by CalRecycle, are empowered to implement delegated CalRecycle programs and locally designated activities. LEAs have the primary responsibility for ensuring the correct operation and closure of solid waste facilities in the state. They also have responsibilities for guaranteeing the proper storage and transportation of solid wastes.[2]

METHANE (CH_4) – A light hydrocarbon that is the main component of natural gas and marsh gas. It is the product of the anaerobic decomposition of organic matter, enteric fermentation in animals and is one of the greenhouse gases.

MICROMETER (um) – An SI unit of length equal to one millionth of a meter, or about a tenth of the size of a droplet of mist or fog.

MOISTURE CONTENT (MC) – The proportional amount of moisture in a substance. In this case, water contents in the food waste feedstocks.[7]

MUNICIPAL SOLID WASTE (MSW) – Locally collected garbage, which can be processed and burned to produce energy.

NATURAL GAS (NG) – Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane, and other gases.

NITROGEN (N) – An essential element of life and a part of all plant and animal proteins. Nitrogen is commercially recovered from the air as ammonia, which is produced by combining nitrogen in the atmosphere with hydrogen from natural gas.[8]

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx) – A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation

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6 Office of Fossil Energy (https://www.energy.gov/fe/science-innovation/oil-gas/liquefied-natural-gas)

7 Lexico (https://www.lexico.com/en/definition/moisture_content)

8 U.S. Geological Survey (https://www.usgs.gov/)

and acid deposition. NO_2 is a criteria air pollutant and may result in numerous adverse health effects.

pH – A measure of how acidic/basic water is. The range goes from 0 to 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water.[8]

RENEWABLE NATURAL GAS (RNG) – Or biomethane, is a pipeline-quality gas that is fully interchangeable with conventional natural gas and thus can be used in natural gas vehicles. RNG is essentially biogas (the gaseous product of the decomposition of organic matter) that has been processed to purity standards. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).[9]

RENEWABLE PORTFOLIO STANDARD (RPS) – Regulates the increased production of energy from renewable sources like wind, solar, biomass, and geothermal. California's RPS program was established in 2002. The California Public Utilities Commission implements and administers RPS compliance rules.[10]

REVERSE OSMOSIS (RO) – A process by which a solvent passes through a porous membrane in the direction opposite to that for natural osmosis, when subjected to a hydrostatic pressure greater than the osmotic pressure.[11]

SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT (SMAQMD) – Created in 1996 under Health and Safety Code Sections 40960 et. seq. to monitor, promote, and improve air quality in the County of Sacramento. It is one of 35 regional air quality districts in California.[12]

SOUTH AREA TRANSFER STATION (SATS) – A permitted MSW transfer station and the site of SBR1.

STANDARD CUBIC FEET PER MINUTE (SCFM) – The molar flow rate of a gas corrected to standardized conditions of temperature and pressure thus representing a fixed number of moles of gas regardless of composition and actual flow conditions.

SULFUR OXIDES (SOx) – Pungent, colorless gases (sulfates are solids) formed primarily by the combustion of sulfur-containing fossil fuels, especially coal and oil. Considered major air pollutants, sulfur oxides may impact human health and damage vegetation.

9 U.S. Department of Energy (https://afdc.energy.gov/fuels/natural_gas_renewable.html)

10 California Public Utilities Commission (https://www.cpuc.ca.gov/default.aspx)

11 Lexico (https://www.lexico.com/en/definition/reverse_osmosis)

12 Sacramento Metropolitan Air Quality Management District (http://www.airquality.org/)

THERM – A non-SI unit of heat energy equal to 100,000 Btu or 1.10 MMBtu.[13]

THOUSAND CUBIC FEET (Mcf) – The volume of 1,000 cubic feet. One Mcf of natural gas equals 1.036 MMbtu, or 10.36 Therms.[13]

TONS PER DAY (TPD) – Measurement to describe a facility's capacity for treatment or processing of relevant materials.

TOTAL SOLIDS (TS) – The residue left in the vessel after evaporation of liquid from a sample and subsequent drying in an oven at 103—105EC.

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

VOLATILE ORGANIC COMPOUNDS (VOCs) – Carbon-containing compounds that evaporate into the air (with a few exceptions). VOCs contribute to the formation of smog and/or may themselves be toxic. VOCs often have an odor and some examples include gasoline, alcohol, and the solvents used in paints.

VOLATILE SOLIDS (VS) – The weight loss after a sample is ignited (heated to dryness at 550EC). Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter because the loss on ignition is not confined to organic matter. It includes losses due to decomposition or volatilization of some mineral salts.[4]

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13 U.S. Energy Information Administration (https://www.eia.gov/)