Clean Transportation Program

FINAL PROJECT REPORT

CleanWorld's Sacramento BioDigester Scale-Up Project

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Prepared by: CleanWorld

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation 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 PON-11-601 to provide funding opportunities for Advanced Biofuel Production for the development of new, California-based fuel for new, low carbon facilities, or for projects that lower the carbon intensity of fuels produced at existing facilities. In response to PON-11-601, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards March 23, 2012 and the agreement was executed as ARV-11-021 on September 24, 2012.

ABSTRACT

CleanWorld was awarded a grant in 2012 from the California Energy Commission to scale up the Sacramento BioDigester. The project increased the food waste diversion from landfills from 25 tons per day to 100 tons per day, as well as produced renewable natural gas for transportation fuel.

This project met 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 waste in area landfills. The project directly supported the legislative and regulatory objectives of CalRecycle, the CPUC, and CARB.

For this demonstration project, tasks included: Preconstruction and Planning; Design Development and Cost Estimating; Procurement and Fabrication of System Components; Construction and Onsite Fabrication and Assembly; System Testing, Startup and Achieving Full Operational Status; and Data Collection and Analysis.

CleanWorld completed the scale-up of the facility and began loading feedstock in June 2015. Two tanks and two pumping and controls skids were added to the existing system. This quadrupled the system's capacity and output. As of publication, the BioDigester was accepting 35-40 tons per day on the way to achieving full capacity. Biogas production was also over twice as high as its historical output, and the biogas yield was as high as required to achieve the projected full energy production (1,080 diesel gas equivalent per day of biomethane fuel) when the system reaches full capacity.

Due to the work performed under this grant, CleanWorld designed, fabricated, constructed, and commissioned a scale-up to an existing BioDigester system, demonstrating the scalability of the technology as well as providing a larger treatment system for Sacramento-area organic waste haulers. The lessons learned here will impact and enhance all CleanWorld's currently operating BioDigesters, and should expand the customer base in the future, particularly for customers with expanding and/or uncertain waste volumes.

Keywords: Anaerobic digestion, BioDigester, Biogas, Renewable Natural Gas, Biomethane

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EXECUTIVE SUMMARY

CleanWorld in collaboration with project partners scaled up the existing 25-ton-per-day Sacramento BioDigester at the County of Sacramento South Area Transfer Station to a larger system 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 gas equivalent per year of renewable natural gas. The Sacramento BioDigester includes an on-site natural gas vehicle fueling facility that fuels solid waste transport, school district, and county owned fleet vehicles with renewable natural gas.

During the pre-development stage, feedstock agreements and biofuel purchase contracts were secured to ensure the project's success. For this second phase, 75 tons per day additional feedstock supply was required for the BioDigester to operate at its full design capacity. At the time of this report's completion, 69 percent of the weekly feedstock demand has been secured. Atlas Disposal signed an agreement to purchase all the biofuel produced in the scaled-up project. Since Atlas's biofuel demand is greater than the volume that CleanWorld can supply in Phase II, they were able to commit to the purchase of the new biofuel volumes.

The site utilities and access were already in place for this project since they were installed during Phase I, with the scaled-up facility design in consideration. The city planning permit, building permit, air permit and lead enforcement agency notifications were secured. Several improvements were made to the design of the Phase II system as a result of lessons learned during the operation of Phase I, including the addition of mechanical mixers, a fluid transfer skid, and a 190-kilowatt engine generator to offset the project's parasitic electrical load.

During the planning and procurement phase, CleanWorld completed a full set of engineering drawings (site layouts, mechanical drawings, tanks drawing, electrical schematics, and detailed piping and instrumentation diagrams) and completed the procurement package for purchasing new components. A list was also prepared for consumables and spare parts needed. To maintain the schedule and timelines, all members of the project team met weekly to review all open action items, determine critical path items, and adjust the schedule as needed. Otto Construction provided project management including formal project scheduling and tracking with input from CleanWorld technical and administration personnel.

A full system mass and energy balance was performed using a CleanWorld's custom process engineering model with assumptions determined from extensive laboratory and field testing. Three scenarios were considered, based on different biogas utilization strategies. A balanced scenario was found to provide the most efficient use of the gas refining and electrical equipment. Air emissions and greenhouse gas emissions were also analyzed to ensure they met local air board standards.

During the fabrication and installation phase, each custom component was fabricated and assembled. Those components that could be fabricated off site began prior to site preparation.

Tank components were shop fabricated by the supplier and delivered to the site for assembly. Skids were fabricated in a Marysville facility according to design plans previously prepared with CleanWorld. A shop site testing plan was developed that allowed 10 weeks to fully test skids before they were installed onsite. The biogas processing equipment was ordered and delivered as separate modular units to be assembled and installed on site. The engine generator also arrived prefabricated and only needed to be installed and piped on site.

Site preparation was completed in December 2012, and installation of the system began immediately. Field assembly and installation involved erecting the two new tanks, plumbing the new skids to the appropriate tank connectors, assembling the flare, route piping for the new gas processing system, and routing electrical to all of the required components. While the skids were being installed and connected to the tanks and the previously existing skids, the controls contractor began reprogramming the control panel, and the gas processing contractor programmed the new gas processing control system. The existing BioDigester program was modified to incorporate the new tanks, pumps, and instruments. Finally, the two control systems were interconnected.

Testing of installed components proceeded in several steps as construction was ongoing. Leak testing of the tanks occurred after tank construction was complete, but before all of the interconnections with the skids were made. Separately, the flare was commissioned, and the biogas collection and processing system was tested. Pipes were leak tested and valve and instrument operations were verified. Installation and commissioning steps were completed in April 2015.

The commissioning of County of Sacramento South Area Transfer Station Phase II was completed on June 15, 2015. During commissioning, feedstock was loaded into the hydrolysis tank and the tank volumes were allowed to increase to their nominal operating capacity. Transfers from the hydrolysis tank to the methanogenic tank were initiated and automated to begin feeding the methanogenic bacteria and increase biogas flow. During start-up, data was collected and analyzed, including tank volumes, tank temperatures, flare temperatures, feedstock loading quantities, biogas output, methane content and mean daily pH. At the time of publication, the BioDigester had begun to reach steady state as evidenced by stabile methane content and biogas production rates, and loading began to be ramped up. The system had achieved over 33 percent of the designed capacity and biogas yields were within normal range based on prior experience with similar feedstocks. The scale-up was functioning as expected. System feeding was being ramped up, but the system was already processing over twice as much feedstock as was processed during Phase I.

In addition to installing and commissioning the BioDigester, CleanWorld expanded its health and safety program significantly as part of this project. The existing orientation training that introduces the anaerobic BioDigester system and the illness and injury prevention plan to all affected CleanWorld employees was improved. In addition, new detailed online training sessions were instigated and made mandatory for key employees.

CleanWorld's scale-up of the County of Sacramento South Area Transfer Station project was a great success for both the company as well as the State of California. The program, technology and economic goals that were established in the project's proposal were accomplished with a great degree of success. CleanWorld believes that this project will serve as a successful demonstration of a scalable BioDigester project that can be replicable throughout the state, especially for communities that have expanding organic waste collection programs. This grant allowed the County of Sacramento South Area Transfer Station project to be economically feasible and lowered the risk for outside investors, permitting CleanWorld to provide the match needed to complete the project.

There are still two areas that need further research and demonstration in CleanWorld's BioDigester system: pre-processing to allow acceptance of more heavily contaminated feedstocks and effluent processing to generate valuable co-products and reduce wastewater disposal costs. Creating innovative solutions in these two identified areas would allow future BioDigester projects to be more commercially relevant and economically feasible, which would greatly increase the number of digesters constructed in California in the near future. CleanWorld has been actively researching and developing technologies in these areas and has plans in place for both areas. CleanWorld has reviewed many different commercial technologies for feedstock decontamination and has applied for grants to pilot test an innovative integrated system at County of Sacramento South Area Transfer Station that promises to open up the anaerobic digester market to over 6 million tons of organic waste in California alone.

CleanWorld also reviewed and tested many digesters effluent processing technologies as part of a separate CEC grant. Along with the market research performed, these technologies have led to the development of a novel integrated system that promises to create a concentrated liquid fertilizer with excellent market potential that can be stored and shipped to a wide range of customers. This technology would simultaneously generate a low strength wastewater that could be easily discharged into the local sewer system as well as a concentrated bacterial solution that could enhance digester stability, provide ready seed for new BioDigester systems, and potentially be turned into a secondary product. CleanWorld's initial testing and economic modeling suggests this system is technically and financially feasible. CleanWorld has tested all of the components and is ready to demonstrate this technology at a larger scale. This technology will be widely applicable to any digester system accepting almost any feedstock, allowing CleanWorld to offer most new customers a complete solution for their waste streams that will greatly accelerate the dissemination of anaerobic digester technology while further reducing greenhouse gas emissions by offsetting conventional fertilizer use.

Chapter 1:
Project Overview and Management

CleanWorld was awarded a grant in 2012 from the California Energy Commission to complete a scale up of the Sacramento BioDigester from 25 tons per day to 100 tons per day. The project increased the food waste diverted from landfills, as well as renewable natural gas production.

This project meets the principal goals of the California Energy Commission by stimulating local economic development and reducing greenhouse gas emissions, petroleum demand, and the environmental impacts associated with disposal of organic waste in area landfills. The project also directly supported the legislative and regulatory objectives of CalRecycle, the Public Utilities Commission and the California Air Resources Board.

For this demonstration project, CleanWorld provided the technology, Otto Construction installed the equipment, and Carson Development provided project management.

Initial Project Goals and Final Project Goals

The goals of the project were to complete the scale-up of the existing 25 ton per day (TPD) facility to a 100- system, thereby contributing to the CEC goal of producing alternative and renewable transportation fuels in California that can stimulate economic development in the state and significantly reduce greenhouse gas (GHG) emissions and petroleum fuel demand.

The project also supported 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 pre-processing system to allow for lower carbon feedstock, further reducing Low Carbon Fuel Standard (LCFS) metrics

Reduce GHG emissions through efficiencies in scale-up

Reduce petroleum dependence by offering a renewable natural gas fueling station for public use

Stimulate economic development in California by developing a replicable plan for constructing phased anaerobic digester (AD) projects

Display anaerobic digestion system integration for waste collection companies with compressed natural gas (CNG) fleets

To achieve these goals, the project team pursued the following objectives:

- Technical

    - Design, engineer, and construct the scaled-up Sacramento Biorefinery #1 facility. This step includes the addition of two large reactors and a material handling skid to the existing Sacramento Biorefinery #1 system
    - Increase diversion of pre-landfill, source-separated food waste from 25 TPD to 100 TPD
    - Increase daily renewable natural gas (RNG) production from 440 diesel gas equivalent (DGE) to 1,550 DGE
    - Increase usable heat from 148 therms (thm)/day to 520 thm/day
    - Increase solid effluent for use in soil amendment from 1-2 TPD to 20 TPD
    - Increase slow-release nitrogen zeolite fertilizer product from 6 TPD to 22 TPD
    - Increase cleaned water reclamation from 4,900 gallons per day (GPD) to 15,000 GPD
    - Increase net greenhouse gas offset from 17 to 66 metric tons of carbon dioxide equivalents (CO2e Digesters with a carbon intensity of -15.29 grams of carbon dioxide equivalent per megajoule) per day
- Economic
    - Expand the CNG-fueled ATLAS fleet from 10 to 20 trucks
    - Create up to 137 short-term jobs in Marysville, California, where fabrication will occur, and construction jobs in Sacramento, California
    - Create 16 long-term operations jobs in Sacramento, California
    - Generate more than $1.1 million in annual payroll, sales, use, and fuel taxes to the benefit of the city, state, and county

Key Contractors and Subcontractors

To complete the project, CleanWorld assembled a team consisting of experts in engineering, design, feasibility, permitting, construction, project development and management, anaerobic digestion, and waste management. As seen below, they were collectively well qualified to complete the project.

CleanWorld – Project Lead and Technology Provider

CleanWorld partners with businesses and communities to convert organic waste to renewable energy, soil enhancement products, and other valuable bio-based products using proprietary technologies that are scalable, cost-efficient, and effective. CleanWorld is a subsidiary of Synergex International Corporation, an industry leader at the forefront of technology commercialization for more than 35 years. CleanWorld provides effective waste management solutions based on anaerobic digestion (AD), an ever-evolving technology that converts waste to renewable energy through a biological in-vessel system utilizing a mix of naturally occurring bacteria. CleanWorld also offers a variety of services, including feedstock analysis, feasibility studies, biogas utilization, residuals management, operational support, and process modeling.

Atlas Disposal—Feedstock Supply and Transportation Fuel Distributor

Established in 1998 in response to California Assembly Bill 939 and its landmark waste diversion mandates, Atlas Disposal Industries, LLC, is currently the fastest-growing waste and recycling hauler in the Sacramento region, servicing more than 4,000 commercial and 800 multi-family customers in the greater Sacramento area. In addition to traditional waste hauling, Atlas spearheads an active recycling effort, including organic waste recycling. In 2014, Atlas created a subsidiary called Atlas ReFuel™ dedicated to marketing and providing renewable natural gas.

Otto Construction—Builder

Established in 1947, Otto Construction creates award-winning multi-million-dollar facilities throughout Northern California. Otto Construction is currently the largest family-owned builder in Sacramento, California. The company provides a broad range of services, including design/build, CM at Risk, preconstruction, lease-leaseback, and special projects. The company's professionals also provide expertise in the practice of sustainable design to improve project performance, optimize environmental quality, and reduce environmental impact. Otto Construction has successfully integrated elements for sustainable design into several of its building projects, including reduction in site disturbance, restoration of open space, light pollution reduction, storm water management, renewable energy, building reuse, recycled materials, and day lighting. Otto Construction has constructed several anaerobic digestion facilities for CleanWorld, including the original Sacramento Biorefinery facility.

Carson Development Company, Inc.—Project Management/Development

Since 1974, Carson Development Company, Inc., has worked with a variety of clients in both the private and public sector in developing, constructing, and leasing commercial, industrial, retail, geothermal, office, and multifamily properties in California. Carson Development Company, Inc., is in Sacramento, California, at 1722 3rd Street in a two-building mixed-use office/warehouse project it developed in 1980. Carson has worked with CleanWorld on the development and implementation of all its existing facilities.

Peabody Engineering—Engineering Design and Fabrication

Peabody Engineering has been providing development and engineering services for numerous communities and private entities throughout the west, including in California, Oregon, Nevada, Hawaii, and Arizona. Peabody Engineering's experience in working to improve redevelopment areas along with suburban areas has allowed it to excel in private land development projects, public improvements, new developments, redevelopments, and site planning for private developers, cities, and counties. Peabody is committed to providing its clients with a professional product, completed in a cost-effective and timely manner. The firm's focus is providing clients and communities with the very best in design and construction. This focus has allowed Peabody the opportunity to work in a wide variety of projects including commercial, residential, and industrial avenues. Peabody has provided site plans and civil drawings for all CleanWorld's existing projects, including the current one.

The County of Sacramento, California—Site Owner

The County of Sacramento, California, owns the Sacramento Area Transfer Station and has leased it to Atlas Disposal and CleanWorld for the purpose of converting organic waste to renewable transportation fuel. The County of Sacramento fully supported the original Sacramento Biorefinery project, following a review of multiple technologies. The County selected CleanWorld's AD technology because of its design flexibility and CleanWorld's interest in working with the County. After awarding the site to Atlas Disposal and CleanWorld, the county agreed to provide the land, access to the site, and several of the base utilities, and continued to do so during this second phase of the project.

Synergex—Administrative Support

Synergex products and professional services help businesses maximize their investments in enterprise applications and technologies. Synergex works to ensure that the technology behind its clients' applications keeps pace with emerging opportunities and demands, enabling them to focus on developing new capabilities that fuel future growth. Synergex Ventures is a wholly owned subsidiary of Synergex International Corporation and a major investor in CleanWorld. Synergex International Corporation provided administrative support on this project, including managerial guidance, accounting, payroll, human relations, office space, and equipment.

TSS Consultants—Permitting

TSS Consultants is an interdisciplinary consulting firm that provides renewable energy, natural resources management, environmental permitting and compliance management, greenhouse gas management, and financial assessment services. Clients served range from public sector agencies to private sector businesses, tribal enterprises, public utilities, municipal utilities, investment banks, and nonprofit organizations. TSS consultants has a time-tested approach implementing comprehensive feasibility assessments of bioenergy projects addressing the financial, regulatory, feedstock supply, technical, and institutional barriers and risks that impacts successful project development. TSS consultants has assisted CleanWorld with permitting and regulatory compliance on all its existing projects, including this project.

Chapter 2: Feedstock Agreements and Fuel Purchase Contracts

Feedstock Agreements

Atlas Disposal had an agreement to supply 25 tons per day of food waste as part of the first phase. For the second phase, 75 tons per day additional supply will be required for the BioDigester to operate at its full design capacity. The daily supply can fluctuate, but the average over each week should be close to the design capacity. Therefore, the weekly supply should be close to 175 tons during Phase I and 700 tons during Phase II. These are maximum capacity figures for the facility. However, actual feedstock supply may be less due to feedstock availability, plant operational capacity, throughput capacity of equipment, and feedstock characteristics.

Table 1 provides a list of all current and potential feedstock suppliers with minimum required and expected feedstock supply quantities. This list is continuously evolving and being revised regularly as new feedstock contracts are secured. CleanWorld also accepts spot loads without contracts that may not be listed in the table as they are irregular and difficult to predict.

Table 1: Feedstock Supply List for CleanWorld BioDigester at the South Area Transfer Station

Supplier	Required Supply (tons* per week)	Expected Supply (tons* per week)	Start date	Status
1	175	175	Jan 2013	Escalating
2	12	30	Jan 2013	Currently accepting
3	1	1	Jan 2013	Currently accepting
4	6	20	May 2013	Currently accepting
5	0	30	May 2013	Currently accepting
6	5	20	July 2013	Currently accepting
7	5	30	August 2013	Currently accepting
8	0	20	December 2013	Currently accepting
9	5	25	September 2014	Currently accepting
10	102	102	January 2015	Currently accepting
11	5	15	February 2015	Currently accepting
12	10	15	February 2015	Currently accepting
Total	**326**	**483**		

Source: CleanWorld

* Tonnages have been adjusted to a standard wet ton of food waste with 75 percent water content.

Fuel Purchase Contracts

Atlas Disposal has an agreement with CleanWorld to purchase all the biomethane produced by the BioDigester. The biomethane is used by Atlas to offset conventional natural gas pumped into vehicles (including Atlas's own fleet) at the fueling station. Atlas buffers demand gaps by blending biomethane with natural gas. Atlas currently delivers more natural gas to third party fleets than the BioDigester alone can or will be able to provide. This essentially guarantees a market for the biomethane if Atlas continues to provide natural gas.

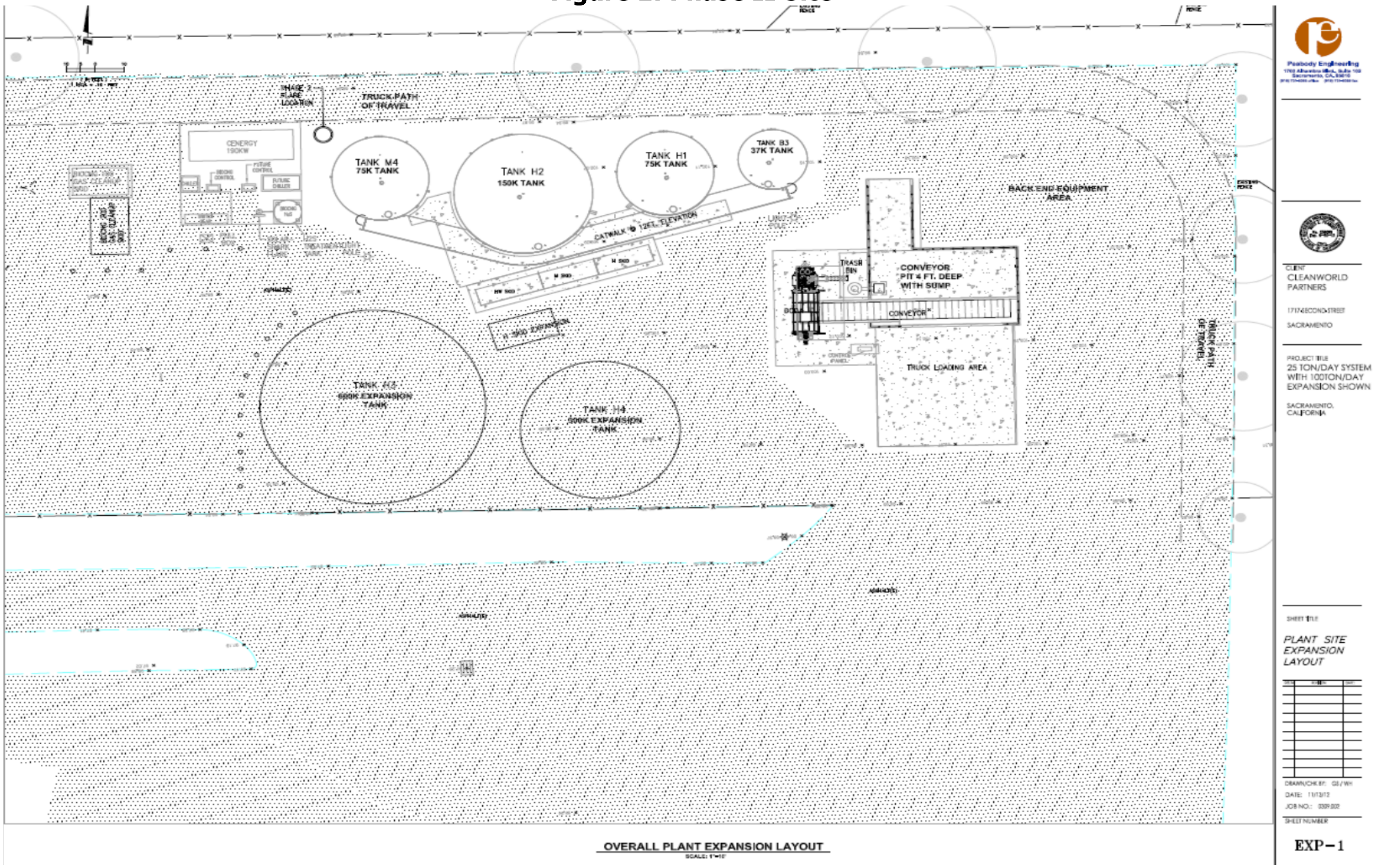
Chapter 3: Site Work, Permitting and System Requirements

Project size and location

The project size assumed that the facility would process an average of 100 tons of source-separated organic waste each day throughout the year. As the original Phase I system was designed to treat 25 tons per day in a combined nominal volume of 300,000 gallons, the scale-up added 900,000 gallons of capacity. To maintain the proper proportions between the reactors, the expansion was split into one 300,000-gallon reactor and one 600,000-gallon reactor. An additional gas processing unit, a BioCNG 200 was installed, and a larger effluent processing system is planned. The location of the equipment within the site footprint for the scale up is shown in Figure 1.

The feedstock loading system was not changed because its current design should allow it to process 100 tons in 8-10 hours, depending on the feedstock. The initial study of materials that would be accepted during Phase II showed that up to 50 percent of the material accepted would be pumpable and bypass the Doda Bio separator. However, the feedstock materials that are accepted at the facility have changed since the initial study. CleanWorld has since designed new equipment for the pre-processing system that would allow for higher levels of contamination in the feedstock to access more and higher value feedstocks. This is discussed in detail in the final conclusions section of this report in Chapter 9.

Figure 1: Phase II Site



Source: CleanWorld

Site utilities

The project site originally did not have adequate power supply to support the project's electrical load, so a new 2,000-amp transformer was purchased by CleanWorld from the local utility district to support the electrical requirements for the expanded project. The AD system utilizes the on-site city water supply and sanitary sewer system. No infrastructure changes were deemed necessary for the sewer system to accept the facility's wastewater. No water from project operations will be discharged to the soil or to the storm-water system, although the site's storm-water prevention plan was updated. Natural gas was not originally available at the site, so a two-inch, high-pressure line was brought into the site from the street to serve the boiler in the AD system for heating the tanks as well as to supplement to CNG fueling station adjacent to the project. The facility is currently in conformance with applicable fire safety standards of the City of Sacramento Fire Department.

Access into and out of the site location

Truck access was from Fruitridge Blvd where there is a dedicated driveway for vehicular traffic to enter and leave the site (see Figure 2). The Solid Waste Facility permit for the County of Sacramento South Area Transfer Station (SATS) site allows up to 522 vehicles per day at the site, which is fewer than are expected even after the scale-up. Waste-hauling trucks bring in the feedstock and pull into the loading area to deposit their load using the truck path shown on the site layout. Vehicles also pull into and out of the site when re-fueling at the natural gas vehicle fueling station.

Figure 2: Entrance to Site

Source: CleanWorld

Engineering Requirements

The facility design specifications were reported to the CEC previously (CEC grant number ARV-10-026). At the time, the facility was referred to as the Sacramento Biorefinery #1. It has since been renamed Sacramento BioDigester. The overall system design remained intact as the second phase was installed. However, some upgrades and changes to the design were made based on operational experience.

Improvements to BioDigester System

The design team for this project held several meetings to examine areas for improvement in the design of the equipment based on prior knowledge. The major components of the scale-up included two tanks (one 300,000 and one 600,000 gallons), larger fluid-transfer skids, and an expanded biogas processing system. Although the components themselves did not change, a few design changes were made to the overall layout, the mixing system, and the gas processing scheme.

One improvement that resulted from the re-design meetings was the addition of mechanical mixers to the feed receiving tank of the AD system (the 300,000-gallon tank). Previously, all the tanks were mixed exclusively with recirculating hydraulic pumps. However, mechanical mixers are more efficient and do not tie up pumps that are used for internal fluid transfer. Furthermore, the pump and pipe sizes could be decoupled from the mixing needs which allows them to be smaller and more cost effective. Several mixer designs were considered before selecting the final models.

Initially, the three existing tanks were envisioned to become parallel feed receiving tanks. However, with the new mixer design and lack of mixers in the original design, it was decided that they should instead be used as parallel polishing tanks. This also allows for variable polishing tank volume which fits the original design intent for the technology.

The fluid transfer skid for Phase II was also a new development for CleanWorld since it was the first skid to be designed for tanks larger than 150,000 gallons. The skids were designed with larger pumps, valves, and pipes to support the larger system. Because the pumps are no longer needed for mixing, the new skid design integrated well with the existing skids.

The additional biogas produced with the expansion requires additional biogas conditioning (i.e., CO2 removal), handling (i.e., flare) and expanded CNG fueling station requirements. Models also predict that at full scale there may be sufficient biogas to simultaneously run the gas cleaning and a small engine generator for parasitic heat and power. This required adding a new control system to balance distribution of the biogas.

Permitting for Phase II

The city planning permit for the SATS Phase II work was approved in January 2013. The building permit was submitted as soon as the engineering designs were completed in March 2013. The air permit was issued in January 2013, but a modification was submitted to change the micro-turbine that was on the original plan to an internal combustion engine. The lead enforcement agency required only a notification 30 days prior to the startup of SATS Phase II.

Chapter 4: Design Engineering and Construction Development

CleanWorld completed the procurement package for purchasing components and the design package for designing custom components as well as overall integration during this phase of the project. The specific components and design work details are considered proprietary information and are therefore held by CleanWorld. The following outlines which individual components of the design and procurement packages were considered and what key changes were made.

Procurement Package for Purchased Components

The procurement package contained all the individual components listed in Table 2. All these components were purchased either at the time of the installation of Phase I or during the procurement stage of this grant, as indicated below.

Table 2: List of Major Purchased Components

Front End	**Controls**
Conveyor	Programmable logic controller
Separator/Grinder	Human machine interface
Tanks	**Biogas Handling**
Skid Components	Flare
Valves	Hydrogen Sulfide (H2S) Scrubbing
Piping	Electrical Generator with Heat Recovery
Pumps	Biogas Upgrading System
Instrumentation	**Balance of Plant**
Temperature	Security fences, gates, and cameras
pH	Scale house and admin building restoration
Pressure	Signage and branding
Liquid level	Landscaping
Gas flow	
Liquid flow	

Source: CleanWorld

Specifications, Utilities, and Operating Parameters

General system specifications followed the design rules set forth in the implementation of Phase I. All system utilities and operation parameters were estimated and considered during Phase I and were confirmed during the design reviews of Phase II. There were no major or unexpected changes in this area. Specific operating parameters for merging Phase I and II hardware and controls were defined, implemented, and tested upon startup and commissioning of Phase II.

Consumables and Spare Parts

A list of typical consumables and spare parts are listed below. This list is regularly revised by CleanWorld as more information is obtained from the original equipment manufacturer suppliers and experience is gained in the operation of the system.

- Consumables (stock on site; deliveries two to four weeks)
    - 4x pH Electrodes
    - 1x charge of sulfur removal media
    - 1x charge of Activated Charcoal media
    - 1x lot of gaskets, O-rings, seals, and sealants
    - 1x lot of lubricants, oils, and greases
- Spare Parts (stock on site; deliveries six to eight weeks)
    - 1x Pressure transmitter (liquid)
    - 1x Pressure transmitter (gas)
    - 1x Resistance Temperature Detector probe
    - 1x Flowmeter (liquid)
    - 1x Human machine interface panel w/ central processing unit
    - 1x each valve actuator (2”, 4” 6” and 8”)

A comprehensive list with part numbers, suppliers, and lead times is part of CleanWorld’s internal operating and maintenance documentation.

Design Package for Custom Components

Design process and review were completed between January and March 2013. Design partners documented all designs with job specific schematics, drawings, specification, and calculations (where required). Critical design partners included F.M. Booth for mechanical design and fabrication, Frisch Engineering and Vasco Electric for electrical design and controls, Peabody Engineering for civil engineering and site work, and Otto Construction for project management and general contracting.

Design Overview, Elevations, Plans and Drawings

CleanWorld's design partners provided schematics and drawings as property of CleanWorld. The schematics and drawings as described in Table 3 below are available for inspection in person upon request pending arrangements with appropriate staff at CleanWorld.

Table 3: Drawings and Schematics

Site Layout	Completed by Peabody Engineering and overseen by Otto Construction and CleanWorld.
Skid Plans and Detailed Drawings	Schematics completed by FM Booth; reviewed and approved by CleanWorld. Shop drawings and final assembly drawings were completed by FM Booth and approved by CleanWorld.
Tank Design and Detailed Drawings	Tank specification completed by CleanWorld and put out to bid by Otto Construction. Bids were reviewed and revised and purchased May 1, 2013. Final drawings were submitted by the selected provider and approved by CleanWorld.
Detailed Piping and Instrumentation Diagrams	Schematics completed by Frisch Engineering reviewed by FM Booth and approved by CleanWorld. Final drawings, Piping and Instrumentation Diagrams and automation schedules (DI, DO, AI, AO) completed and approved by CleanWorld.

Source: CleanWorld

Control System Design and Interface

Frisch Engineering completed the hardware selection for the control system. All the control hardware components were similar or compatible with those selected for the Phase I design. These include, but are not limited to the following:

- Programmed logic controllers
- Variable frequency drives
- Distribution panels
- Instruments and sensors

The same vendors were used where possible to simplify servicing and access to suppliers. Previously installed components were re-used, when possible, for example the same Human machine interface was utilized but it was reprogrammed to work with the new components.

The software and process control programming were also completed by Frisch Engineering. The implementation of the controls for the Phase II system was based on the Phase I architecture and included process control, recipe mode, automatic process mode, and manual mode. Frisch also helped implement remote monitoring, control, and data acquisition for both the BioDigester system as well as the biogas processing equipment. Offsite data processing, analysis, and reporting was handled by CleanWorld and third-party software providers. Data processing and analysis packages were tested and selected by CleanWorld, and a replicable system was developed and implemented for all CleanWorld's BioDigester systems. This system will be expandable to all CleanWorld's systems as they are added in the future.

Schedules and Timelines

The project team met formally on a weekly basis with all team members present. A complete review of all actions, critical path items and schedules were reviewed at each meeting. A formal project schedule was maintained and produced by Otto Construction. Specific task lists and action commitments were tracked by CleanWorld technical and administration personnel. CleanWorld held additional weekly administrative meetings to coordinate project management and execution. Deviations from schedules or critical actions were reported in real time and addressed accordingly.

Procurement actions were a critical part of the project scheduling efforts. Deadlines for procurement actions were based on expected lead times. Critical procurement items included:

- Tanks and options (heat exchangers, ladders, platforms, ports, and flanges)
- Process Skids (pumps, valves, instrumentation, integrated controls)
- Gas processing and gas utilization equipment
- Front-end and back-end process equipment
- Site work and foundations

Actual project schedules were prepared by the Otto Construction Project Manager and are available for inspection in person upon request.

Chapter 5: Material Balance, Energy Balance, and Process Flow

Design Development and Cost Estimating

To design the scale-up of the Sacramento BioDigester system (referred to as SBR1 or Sacramento Biorefinery #1 in previous related documents) from 25 TPD to 100 TPD, the mass and energy balance were calculated and used to develop full design specifications including instrumentation and controls. The design specifications informed the equipment selection which determined the process flow and site layout, as well as the overall cost estimates.

System Mass and Energy Balance Determination

The system boundaries for the analysis were defined to include the feedstock receiving and processing station, the BioDigester, the biogas treatment and refining system, and the BioDigester effluent treatment and upgrading system. For the mass balance calculations, the only mass input considered was the feedstock mass and some water needed to dilute ammonia in the reactors. No chemical inputs are required for a properly operating BioDigester, and any chemical control agents that may be used would be on an as-needed not a continuous basis. Therefore, they were not included in the mass balance. The feedstock mass was assumed to represent the mass of feedstock available to the BioDigester after pre-processing removed contaminants. The mass outputs included in the analyses were the biogas and the BioDigester effluent, including solids and liquids leaving the BioDigester. The biogas constituents were also calculated separately.

Material Mass Balance

Mass Balance Input and Output Analysis

The mass balance as shown in Table 4 was calculated using a process engineering model that relied on empirically measured annual average conversion and recovery rates. The assumptions were determined from extensive laboratory and field data. The model assumptions were continually updated to reflect the most recent results of real-world applications. Any assumptions based on equipment that had not been field tested (i.e., screw press) were developed with the help of manufacturer input, literature review, and industry expert consultation. For a more complete description of the model, see Biomass and Bioenergy, 35 (2011): 1263-1272.

For this BioDigester system, the primary goal is the production of transportation fuel. However, the biogas-to-biomethane conversion system comes in discrete capacity sizes. Initially a 100 standard cubic feet per minute (scfm) system was installed. During the scale-up, an additional 200 scfm unit will be installed. The combined 300 scfm capacity will consume 87 percent of the expected biogas production. The remaining 13 percent will be combusted in a 190-kilowatt (kW) co-generation system to produce heat and power to offset the Biodigester's demand. The mass balance boundary was defined to end at the input to the biogas processing equipment, so the air consumption and exhaust of the engine was not included. However, the air emissions were estimated as described in the following section.

Table 4: Mass Balance Summary

Input Item	**Amount**	**Fraction of Input Mass**
Feedstock	100 wet tons per day	62 percent
Water	15,000 gallons per day*	38 percent
Chemical Additives	None anticipated	0 percent
Output Item	**Amount**	**Fraction of Input Mass**
Biogas	500,200 standard cubic feet per day	12 percent
Bio-methane (RNG)	175,100 standard cubic feet per day	2 percent
Hydrogen Sulfide	500 standard cubic feet per day	<0.01 percent
Condensed Water Vapor	550 gallons per day	1 percent
Biogas Leakage	None anticipated	(<0.5 percent)
Solid Digestate	15 tons per day	10 percent
Liquid Effluent	30,500 gallons per day	77 percent
Liquid Effluent Converted to Fertilizer	10,000 gallons per day	25 percent
Dry Solid Soil Amendments	11 tons per day	7 percent
Odors	Non-detectable except during feedstock loading	0 percent

*** Water may need to be added to control ammonia concentration. It was included in the mass balance for completeness. However, operationally, it would only be added when the measured ammonia concentration in the BioDigester exceeds a threshold to be determined based on BioDigester performance.**

Source: CleanWorld

Air Emissions

An internal combustion engine (2G-Cenergy®) was installed at Sacramento BioDigester to generate electricity to help offset the parasitic load of the equipment on site. The engine (Model 2G 190 BG IC) can produce up to 190kW three-phase power at 480 VAC and 60 Hz with 36.40 percent electrical efficiency. The engine was equipped with a Selective Catalytic Reduction unit for emissions control. Table 5 outlines the emissions factors for the engine with the Selective Catalytic Reduction control device and the hourly, daily, quarterly, and annual criteria pollutant emission amounts based on continuous uninterrupted use of the engine at full capacity.

As of the completion of this report, the engine was installed, commissioned, and tested. However, the Selective Catalytic Reduction unit failed to meet the emissions specifications required by the Air Board. Therefore, the engine was shut down until an alternative emissions control system could be installed. Currently, the engine is planned to be re-commissioned as the expanded facility provides more biogas, after the permit can be modified to incorporate the new emissions control system.

Table 5: 2G-Cenergy 190 kW Internal Combustion Engine with Selective Catalytic Reduction Control Emissions Factors

	NO_x	VOC	CO	SO_2
Uncontrolled Emissions [g/bhp-hr.]	0.99	0.26	1.6	-
Emissions Reductions with Control Devices [%]	90.0%	-	54.7%	-
Controlled Emissions				
[g/bhp-hr.]	0.099	0.26	0.7248	-
[lbs/MWh]	0.289	0.760	2.118	0.0149*
[lbs/hr]	0.019	0.049	0.136	0.001
[lbs/day]	0.44	1.17	3.25	0.02
[lbs/qtr]	40.5	106.5	296.8	2.1
[lbs/yr]	162.2	425.9	1,187.3	8.4
[tons/yr]	0.081	0.213	0.594	0.004

* Calculated from a maximum of 50 ppm scrubber outlet H_2S concentration

Source: CleanWorld

Although not a criteria pollutant, carbon emissions and offsets were also estimated for this project. Carbon emissions attributed to the project were due to heat and electrical demand. Carbon emission offsets credited to the project were due to electrical and heat production, diesel use offset due to biomethane production, and food waste emissions offsets due to landfill diversion. The emissions factors for heat, electricity, and diesel fuel use were taken from the greenhouse gases, regulated emissions, and energy use in transportation Model (Argonne National Laboratories) with the "California Mix" used for the electricity carbon emissions factor. The emissions factor for landfill offset was based on the California Climate Action Registry first-order emissions model for landfills in the Central Valley with landfill gas capture and destruction of 75 percent. As seen in Table 6 below, landfill emissions reductions make up the majority of the GHG offset, but even without this source of carbon emissions reductions the BioDigester reduces net carbon emissions.

Table 6: Greenhouse Gas Emissions and Credits Summary

Greenhouse Gas Emission Source	**CO_2 Equivalent Emissions**	
Heat demand	689 tons per year	53 percent
Electricity demand	602 tons per year	47 percent
Total GHG emissions	**1,291 tons per year**	**100 percent**
Electricity production credit	597 tons per year	3 percent
Heat production credit	803 tons per year	8 percent
Diesel use offset credit	1,636 tons per year	4 percent
Landfill diversion credit	18,566 tons per year	86 percent
Total GHG emissions reduction	**21,602 tons per year**	**100 percent**
Net GHG emissions	**(20,311 tons per year)**	

Source: CleanWorld

The Air Board released a Low Carbon Fuel Standard pathway for High Solids Anaerobic Digesters with a carbon intensity of -15.29 grams of carbon dioxide equivalent per megajoule (GCO2e/ MJ). CleanWorld was approved by the Air Board to register LCFS credits using this pathway while the company develops a custom pathway for a 2b application. The final sources of feedstock and destination for the BioDigester effluent will greatly influence the pathway. Therefore, CleanWorld will continue to utilize the existing pathway as these items are more fully developed. In addition, the federal Renewable Fuel Standard was also released with a pathway for renewable natural gas produced from solid waste. CleanWorld is in the process of applying for the Renewable Identification Numbers based on the Renewable Fuel Standard.

Energy Balance

The same model used for calculating the mass balance was also used to calculate the energy balance of the BioDigester system with the same system boundaries. Energy balance was calculated based on the available energy in the feedstock. The results of the simulation model for Sacramento BioDigester Phase II are outlined in Table 7 below:

Table 7: Energy Balance for the Anaerobic BioDigester System with Fraction of Feedstock Energy Content for Each Energy Input and Output

Energy Content of Feedstock*	350 MMBtu per day	100 percent
Biogas Energy Output	320 MMBtu per day	91 percent
Transportation Fuel (Biomethane) Production	1,440 DGE per day	53 percent
Electricity Generation	4,020 kWh per day	4 percent
Useable Heat Generation	21 MMBtu per day	6 percent
Electricity Demand	4,640 kWh per day	5 percent
Heat Demand	39 MMBtu per day	11 percent
Net Electricity Output	-536 kWh per day	
Net Heat Output	-180 thm per day	
Total Net Energy Output	167 MMBtu per day	48 percent

***Varies based on the composition of the feedstock; estimated here at 14 MMBtu per dry ton.**

Source: CleanWorld

This energy balance was refined by CleanWorld engineers to utilize the biogas produced by Sacramento BioDigester Phase II for the highest and best use by evaluating the amount of biogas diverted to the engine to offset parasitic load and the amount of biogas that would be refined to produce RNG (Table 8).

Three scenarios were considered:

1. The baseline scenario described above: enough biogas to run a 190-kW generator, with the residual biogas (300 scfm) converted to RNG
2. Converting 100 percent of the biogas to RNG
3. Converting enough biogas to offset 100 percent of the parasitic electrical demand with the residual converted to RNG

Table 8: Energy Balance for Alternative Biogas Usage Scenarios

	Scenario 1: 190 kW electricity, balance of RNG	Scenario 2: 100 percent RNG	Scenario 3: 100 percent parasitic electricity, balance of RNG
Total Energy Output	500,200 standard cubic feet per day biogas	500,200 standard cubic feet per day biogas	500,200 standard cubic feet per day biogas
Transportation Fuel Production	1,440 DGE RNG per day	1,655 DGE per day	1,407 DGE RNG per day
Electricity Demand	4,640 kWh per day	4,239 kWh per day	4,640 kWh per day
Heat Use	389 thm per day	389 thm per day	389 thm per day
Net Electricity Output	-536 kWh per day	-4,239 kWh per day	0 kWh per day
Net Heat Output	-180 thm per day	-389 thm per day	-148 thm per day

Source: CleanWorld

Alternative Scenarios

Scenario 1 was the chosen energy and material scenario for Sacramento BioDigester Phase II. This scenario diverted 13 percent of the total biogas to one 190 kW engine that would be run at 88 percent capacity to create 4,020 kWh per day of renewable electricity. The remaining 300 SCFM of biogas would be refined to create RNG using one BioCNG 200 system in addition to the one BioCNG 100 system already at Sacramento BioDigester in Phase I of the project. This scenario utilized the full capacity of both BioCNG units by sending a full 300 SCFM of biogas to be refined to RNG, allowing for the maximum RNG production without purchasing a third unit. The diversion of 13 percent of the biogas to create renewable electricity decreased the electrical load needed from the grid by 88 percent. This reduced electrical costs for Sacramento BioDigester while also making the project more renewable overall.

In Scenario 2, all the biogas was refined to produce RNG. This scenario maximized the amount of RNG created, producing 215 DGEs more of RNG per day than the chosen scenario. Scenario 2 included no renewable electricity, forcing the project to draw over 4,000 kWh per day from the grid. Without a generator onsite, there would also be no waste heat to utilize in the heating of the tanks, so a boiler was sized to handle the entire load of 389 thm per day. Another drawback of Scenario 2 was that it required the purchase of a third BioCNG™ biogas refining system (BioCNG), sold in 50 scfm, 100 scfm and 200 scfm models. Sacramento BioDigester has one BioCNG 100 system from Phase I that was sized to process 100 scfm of biogas per minute. For Phase II, Sacramento BioDigester should produce 347 scfm of biogas per minute, requiring one BioCNG 200 system and one BioCNG 50 in addition to the existing

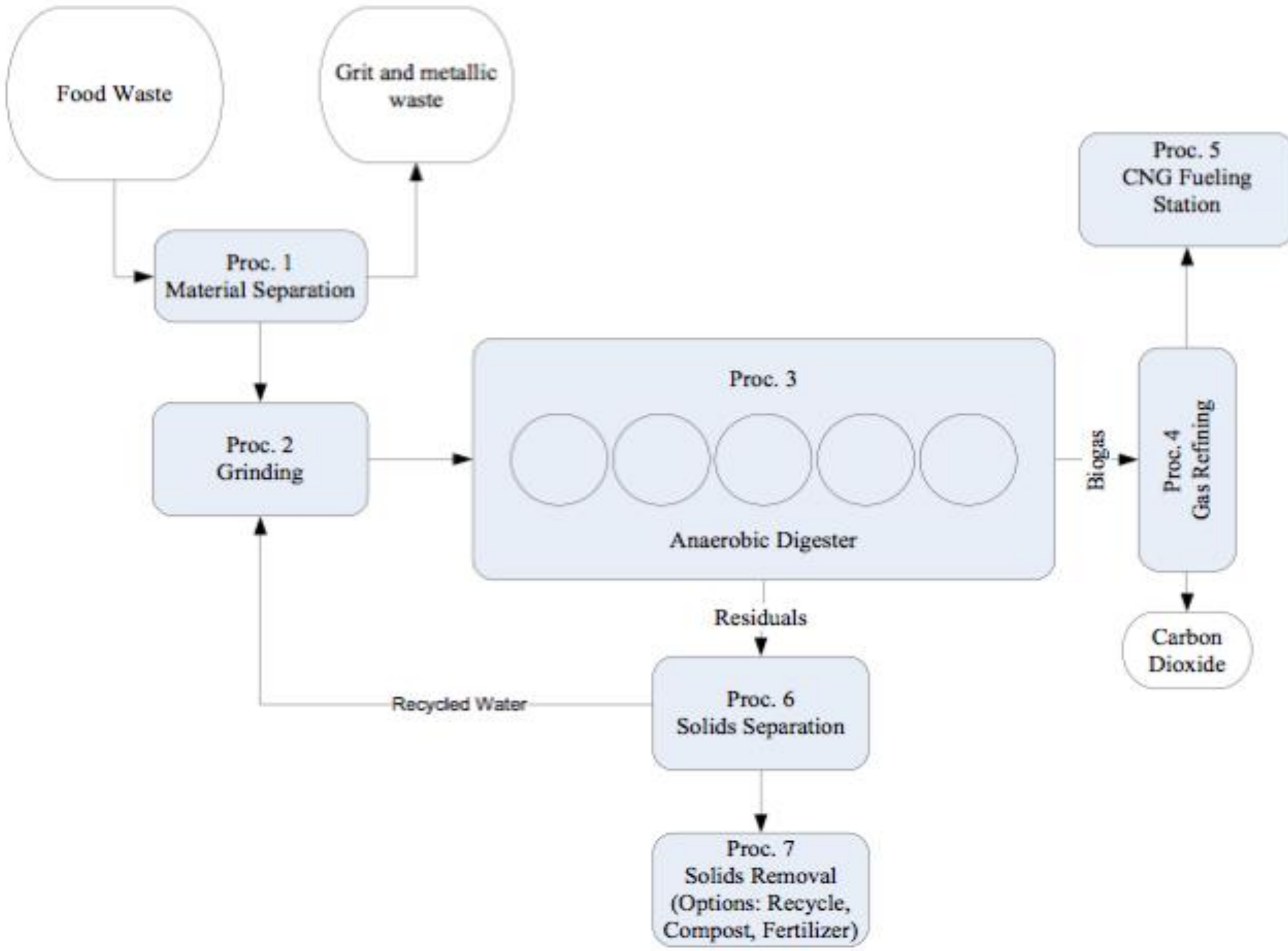
BioCNG 100 to process all the biogas. Since there was an economy of scale on the BioCNG systems, purchasing only one BioCNG 200 system in Phase II would save a significant amount in equipment cost. CleanWorld's desire to demonstrate the generation of renewable electricity as a co-product and to make Sacramento BioDigester less dependent on grid electricity resulted in CleanWorld's decision to not choose Scenario 2.

Scenario 3 was a slight variation of Scenario 1, increasing the biogas diverted to electrical production from 13 percent to 15 percent. The benefit of Scenario 3 was that the increase in biogas diversion would allow for the 190-kW engine to run at full capacity and supply all the electricity to run Sacramento BioDigester, which reduced the RNG production by 33 DGE per day. The drawback of Scenario 3 is that RNG was worth more economically than electricity so replacement of the 33 DGE of RNG for 537 more kWh of electricity per day reduced the daily revenue for Sacramento BioDigester. The revenue generated by the additional 33 DGE of RNG in Scenario 1 was determined to be more valuable to Sacramento BioDigester than the ability to generate all the electricity for the parasitic load.

Top Level Flow, Process Sequence and Equipment Layout

The top-level system process flows, and sequences were confirmed and used to create process flow and Piping and Instrumentation Diagrams. These were used to develop and update the equipment layout at the site. The Phase II Sacramento BioDigester followed the same process flow as in Phase I shown in Figure 3, but included two additional, skid-mounted liquid transfer systems.

Figure 3: The Process Flow Diagram for Sacramento BioDigester Phase I and II



Source: CleanWorld

Materials Pre-Processing

Waste transfer vehicles deliver waste and unload it in a receiving area, where it is transferred to a BioSeparator system (Unit Process #1) for removal of rocks, glass, metals, plastics, and other non-biodegradable materials. This process facilitates handling and material flow and reduces the number of inert materials introduced into the BioDigester vessels. In Unit Process #2, the system utilizes a grinder and chopper pump to shred all incoming organic solids before pumping them into the BioDigester (Unit Process #3), protecting the downstream equipment from clogging and improving the performance of the AD process and the quality of the residuals recovered from the BioDigester effluent (Unit Processes #6 to #7).

Anaerobic Digestion

CleanWorld continued to use its High Rate Digestion technology for Phase II, a proven and commercially successful Anaerobic Digestion approach already in operation in Phase I. CleanWorld's High Rate Digestion system combines favorable features of both batch and continuous biological processes in a single system and makes it possible to achieve highly efficient and stable production of both hydrogen and methane gases from a variety of organic solid and liquid wastes, including grass clippings, food scraps, food-processing byproducts, crop residues, paper products, and animal wastes.

The High Rate Digester comprises a hydrolysis tank, a methanogenic tank and a polishing tank. The BioDigester is a three-phased, sequenced, batch-fed solids BioDigester capable of producing a steady biogas production rate. When compared to traditional AD systems, the High Rate Digester employs fewer moving parts, requires smaller tanks, uses less energy to operate, is highly scalable, relies upon commercially available components, and possesses innovative design features that optimize the bacterial degradation of organic wastes and minimize pretreatment time.

Additionally, the system's low parasitic load increases system efficiency in comparison with traditional, power-hungry, high-liquid AD systems. The High Rate Digester operates at a thermophilic temperature (125-135 degrees F) and destroys pathogens in the waste, making the residual materials safe for use as compost and organic soil amendment products.

The source-separated food and waste is introduced into the hydrolysis tank where slurried feedstock is consumed by bacteria and converted biologically to organic acids and nutrients that become feedstock for the micro-organisms. The organic acids are transferred to the methanogenic tank, where they are converted to methane and carbon dioxide biogas, and the residuals are further liquefied. The polishing tank digests any remaining acids to maximize biogas production. The resulting biogas is a flammable mixture of methane, hydrogen, and carbon dioxide.

Biofuel Production and Distribution

The waste industry has been moving toward the use of CNG vehicles for its operations to reduce costs and build a greener business model. Many waste operators currently operate their own CNG fleets but must travel long distances to obtain CNG fuel. The system provides a replicable, closed loop solution to waste haulers by digesting organic waste that is collected, creating biogas which is used to produce renewable CNG along with some heat and electricity.

Biogas produced during the AD process passes through a BioCNG system designed by Cornerstone Environmental Group, LLC, to handle biogas at a flow rate of 300 standard cubic feet per minute. This system consists of moisture and hydrogen-sulfide removal sub-systems, a compression and dehydration sub-system, a siloxane adsorption column, and a membrane mediated carbon dioxide removal sub-system (Unit Processes #4 and #5). The effective removal of contaminants from the biogas is essential to meet natural gas vehicle specifications. Upon completion of this process, hydrogen sulfide levels are less than 6 ppm and methane recovery will range from 65 to 75 percent. Although this is lower than other biogas cleaning technologies, Cornerstone optimized its technology for low cost rather than high methane recovery. However, CleanWorld is investigating cost effective uses for the rejected methane. The resulting biomethane stream is comprised of at least 90 percent methane (although typically the membrane produces gas with more than 98 percent methane), less than 5 percent carbon dioxide, oxygen, and nitrogen, and meets the gas quality requirements of SAE J1616 Recommended Practices for Compressed Natural Gas Vehicle Fuel. To comply with National Fire Protection Association standards for properties of natural gas as a transportation fuel, CleanWorld odorizes the biomethane.

The methane that is not recovered as fuel may be converted to heat, electricity, or it can be flared. Because the rejected CO2 is mixed with the methane, the gas has a relatively low energy content on a volumetric basis (i.e., 250 – 350 BTU/scf), making conversion a challenge for standard biogas processing equipment. Research is underway to identify manufacturers capable of converting low energy gas to heat and/or electricity in a cost-effective manner. Because the "tail" gas will have passed through siloxane and H2S removal systems, the only contaminant that may need to be removed is water vapor. The BioCNG manufacturer is also investigating process changes that would prevent re-absorption of water vapor, allowing for less costly conversion equipment to be used to generate electricity and heat from the tail gas.

Process and Equipment Alternatives, Cost Estimates and Economics

CleanWorld engineers examined areas for improvement in the design and selection of the equipment required for critical facility components. The key areas of focus were tank design and material of construction, mixing methodology and mixer selection and design, fluid transfer skid design, and heat recovery. The biogas processing and utilization proceeded as designed. Co-product manufacturing from back-end solid and liquid effluents continues to be an area of active research and development. Site and system layout were finalized and fully specified.

Digester Tanks

The two tanks for the Sacramento BioDigester scale-up (one 300,000 and one 600,000 gallons), larger fluid-transfer skid, an expanded gas processing system, and increased effluent processing capacity were all examined. Although the components themselves did not change, a few design changes were made as described on page 12.

The material of construction and provider of tanks was also re-evaluated. The original tank design called for carbon steel tanks coated with epoxy lining. Due to concerns regarding the performance and longevity of the epoxy and the carbon steel, as well as the installation time for the tanks, bolted tanks made from glass-lined panels were selected as a more quickly erected, robust, longer lasting, and cost-effective alternative to field-welded steel tanks.

Fluid Transfer Skids

The fluid transfer skid for Phase II was also a new development for CleanWorld since it was the first skid to be designed for tanks larger than 150,000 gallons. However, with a shift from hydraulic to mechanical mixing, the essential skid design remained very similar to previously designed systems. Pump and pipe sizes and layout remained nearly identical to the current design. Differences were in instrumentation, interconnection to existing skids, and the necessary devices and logic to control the new mechanical mixers, as well as the integration of a third skid with two existing skids, which is different than the typical design.

Sludge Heat Exchanger

Sludge heat exchangers could theoretically replace internal heating coils, eliminating many feet of on-site piping and field installation. The heat exchanger could be integrated into the fluid transfer skid such that any time reactor liquids were mixed or transferred, they would be heated via the heat exchanger. However, the viscosity of the liquid and the need to prevent exposure to temperatures high enough to kill bacteria would necessitate large heat exchangers. In addition, the tanks could only be heated in sequence as they are mixed. This would require hydraulic recirculation which was eliminated as a mode of mixing with the new design.

After investigating and pricing sludge heat exchangers, it was decided to postpone any implementation of this technology. The costs were too high, and the size of the equipment became too large to fit compactly into a fluid transfer skid. For the same reason, hydraulic mixing was eliminated from the larger tanks. Therefore, ultimately, sludge heat exchangers were not seen as a viable alternative to the current heating scheme. This technology will continue to be investigated as an alternative for future designs.

Biogas Processing and Utilization

The combined heat and power generator installed during Phase I will continue to be utilized for parasitic power demand during Phase II, pending solving the air permit issues described previously. The same biogas to natural gas conversion system used during Phase I was selected for Phase II. The additional biogas produced with the expansion will require additional biogas conditioning, handling, and fueling station requirements. A second BioCNG unit, an enclosed flare, and a second hydrogen sulfide removal vessel were specified to handle the higher flow, as well as larger biogas collection pipes for reducing the working pressure on the tanks whose larger size requires lower working pressure to avoid excessive forces on the tank structure. Additional instruments and control valves were also required to manage distribution of the biogas to the numerous different treatment units that were installed after the expansion.

Back-end Co-product Manufacturing

The manufacturing process of co-products is currently under development and scale-up. A system was installed and is currently used to separate solids from the liquid effluent stream. The design of this equipment is being revised and new technologies are being tested for solid/liquid separation as of the publication of this report. In addition, a new system is currently being developed that will allow a high-value liquid fertilizer product to be created from the liquid fraction of the digester effluent in the future. This is an active part of CleanWorld’s research and development efforts, and significant progress has been made. Additional development is needed, however, to fully implement an effective effluent treatment system.

Final Selection, Approval and Specification of Processes and Equipment

Design review and specification for all system components, including final vendor selection and evaluation of suppliers of process tanks, mixers, and associated hardware, were completed at the end of the first quarter of 2013. All components for Phase II were ordered shortly thereafter.

Control development and integration reviews were completed with our control partners. Consistent with CleanWorld's "modular design", the new components, skids and controls were built and tested off-site with independent controls and instrumentation mounted in a new control enclosure complete with slave programmable logic controller control and data acquisition hardware. Upon integration on-site via simple communication cable and single point power supply, the new hardware was seamlessly integrated into the existing control system master programmable logic controller, and the existing Human machine interface was reprogrammed to run all the new equipment and routines. Remote monitoring and data logging were incorporated into the new system from the start using the strategies developed during Phase I.

In addition to mechanical and Piping and Instrumentation Diagrams drawings of the skids, full 3- dimensional drawings of the tanks and interconnections with skids were created upon final selection of the tank provider in order to fully and accurately integrate the tanks with the skids. Site layouts were updated with the latest equipment specifications and locations of pads and electrical stub-ups. The vehicle fueling station was built independently by our partners at Atlas Disposal. They provided the site layout drawings and piping specifications needed to integrate our biogas upgrading system with their CNG fueling system. Their drawings indicated the interconnection sites and piping specifications. The drawings are available for discrete review at our office and are not included in this report due to the proprietary nature of the data and design.

Chapter 6: Equipment Procurement Schedule

Buyers and Sources for Project Equipment

The BioDigester system can be subdivided into the following subsystems:

- Feedstock receiving and processing
- Tanks and supporting equipment
- Pumping and heating skids
- Biogas processing
- Effluent management

Each subsystem incorporates equipment and components supplied directly or integrated into a larger package. CleanWorld designed pumping and heating skids that comprise the core of the AD system. These skids manage material handling and transfers into, out of, and between tanks. Material transfers include feedstock, effluent, as well as heating water. The heating water is not transferred directly into the tank, but rather through internal heat exchangers. However, the control skid for the hot water is part of the core pumping skids.

Design and fabrication of the skids was managed by mechanical engineering subcontractor Frank M Booth Inc. The procurement package of components for the skids was developed by Booth and approved by CleanWorld. Booth managed relationships with suppliers and provided backup parts for skid components as needed on a schedule determined in collaboration with CleanWorld.

All the components that interface with the skids – tanks, feedstock processing equipment, and effluent management equipment – were considered ancillary equipment provided by third-party suppliers. Similarly, the ancillary equipment for processing biogas to remove hydrogen sulfide, trace impurities, and moisture, flare the gas in case of emergency, and convert biogas to RNG and/or electricity were all provided by third party suppliers.

CleanWorld worked with subcontractor Otto Construction on providing equipment specifications for bidding major ancillary equipment packages. In some cases, CleanWorld procured equipment bids directly from suppliers, particularly when doing so involved developing long-term business relationships. A catalog of suppliers and copies of all bid packages is maintained by CleanWorld.

Equipment Procurement Schedule

Project management services were provided by subcontractor Otto Construction. The project schedule was maintained and updated regularly and discussed at weekly project review meetings. Table 9 highlights some of the major pieces of equipment and their lead times. The complete schedule can be viewed with special permission by CleanWorld.

Table 9: Equipment Procurement, Fabrication, and Installation Lead Times

Activity	Lead Time
Procure bio separator	8 – 12 wks.
Procure feed conveyor	4 – 6 wks.
Procure pumps and equipment	6 – 8 wks.
Procure valves	6 – 8 wks.
Procure flare	8 - 12 wks.
Fabricate tanks (off site)	6 – 8 wks.
Install and test tanks	8 - 10wks
Procure mixers	8 – 10 wks.
Procure gas processing equipment	16 - 18 wks.
Procure hydrogen sulfide scrubbing system	8 – 10 wks.
Procure effluent processing equipment	8 – 12 wks.

Source: CleanWorld

Shop Site Testing Plan

The pumping skids were tested for 10 weeks in the shop prior to acceptance by CleanWorld. Test results were reported to CleanWorld at the end of the 10 weeks, and adjustments were made in the shop prior to final delivery. Shop testing included:

- Pump direction check
- Controls operation check
- Pump speed and variable frequency drive check
- Valve installation and function check
- Verification of piping integrity
- Final quality control review

Skids were not released until the final checklist had been completed and signed off by the shop supervisor. The certification of testing was provided to CleanWorld upon delivery of the skids.

Chapter 7: System Installation, Assembly, and Testing

Site Preparation

Site preparation included the civil site work required to prepare the site for construction and to install all necessary services (electrical, water, plumbing and sewer) to make the system functional once construction was complete. The site work included preparing the area underneath the new tanks, as well as the areas adjacent to the tanks where the new material transfer skids and gas processing equipment were located (Figure 4). Since the expansion plans were in place when the original Phase I system was built, some of the preparation work was completed with the Phase I construction. For example, electrical service was sized for the expansion, so minimal additional electrical service was added. The electrical generator was installed as part of the Phase I system, but it was sized for the gas flows expected after scale-up. The sewer piping and front-end were also sized in anticipation of the higher flows expected after completion of Phase II.

Civil Site Work

The civil work for the anaerobic digester system was subdivided into the following tasks that were executed during the construction period:

- Site grading (cut and fill)
- Excavation (footings, foundations, and underground utilities)
- Concrete pouring (footings, pads, and structural supports)
- Utility interconnections

Site grading was performed to prepare the area underneath the tanks. Trenches were dug around the tank area to support the foundation and starter ring. Concrete was poured over the supports and across the bottom of the tank prior to assembly. A starter ring (the first ring of the tank) was anchored in place and additional concrete was poured to lock in the assembly. This was an integral part of the tanks and provided both the tank side to tank bottom seal as well as the first steel ring to which the tank was eventually anchored. Additional trenching was laid to contain the conduits for the electrical connections and underground plumbing. The site was also trenched and graded for proper drainage.

Figure 4: Site Work Performed to Prepare for Tank Installation

Initial site marking and layout for tank installation (12.15.14)

Tank foundation trenching (1.9.14)

Pouring concrete tank footings (1.21.14)

Installing tank starter ring (1.30.14)

Curing the larger tank floor (2.10.14)

Installing tank wall support scaffold (2.10.14)

Source: CleanWorld

Utilities
The grant that assisted in the funding of SATS II was granted during the late stage of the SATS I planning and initial construction. CleanWorld was able to increase the size of the original electric service, switchgear, and provide conduits and "stub-ups" in anticipation of the SATS II construction. This greatly facilitated the SATS II construction and eliminated 90 percent of the demolition normally associated with such an upgrade. Utilities and process piping were extended to supply the new process skids and tanks. While the modification of an existing system always presents special challenges and complication, the forethought in this case simplified the interconnections with the existing system.

Fabrication and Assembly
Feedstock Collection, Transport and Preprocessing System
CleanWorld completed the pre-processing system seen in Figure 5 consisting of a Doda Bio Separator, conveyor, and tipping floor during Phase I of the SATS project. This system removes contamination from incoming feedstocks and grinds the organics into a slurry that is pumped into the BioDigester system.

Figure 5: Pre-Processing System as Built for Phase I and II

***(November 3, 2014) close-up of the hopper on the right**

Source: CleanWorld

A new pipe was installed as part of the Phase II material transfer system to return process liquid to the Bio Separator sump from the new hydrolysis tank. A pump was also added to the return line and the pipe was sized larger than the previous return line. All other components of the feedstock processing system were utilized as built for Phase I. Plans were made to allow for expansion of the processing system, outside of the scope of this grant. However, the existing system has been capable of handling the flows required for loading during Phase II. Therefore, those plans were placed on hold until deemed fully necessary.

Anaerobic Digestion System

The anaerobic digestion system installation components consisted of the two new tanks and two new pumping skids seen in Figure 6: a process skid and a hot water supply skid for heating the new tanks. The tank plates were fabricated, coated, and tested in a factory prior to delivery to the site. The tanks were assembled and erected by trained workers on site (see photos below). After the tanks were assembled, ports were cut and installed in the field, mixer mounts were installed, and the heating coils were hung inside the tanks on hangers installed during tank assembly. Fittings and valves were attached to the ports, and the mixers were installed to completely seal the tanks for leak testing. Leaks that were discovered were re-sealed before the tank installer signed off on the completed tanks. Insulation was applied after all the field connections were made to the tanks.

Simultaneously, the material transfer and hot water supply skids that had been previously fabricated and tested in the factory were delivered and installed on site. The skids were placed in the locations as specified by the engineers to simplify the field piping. The skids were then anchored in place before the field piping was installed. Field piping to connect the skids to the tanks (either to the hot water distribution system or the inlet and outlet ports) was lain after the tanks were completed and the skids were anchored. After the tanks were sealed and tested and all the field piping connections were made, the electrical connections to the pumps, valves, and instruments were installed by the electrical contractor.

While the skids were being installed and connected to the tanks and the previously existing skids, the controls contractor began reprogramming the control panel. The existing program was modified to incorporate the new tanks, pumps, and instruments. In addition, the "recipes" used for automating transfers between the tanks were also redesigned to accommodate the new system configuration with the existing Phase I tanks serving as polishing tanks. The new controls allowed for parallel or series loading of the existing tanks, and the ability to bypass any of the tanks was incorporated into the new control scheme. The controls contractor calibrated and initiated all the instruments and tested the pumps and valves while installing the new program on the existing control panel.

The AD system installation was considered complete and ready for operation when the controls were finalized and tested on all the installed components.

Figure 6: Tank Assembly and Installation

As of 2.10.14

As of 4.8.14

As of 9.15.14

As of 3.2.15

As of 6.2.15

As of 4.17.15

Source: CleanWorld

Skid Installation and Field Piping

The skids were fabricated in the shop per CleanWorld’s design and specifications and were delivered to the site for installation and interconnection. The skids were electrically connected and plumbed in the field to the tanks as seen in Figure 7.

Figure 7: Installation of Phase II skids and Field Piping Connections

Skid piping (9.15.14)

Skid piping (11.18.14)

Final skid piping (4.17.15)

Hot water piping (9.30.15)

Hot water piping (3.2.15)

Final hot water piping (4.17.15)

Completed material transfer skid (4.17.15)

Completed boiler/hot water skid (4.17.15)

Complete skid integration (4.17.15)

Source: CleanWorld

Field piping was designed to minimize the potential for clogs, and sufficient clean-out points were added to allow for ease of maintenance. CleanWorld field technicians with extensive experience operating CleanWorld's other AD facilities provided guidance on the proper design and layout of field piping. Trained contractors built and installed the piping, and the fully installed tanks can be seen in Figure 8.

Figure 8: Fully Installed Tanks and Skids with Insulation and Completed Field Piping Connections

Source: CleanWorld

Gas Processing and Refining System

CleanWorld updated the biogas collection and processing system during Phase II of the grant as seen in Figure 9 and 10. Because the flow rates of biogas produced and processed were anticipated to be four times higher than previously seen and the working gas pressure for the Phase II tanks was significantly lower than the Phase I tanks, larger pipes had to be installed to handle the higher flows without creating excessive pressure on the tanks. The larger pipes necessitated new instruments, and second hydrogen sulfide removal vessel, and a new flare to meet air quality requirements, as well as a second biogas refining skid (BioCNG 200) with twice the capacity of the skid installed during Phase I. The two skids together were sized to handle the expected full flow of biogas when the system reaches capacity, with any excess biogas being utilized for co-generation of heat and power.

With a new flare and a second biogas refining skid, the need for an integrated control system became critical. CleanWorld contracted their partner gas processing and engineering company to develop the control system. The new system integrated several flow meters and automated valves which allowed CleanWorld to direct biogas to the appropriate piece of equipment while optimizing the use of the biogas for energy production. To accommodate the enhanced control system, an expanded electrical network was installed to power the numerous instruments and valves, as well as several new control panels. In addition, the CleanWorld's controls team was contracted to log the values from the various instruments, which were stored on CleanWorld's HMI for remote monitoring and data logging.

Finally, the existing generator (a 190kW internal combustion Engine (2G Cenergy, Germany) installed and in interconnected during Phase I but sized to accommodate Phase II power loads) was integrated into the new gas collection and processing system. However, the cost of re-commissioning the generator was not included under the current scope. The engine package included a Selective Catalytic Reduction system to meet air board requirements, but it has not yet performed to the level required by the air board for permitting of the engine. Therefore, the generator will be plumbed and controllable, but operating the generator will require additional work on the emissions control system and another source test. These activities have been planned but are outside the scope of work for this grant.

Figure 9: Enhanced and Expanded Biogas Collection and Conversion System

Original biogas processing system (2013)	Second biogas processing system (9.15.14)	Final biogas processing system (4.17.15)

New biogas chiller (4.17.15)	New H2S scrubbing system – left – and flare – right (4.17.15)	Biogas-to-electricity generator (11.3.14)

Source: CleanWorld

Figure 10: Overview of Fully Installed Biogas Collection, Cleaning, and Conversion System

***Compressors and low-pressure storage for filling station in the background**

Source: CleanWorld

Back End Co-product Processing System

CleanWorld has been developing a new effluent processing system that will accommodate the SATS Phase II effluent volumes and produce higher-value fertilizer products and cleaner water for sewer system disposal. As part of another CEC grant, CleanWorld designed and built a system for processing liquid effluent in a solid-liquid separation system (see Figure 11). This system proved itself to be effective at separating the solid and liquid streams of the BioDigester effluent as well as creating products that have a greater market demand and can generate revenue for the project.

Figure 11: Solid-Liquid Separation System

Source: CleanWorld

Testing and Validation

Testing proceeded in several steps as construction was ongoing. Leak testing of the tanks occurred after tank construction was complete, but before all the interconnections with the skids were made. The skids were factory tested for proper operation of valves and rotation of pump motors. However, final testing of the skids was not completed until after the interconnections were finalized and the controls were installed. Once the controls were installed, the individual skid components and instruments were tested, the boiler and mixers were commissioned, and the piping and valves were leak tested. Finally, the semi and fully automatic transfer routines were tested, and the control system was debugged.

Separately, the flare was commissioned, and the biogas collection and processing system was tested. Pipes were leak tested. Valve and instrument operations were verified. The BioCNG and the fully integrated gas collection controls will be tested when biogas flows have reached a critical threshold. At the time of publication, the biogas flows had just began to reach this threshold and the commissioning of the BioCNG skid was planned for the end of September 2015. Table 10 below indicates the dates that testing occurred for major components of the BioDigester system.

Table 10: System Test Log

Testing and Verification of Functionality Task List	**Completion Date**
Verify all point-to-point connections	24 MAR 2015
Test installed tanks for wet and dry leaks	20 AUG 2014
Pressure test biogas collection piping	08 APR 2015
Commission and inspect the flare	06 APR 2015
Test and validate functionality of the following:	
Hydraulic mixing and material circulation system assemblies	27 MAR 2015
Mechanical mixing assemblies	23 MAR 2015
Hot water distribution system and valve assemblies	18 MAR 2015
Boiler commissioning and source testing	26 MAR 2015
Circulation piping systems and valve assemblies	15 MAR 2015
Biogas routing valves and safety devices	10 APR 2015
High-high safety device and interlock	15 APR 2015
Computer controls system and control components	24 APR 2015
Remote access and data monitoring	30 APR 2015
Data acquisition and historical logging	30 APR 2015
Manual and semiautomatic subroutines	30 APR 2015
Fully automatic operation of material transfer and mixing	30 APR 2015

Source: CleanWorld

Local Agency Signoffs

Table 11 lists all the local agencies who signed off on the readiness of the facility to resume commercial operations.

Table 11: List of Agency Signoffs

Agency	Item	Signoff Date
City of Sacramento	Final Building Inspection	April 15, 2015
City of Sacramento	Fire Inspection	April 7, 2015
Sacramento Metropolitan Air Quality Management District	Boiler Air Permit	March 26, 2015
Sacramento Metropolitan Air Quality Management District	Flare Air Permit	April 24, 2015

Source: CleanWorld

Chapter 8: System Testing, Start-up, and Operational Status

After installing the individual components, the system would not be ready for full operation until after finishing the completion of the final dry and wet test of the system, training orientation of operations personnel, initiation of system feeding and start-up, initiate automatic controls, and attainment of operational status. This also included the introduction of biological seed in the form of anaerobic sludge to initiate the AD process and ramp up of loading to achieve steady-state conditions at the designed loading rate (four to six weeks).

The commissioning of SATS Phase II was completed on June 15, 2015. This was later than planned because a significant installation issue with the 600,000-gallon tank was discovered in April, which required inspection, repair, and re-testing before the tank was safe for use. CleanWorld worked as quickly as possible with the tank installer to identify and rectify the issue. However, the repair involved fully draining, servicing, and re-filling the largest tank. This also delayed the startup of the facility, since the drained liquid was the starting seed which had to be replenished and re-acclimated before loading could begin.

Loading of feedstock for the SATS Phase II system resumed in June after the repairs were finalized and the tanks had been re-tested at temperature. At that point, the BioDigester system resumed the startup process with full data collection and analysis.

Component Testing and Initiation

CleanWorld performed the extensive testing prior to start-up of the Phase II System.

Tank Testing

Tank testing was performed under the guidance and observation of the tank fabricator. Both dry and wet tests were run. Dry testing for detecting gas leaks involved slightly pressurizing the tanks to a sub critical pressure (i.e., less than eight inches of water) and simultaneously checking for audible hisses indicating loose fittings or faulty components. Liquid leaks were tested following dry testing by filling the tanks with clean water and inspecting for drips or leaks around fittings, instruments, and process equipment (this is wet testing). After resolving all leaky fittings and ensuring no water leaks, the system was wet tested for gas leaks around the head space. CleanWorld pressurized the tanks during wet testing by sealing all gas valves/connections and then slowly filling the tank. Gas pressure sensors atop the tanks were monitored for pressure drops indicating gas leaks. If leaks were detected, soapy water was applied around the tank to locate the source of the leaking. Once the suspected leak was fixed, the pressure test was repeated until all leaks were found and the gas pressure did not drop by more than 5 percent in a one-hour period.

After the tanks were tested, the installer signed off that the tanks were fit for use under the expected conditions. However, after beginning to seed the BioDigester, audible leaks around the topmost ring of the tank were noted by field staff. Leak testing was repeated, and significant gas leaking was confirmed. The tank fabricator was contacted, and CleanWorld field staff worked on applying patches as recommended by the fabricator. When these failed, a plan was created for draining the tanks, applying patches on the interior surface, re-sealing the tank, and re-testing. In total, this required about four weeks, and at the end of the operation, the tanks were holding pressure and free of all gas leaking.

Skid Testing

During skid testing, pump and valve positions were checked to ensure that the proper valves and pumps were installed in the proper locations. The valves were checked to make sure their indicators matched the reported status (i.e. open/closed) on the operator interface. Pumps were then run and observed to confirm that they rotated in the proper direction. All valves were cycled open and closed, noting the proper functioning of valve indicators and limit switches. Adjustments to valve actuator travel stops were made as needed. Finally, all valves and pumps were signed off as fully functional.

After testing the pumps and valves, the skid instruments and controls were tested. The skid houses the programmable logic controller, instrument transmitters, electrical connections, conversions, and distribution, as well as backup power and programming. All system instrumentation and controls were validated and checked for accuracy. The pH probes were calibrated and inserted into the tanks once the liquid levels were high enough to submerge the probes. Instruments that were found to be either faulty or improperly installed and/or connected underwent extensive troubleshooting with the assistance of the control's contractor and in some cases the field technician from the instrument provider's company. Several components were sent to the manufacturer for service. Those that could be fixed in the field were, and those that needed replacement were replaced. A couple of meters were still being serviced by the manufacturer as of the writing of this report, but the essential instruments were all installed.

Next, heating systems and components were tested. The boiler was started and stopped per original equipment manufacturer instructions noting the set points and the temperatures leaving and returning to boiler. The set points were adjusted to ensure that the boiler responded appropriately. The various pressure relief valves and makeup water supply systems were checked for functionality. Finally, the heating system was started along with the hot water pumps and the boiler temperature was set to a safe level for the BioDigester, and the hot water system was allowed to run continuously for several days to ensure proper operation over an extended period. Once the BioDigester had reached its operating temperature and the temperature was held without issue, the heating system was signed off as ready for operation.

The final step in testing the BioDigester skids was to verify proper operation of the automatic controls system, including the following parts:

- manual valve, pump, and mixer controls
- alarm and warning set points

- semiautomatic tank-to-tank transfers
- automatic and scheduled mix routines
- automatic and scheduled heating routings
- automatic and scheduled multiple tank transfer recipes

Each control was tested and verified to operate the proper components. Scheduled transfers were set with convenient start and stop set points and observed for proper operation. Alarm set points were determined, set, and tested. All coding errors and bugs were noted and reported to the control's contractor for adjustment. Once each control was verified and all automatic transfers were confirmed, the system was run in fully automatic mode with on-site oversight for several days before after-hours operations were allowed.

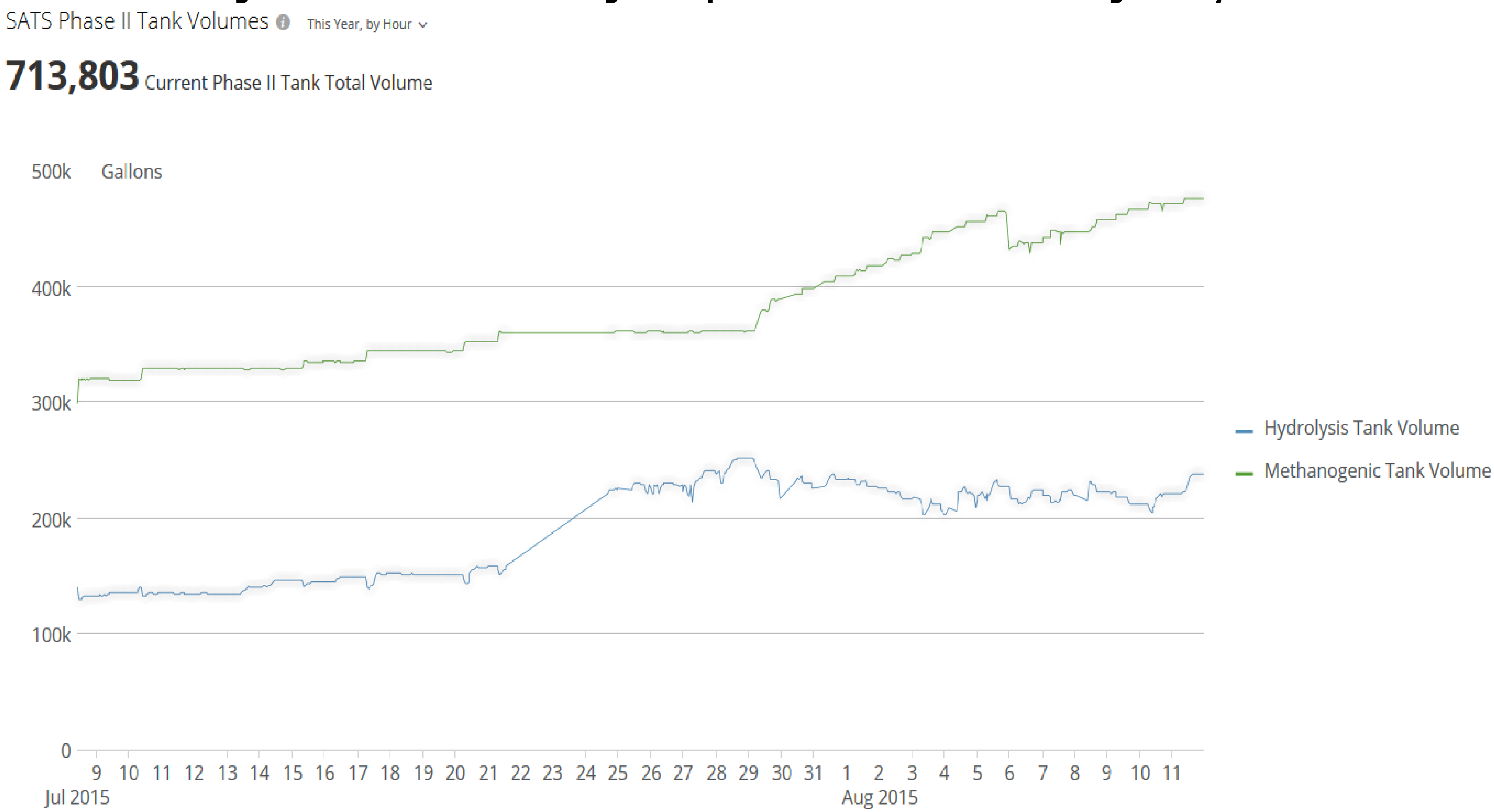
Data from the instruments on the new tanks and the new gas processing system began to be logged when the controls system was finalized. This occurred on June 29, 2015. Several instruments had not been commissioned at that time. Therefore, some of the data points read zero until the instrument was commissioned.

Initial Feeding and Digester Start-Up

Before the initial feeding of the BioDigester, each of the two new BioDigester tanks was loaded to half of its operating volume (nominally 250,000 gallons for the hydrolysis tank and 500,000 gallons for the methanogenic tank) with biologically active inoculant from an operating CleanWorld AD system. Tank volume sizes can be found in Figure 12. Feedstock began to be loaded into the hydrolysis tank and the tank volumes were then allowed to increase to their nominal operating capacity.

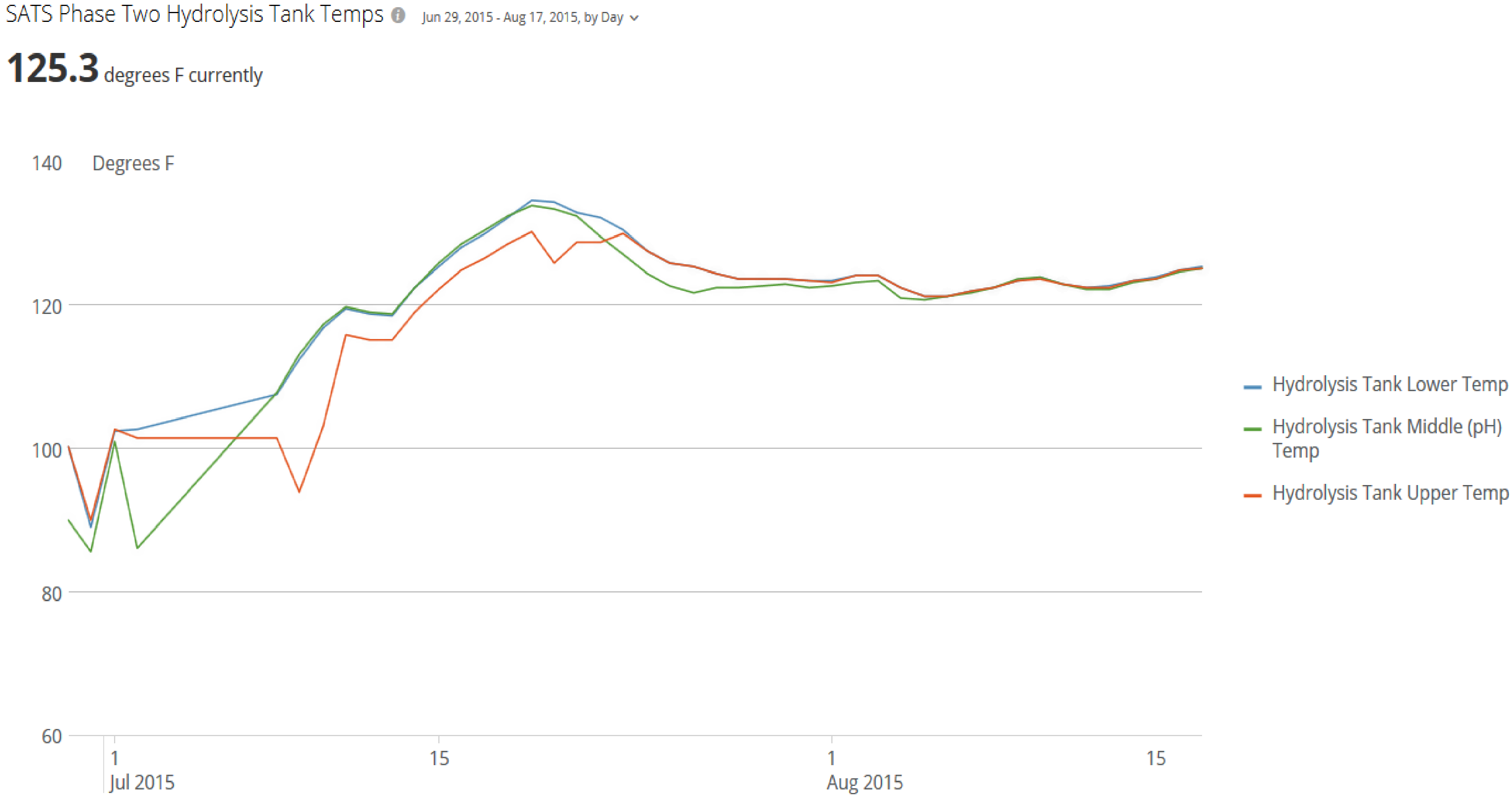
The tanks were then heated to 125 degrees Fahrenheit, which required about two weeks, and the inoculant was allowed to acclimate for several weeks. Temperatures were monitored to ensure that the tanks were consistently in the proper temperature range and this data can be found in Figure 13 and 14.

Figure 12: Tank Volumes During Startup of the New Phase of the BioDigester System.



Source: CleanWorld

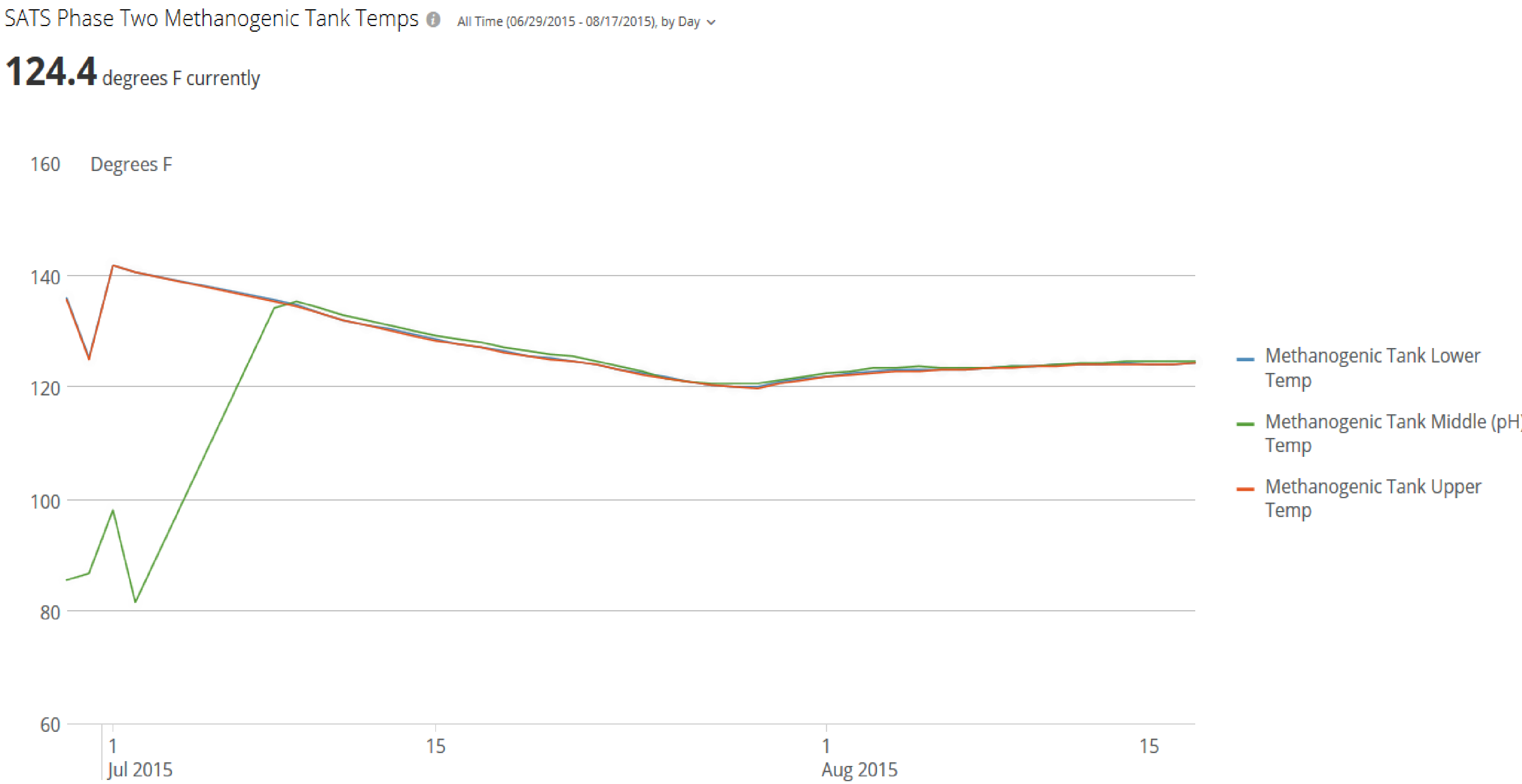
Figure 13: Hydrolysis Tank Temperature During Startup Phase of the New BioDigester System.



***Measured via three probes spaced vertically**

Source: CleanWorld

Figure 14: Methanogenic Tank Temperature During Startup Phase of the New BioDigester System.

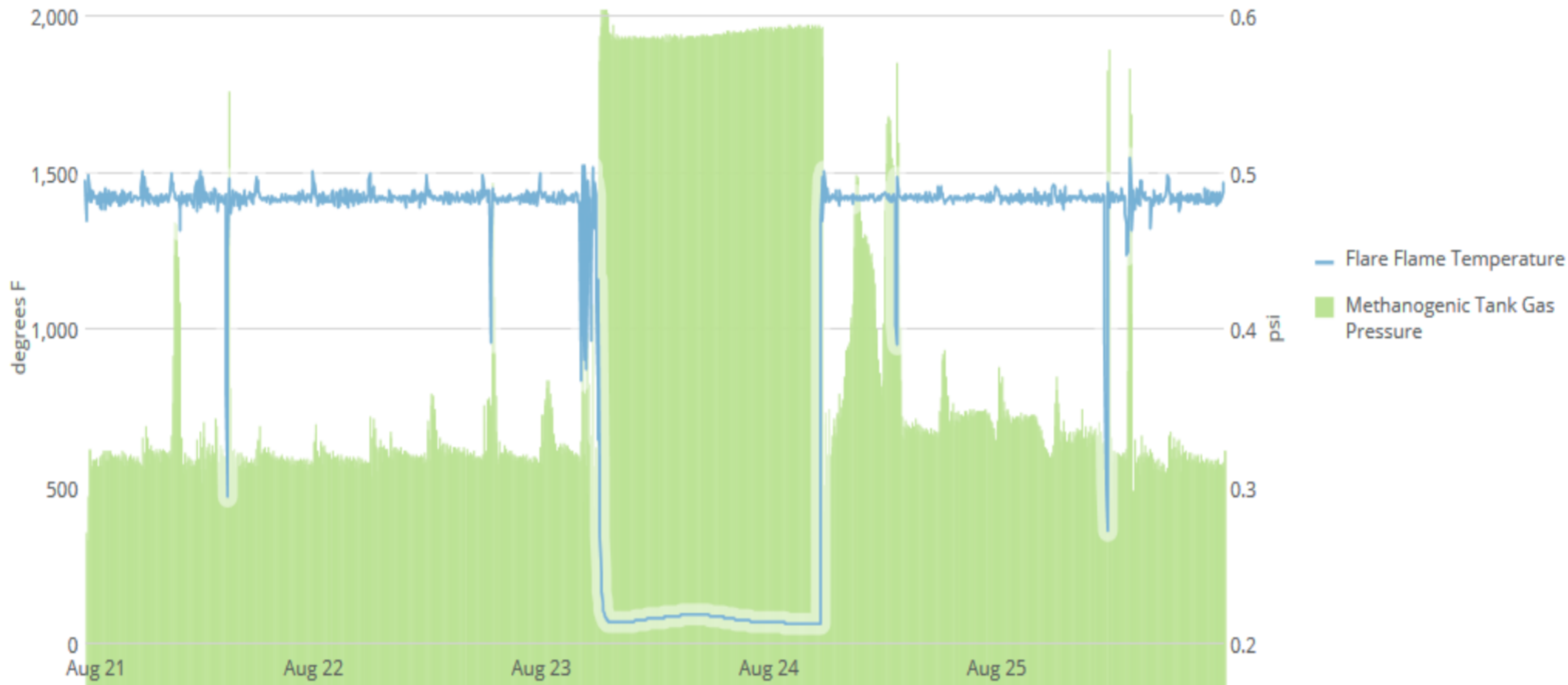


***Measured via three probes spaced vertically**

Source: CleanWorld

As the BioDigester acclimated, biogas began to be produced and the flare was commissioned. The data on tank pressure and flare temp was collected and is displayed in Figure 15. The flare control system had to be adjusted to accommodate the pressure drops and flow rates produced by the BioDigester. Once the proper set points were entered, all communications were confirmed between the gas processing skid and the flare control panel, and the controls programming was fully debugged, the flare was confirmed to start before the gas pressure in the tanks had reached the point at which the pressure relief valves would open to vent the biogas. The alarms in the BioDigester control panel were then configured to activate whenever the gas pressure exceeded the flare activation pressure for more than five minutes. If such an alarm is triggered, it sends an email to key personnel to notify them of a flare failure.

Figure 15: SAT Phase II Flare Temp and Biogas Pressure



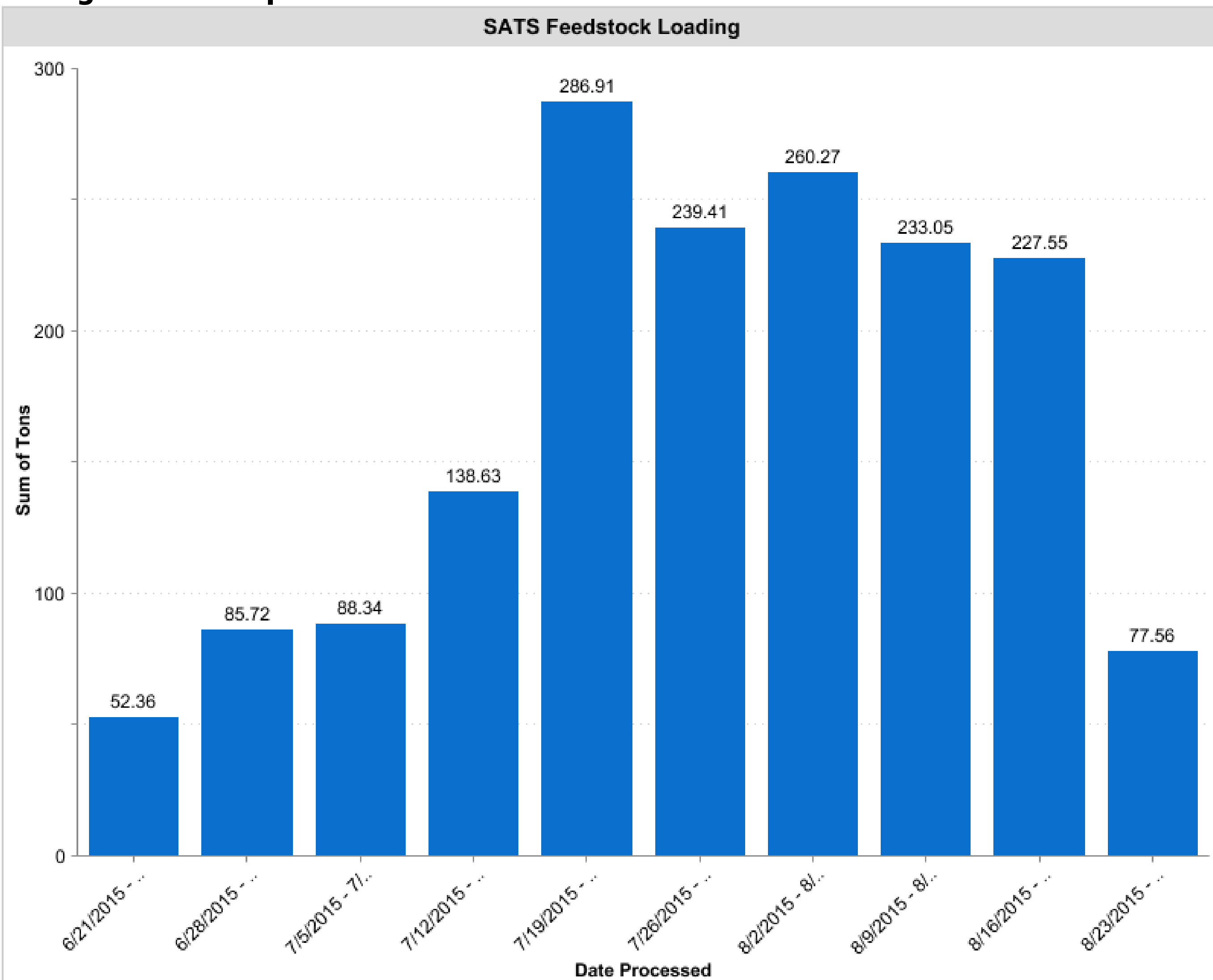
***Flare temperature (blue) and gas pressure (green). Flare set to activate at 0.48 psi. PRV set to open at 0.6 psi. Note flame temperature maintained over 1,400 degrees F on Aug. 19 when the flare remained lit for an extended period.**

Source: CleanWorld

Transfers from the hydrolysis tank to the methanogenic tank were initiated and automated to increase biogas flow and begin feeding the methanogenic bacteria. When both tanks reached capacity, transfers from the methanogenic tank to the sewer began in order to make room for the hydrolysis to methanogenesis transfers.

Throughout the startup process, the BioDigester was loaded with new incoming waste. Initially, the loading rate was low (less than 100 tons per week) in order to monitor the response of the bacteria to the new feedstock; this data was collected and displayed in Figure 16. Biogas flow rate, methane content, and BioDigester pH were used to judge the response of the bacteria to the loading ramp up. By the middle of July, the BioDigester temperatures were stable, and loading was increased to over 200 tons per week. This was equivalent to 1.5 – 2.0 grams per liter (g/L) per day organic loading rate. The BioDigester responded quickly and adequately. As of the publication of this report, the BioDigester loading rate has reached over 2 g/L a day which is over 30 percent of the system’s designed capacity.

Figure 16: Weekly BioDigester Feedstock Loading Quantities During the BioDigester Startup Period



***Units are tons per week**

Source: CleanWorld

Digester Performance During Start-up

During the start-up period, the BioDigester was monitored daily for increasing biogas production, stable pH in the methanogenic tank and a declining pH stabilizing between 4 and 5 in the hydrolysis tank, and wastewater samples were drawn twice per month as per the discharge permit requirements for analysis of total suspended solids, biological oxygen demand, ammonia, and total nitrogen. A baseline sample was also drawn before loading began. The parameters measured as required for wastewater disposal also provide important operational information. Total suspended solids measure the quantity of remaining undigested solids which indicates the degree of degradation of solids in the BioDigester. Along with total dissolved solids (which is typically also included although not strictly required for wastewater analyses), total suspended solids provide a measure of the quantity of solids leaving the BioDigester via wastewater discharges. This can be utilized to determine the degree of solids reduction as well as the solids retention time. Biological oxygen demand provides another indication of the degree of degradation, as residual biological oxygen demand could presumably be converted to biogas. Ammonia is an important inhibitor of the anaerobic digestion process and therefore must be monitored to ensure it stays within allowable levels. The difference between total nitrogen and ammonia indicates the quantity of bacteria in the BioDigester, as most of the nitrogen not in the form of ammonia is from proteins in the bacterial biomass. This can be an important indicator of BioDigester health. In addition, CleanWorld may monitor volatile fatty acids such as acetate, propionate, and butyrate, and alkalinity as a further indication of BioDigester health.

Online biogas flow rate and methane content data were collected via the data logging system designed into the controls interface. This system records and stores data from 105 instruments and system states on five second intervals. This data is then uploaded to a secure server where it is reprocessed to shrink the file size and then made available for visualization and reporting.

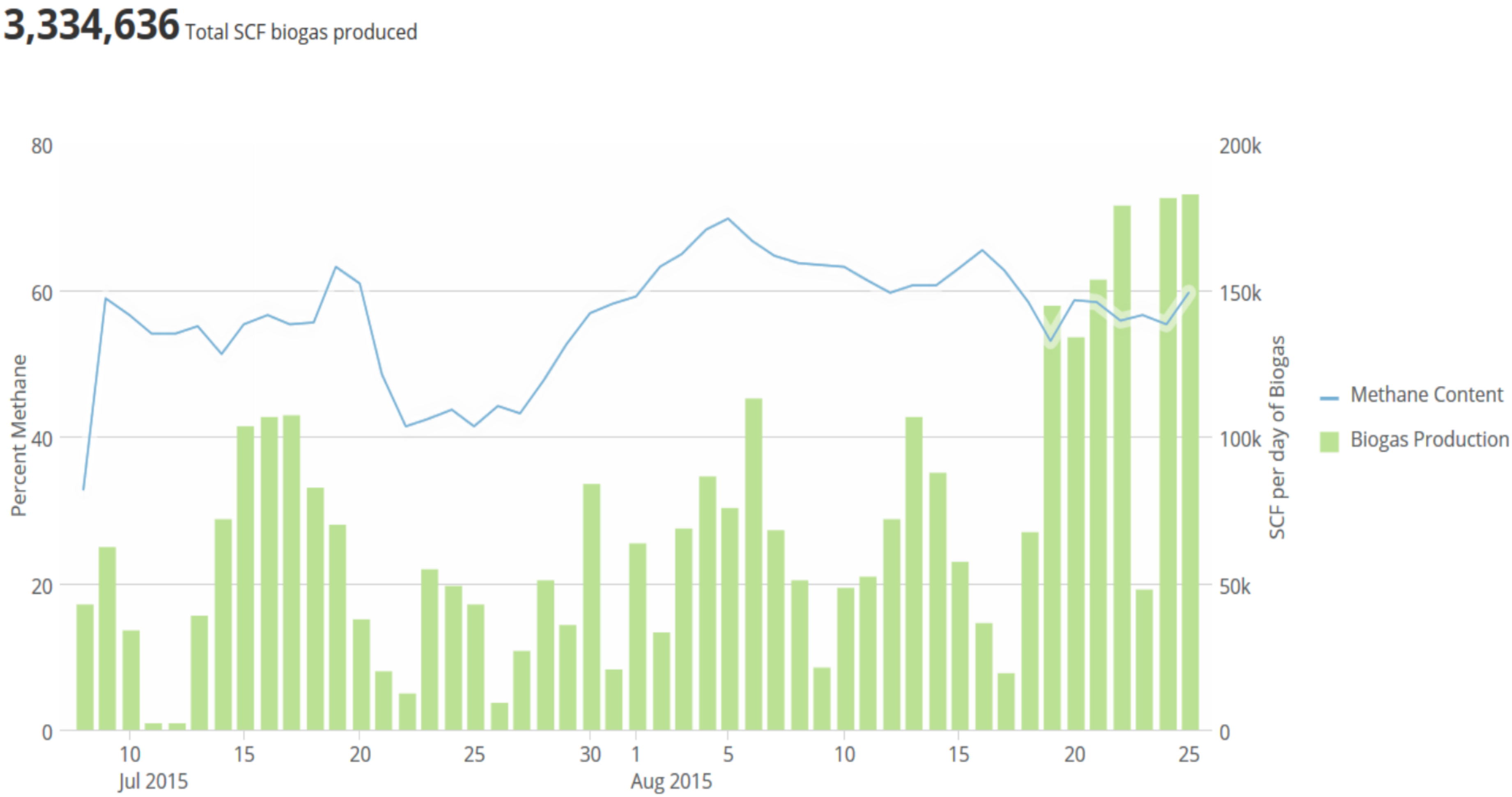
Biogas Production and Quality

Biogas was produced at low levels from the endogenous activity of the bacteria in the inoculant. However, this biogas was not recorded because it was not considered to have resulted from the loading of feedstock to the BioDigester system. Biogas production was recorded beginning with the regular transfer of hydrolysate to the methanogenic tank in July 2015.

As shown in Figure 17-20 below, biogas flows immediately commenced upon loading of the BioDigester. Periodic losses of biogas due to flare failures biased the biogas flow measurements during these periods. Towards the end of the startup period, biogas flow rates were much higher and more consistent, indicating an approach to steady state. These flow rates surpassed those achieved during the Phase I startup where daily biogas production did not exceed 100,000 scf. With flows consistently over 150,000 scf per day, the BioCNG 100 can be commissioned and run at full capacity.

In addition to higher flow rates, the methane content of the biogas is exceptionally consistent considering that the system is in the startup phase. The daily fluctuation in methane content was less than five percentage points over half of the startup period. This is remarkable because transient fluctuations in methane content are common for the BioDigester daily.

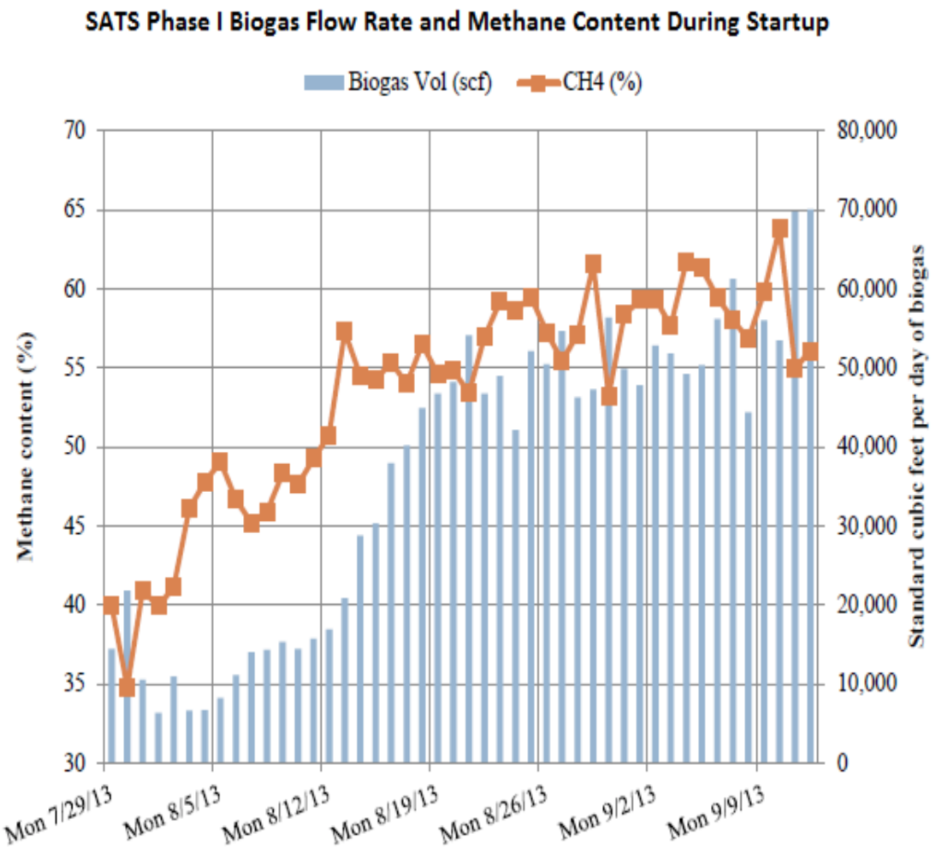
Figure 17: SATS Phase II Biogas Production and Methane Content

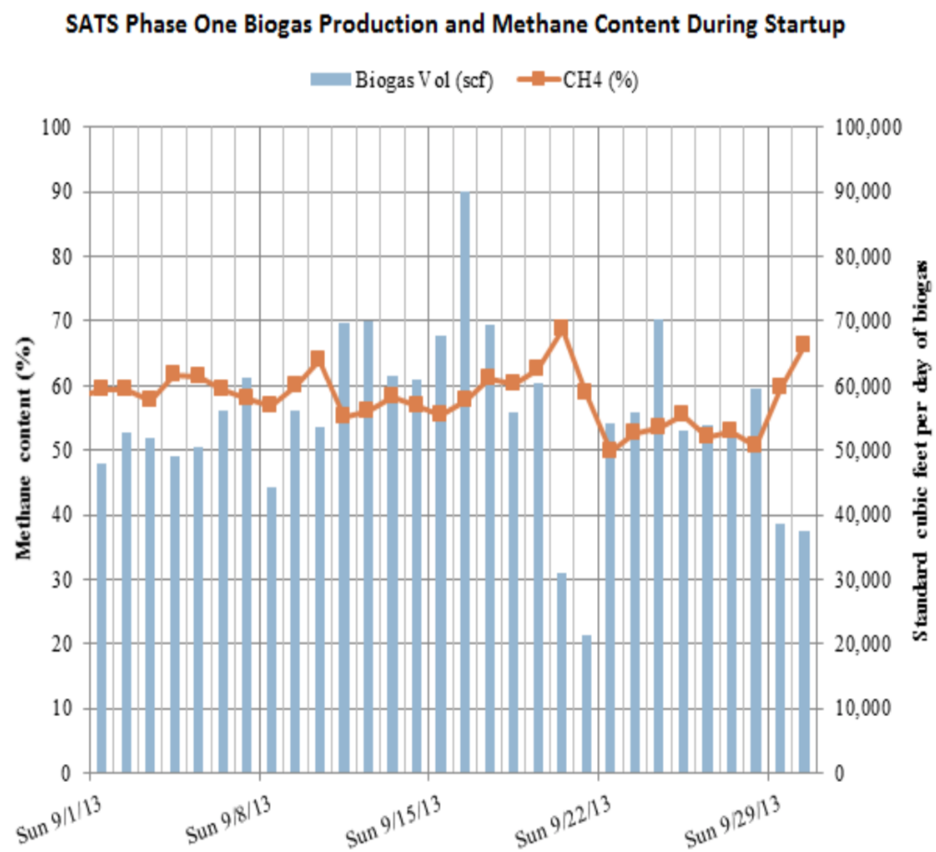


***Daily total biogas output (measured as the sum of five-minute average flow rates in standard cubic feet per minute times five minutes for each day) and mean methane content during the startup period.**

Source: CleanWorld

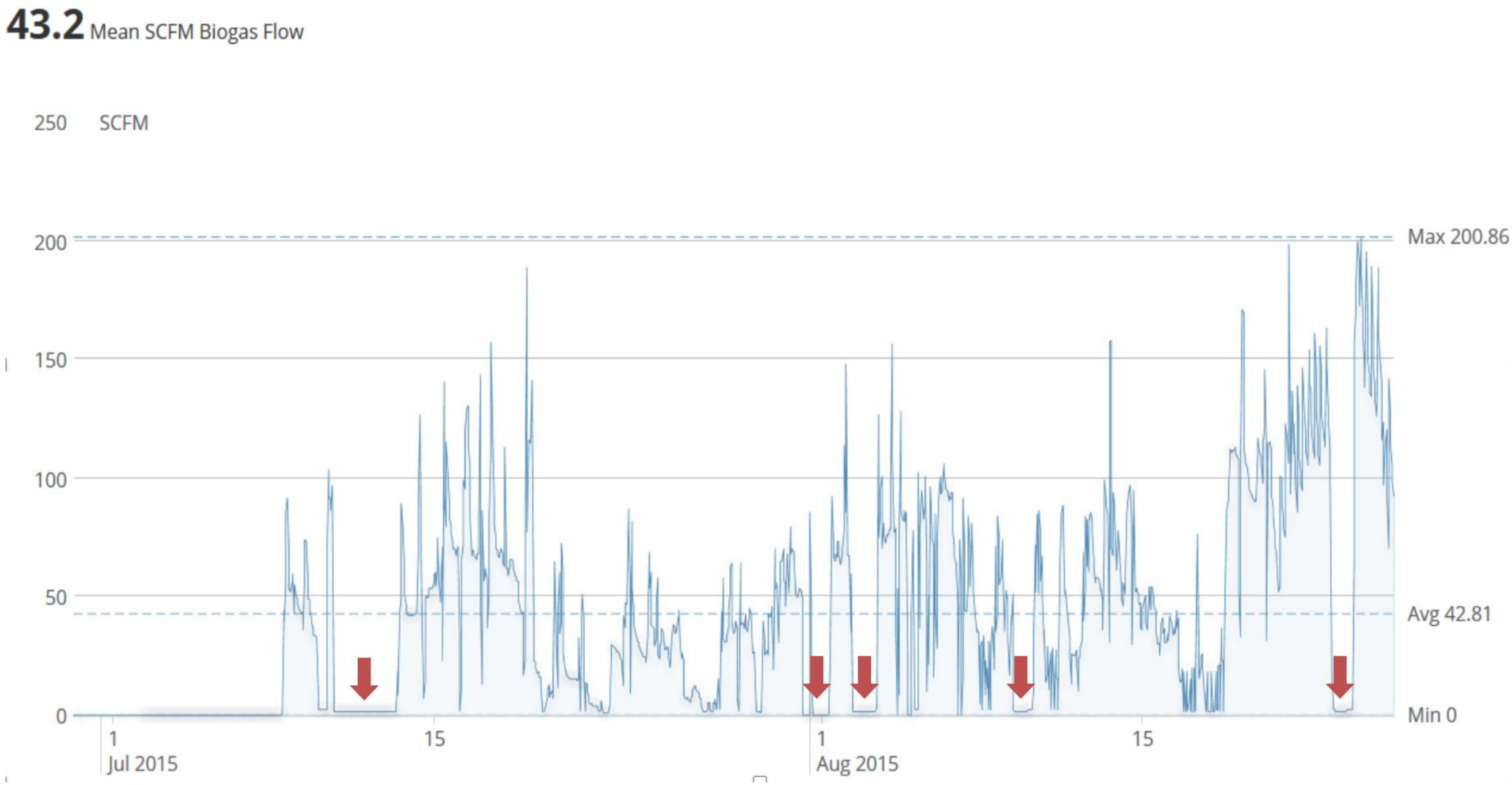
Figure 18: Phase One Biogas Production and Methane Content During the First (left) and Second (right) Months of Startup.





Source: CleanWorld

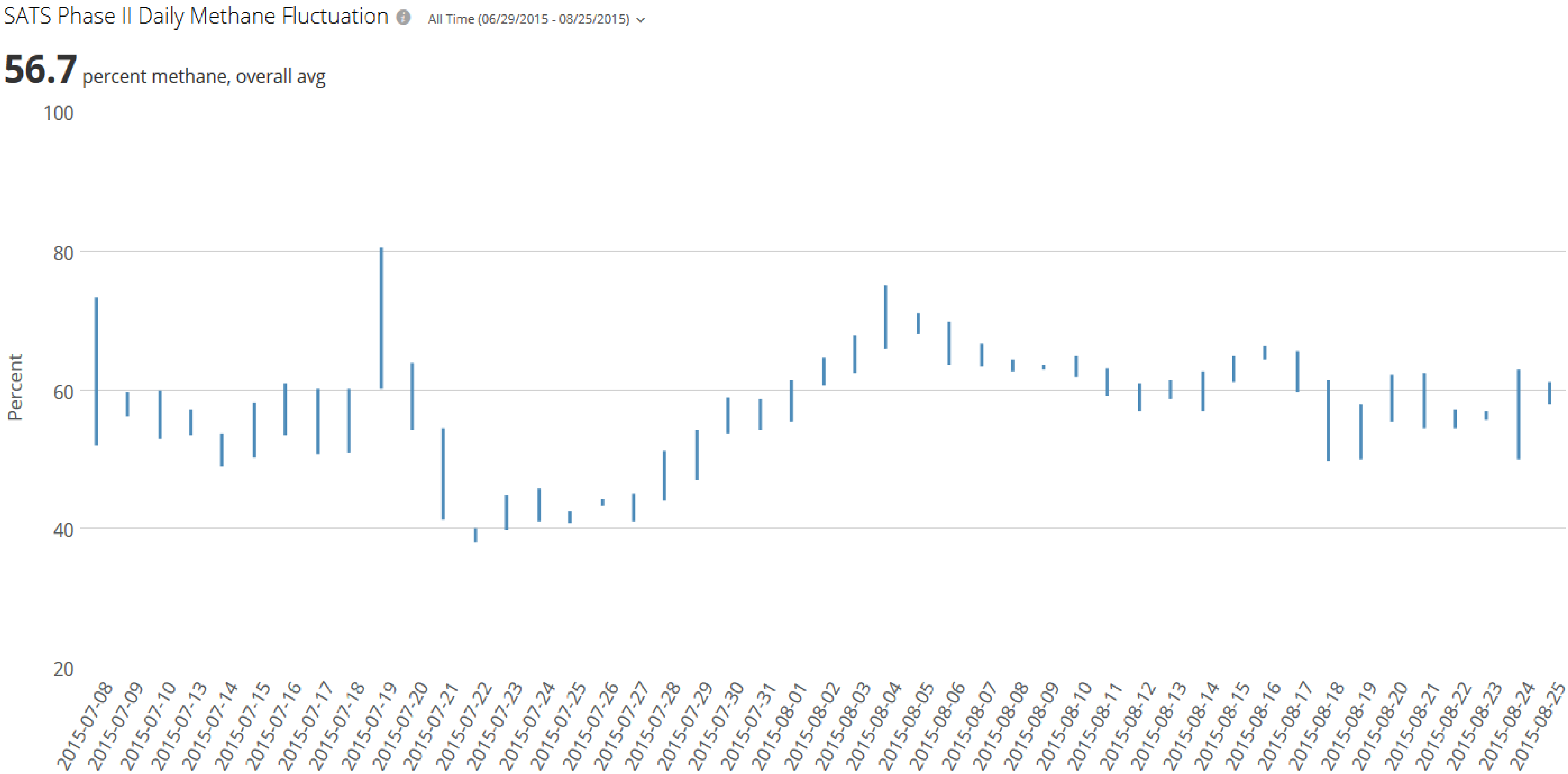
Figure 19: SATS Phase II Biogas Flow Rate



***Hourly mean biogas flow rates during BioDigester startup. The maximum expected mean flow rate at full capacity is 300 – 350 scfm. Red arrows indicate periodic flare failures that led to loss of biogas via the pressure relief valves on the tanks.**

Source: CleanWorld

Figure 20: SATS Phase II Daily Methane Fluctuation



***High and low methane content values for each day, indicating intra-day variability.**

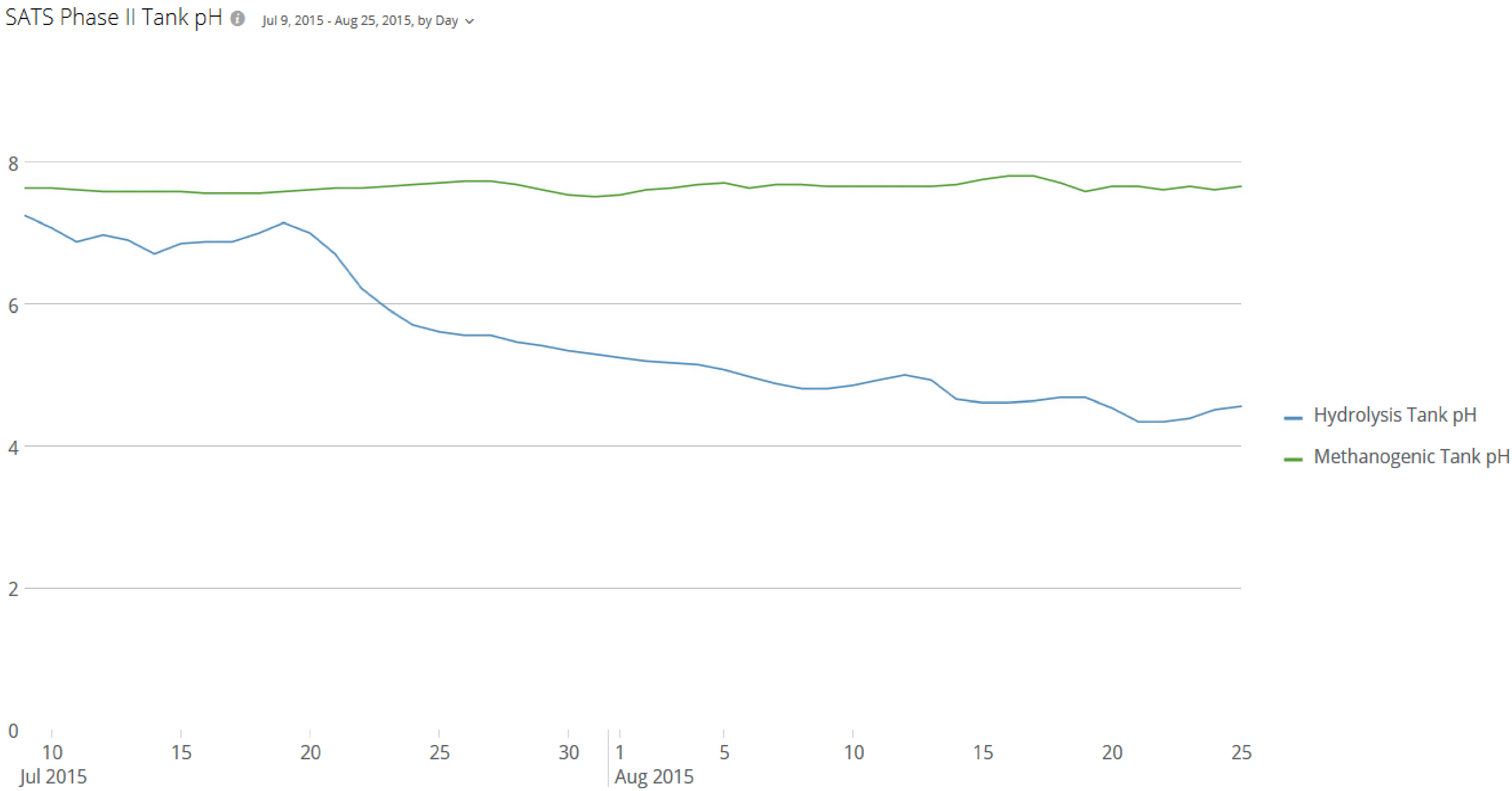
Source: CleanWorld

Digester Health Indicators

The primary indicators of BioDigester health and stability were methane content and pH. During startup, large fluctuations in methane content are common as the microbial populations adjust to the changing environment. As noted, methane content was particularly stable during startup. In addition, dips in the methane content indicated lags in the response of the methanogens to the production of organic acids. The methane content declined and then quickly recovered and stabilized at a high level. This indicated that the methanogenic population also increased and then stabilized.

In addition to the methane content, pH is a common indicator of reactor health. As organic acids are produced during hydrolysis, the pH declines. As those acids are then fed to the methanogenic bacteria, the pH should stabilize. In a two-stage reactor, the decline in pH occurs in the hydrolysis stage, as is seen in Figure 21. The pH began in the neutral range and then began to decline as loading rate increased. Over several weeks, the pH approached 4.5 where it remained relatively stable during the final two weeks of the startup period. This is typical for the CleanWorld hydrolysis tank. During the same period, the pH in the methanogenic tank remained consistently stable at 7.6 – 7.8, despite the increase in loading rate and decline in pH of the hydrolysate as it was transferred to the methanogenic tank. The stability of the pH in the methanogenic tank was another sign of a healthy methanogenic bacterial population.

Figure 21: Mean Daily pH of Both New BioDigester Tanks During the Startup Period



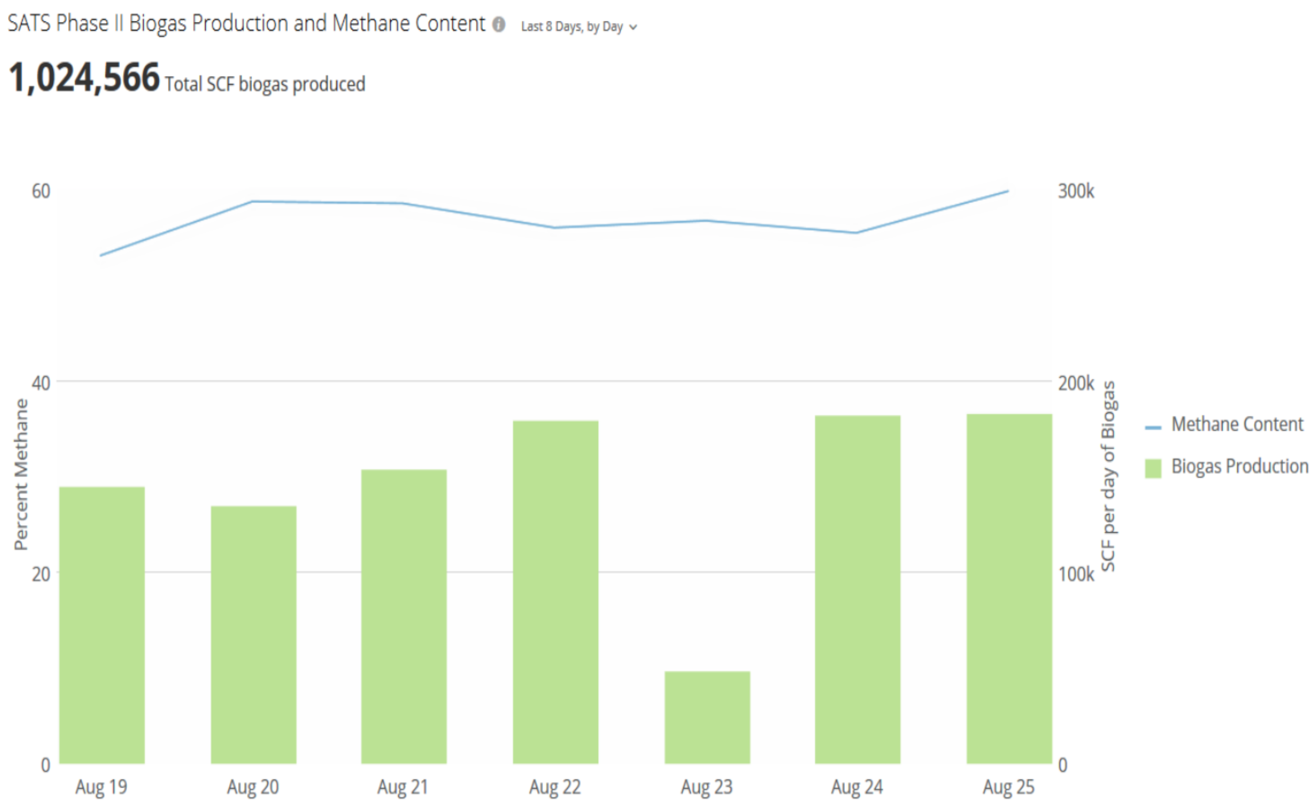
Source: CleanWorld

Digester Performance at Steady-State and Normal Operations

At the end of the startup period, the BioDigester had begun to reach steady state. During the last week of startup, biogas production rates and methane content had stabilized, as shown in Figure 22. On August 23, as noted previously, the flare failed, and biogas was lost through the pressure relief valve on the tank. Therefore, the weekly total biogas production should be about 130,000 scf higher, bringing the total to 1.15 million scf for the week. As shown previously, the weekly loading rate averaged 235 tons per week over the last four weeks of the startup period. Together, that gives the BioDigester a biogas yield of 4,894 scf per ton of feedstock loaded.

The feedstock total solids content was calculated to average 22 percent and the volatile solids content was assumed to be 85 percent of the total solids, based on past studies. This gives the BioDigester a biogas yield of 13 scf per pound of volatile solids loaded. This is higher than the predicted 11.2 scf per pound used in our original modelling of the system. Longer term trends will be needed to confirm that this high biogas yield is sustainable, but it indicates a healthy anaerobic BioDigester system currently operating.

Figure 22: Biogas Production Rate and Methane Content Over the Final Week of the Startup Period



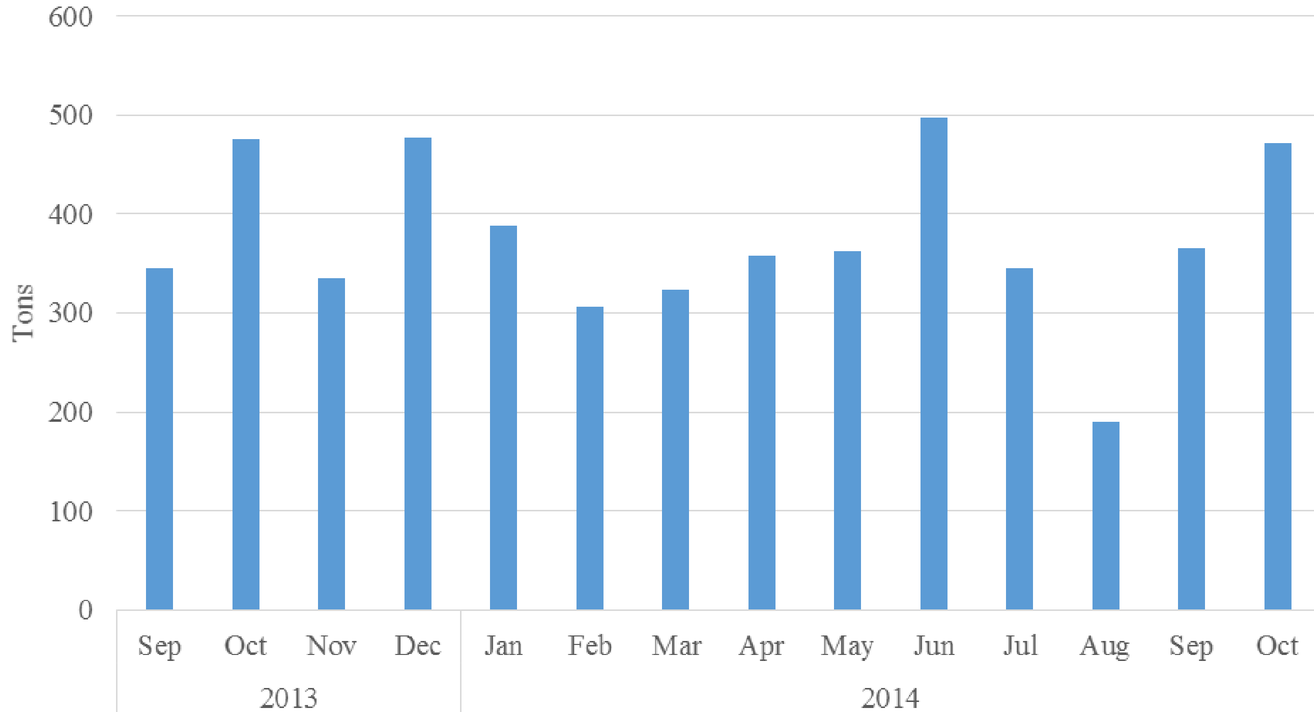
Date	Methane Content	Biogas Production
8/19/2015	53.13	144,785
8/20/2015	58.64	134,135
8/21/2015	58.51	153,994
8/22/2015	56.01	179,070
8/23/2015	56.8	48,062
8/24/2015	55.49	181,595
8/25/2015	59.85	182,924
Total	**56.92**	**1,024,566**

Source: CleanWorld

Phase One Performance

By comparison, during the Phase I steady-state period of operation (during 2014), the average loading rate per month was 375 tons (see Figure 23). In July and August of 2015, SATS Phase II loaded 710 and 840 tons, respectively.

Figure 23: SATS Monthly Loading Rate During Phase I Operations at Steady State



***The BioDigester began receiving feedstock in February 2013**

Source: CleanWorld

Over that same period, biogas production rates averaged 1.6 million scf per month at 59 percent methane content (see Table 12). This resulted in an average biogas yield of 4,686 scf per ton of feedstock loaded, which was very similar to the biogas yield and methane content for Phase II at steady state.

Table 12: Monthly Performance Metrics During the Steady-State Period for Phase I Operations of the SATS BioDigester.

Month	Feedstock Loaded (tons)	percent of Max Capacity	Biogas Output (scf)	Methane Content (percent)	Biogas Yield (scf/ton)	Methane Yield (scf/ton)
2013-Sep	489	61 percent	1,656,896	57 percent	3,388	1,931
2013-Oct	455	43 percent	1,758,306	56 percent	3,864	2,164
2013-Nov	413	40 percent	2,134,477	60 percent	5,168	3,101
2013-Dec	530	58 percent	2,080,033	58 percent	3,925	2,276
2014-Jan	368	0 percent	2,243,674	58 percent	6,097	3,536
2014-Feb	293	0 percent	1,784,890	59 percent	6,092	3,594
2014-Mar	283	0 percent	1,663,369	60 percent	5,878	3,527
2014-Apr	320	0 percent	1,635,465	61 percent	5,111	3,118
2014-May	221	0 percent	1,844,470	61 percent	8,346	5,091
2014-Jun	445	0 percent	1,813,277	61 percent	4,075	2,486
2014-Jul	306	0 percent	980,674	62 percent	3,205	1,987
2014-Aug	172	0 percent	742,974	61 percent	4,320	2,635
2014-Sep	343	0 percent	1,241,188	58 percent	3,619	2,099
2014-Oct	441	0 percent	1,111,825	53 percent	2,521	1,336
Monthly Average	**363**	**14 percent**	**1,620,823**	**59 percent**	**4,686**	**2,777**

Source: CleanWorld

Based on this analysis, the BioDigester appeared to be performing as expected, and the scale-up had already allowed the system to process twice as much feedstock as was loaded during most months of Phase I.

Steady-state Gas Processing Systems Performance

The gas processing system was in the process of being fully commissioned, as of the publication of this report. The flare was commissioned, as described previously, and was operating reliably. All the biogas was being flared while the remaining gas processing system components were commissioned or re-commissioned.

The BioCNG 100 unit that previously processed biogas to generate transportation fuel will be re-commissioned once the gas storage tank has been fully purged and tested to ensure that no unwanted gases are present. The BioDigester was already producing over 100 scfm biogas on average which would run the BioCNG at full capacity. At the time of publication, samples were drawn and sent for analysis, and the BioCNG unit was scheduled to be recommissioned when the sample results are received.

The BioCNG 200 unit will be commissioned when biogas flows are reliably over 100 scfm consistently. The commissioning will be performed by the system manufacturer since it will be the first time this unit will be operated. Commissioning will be scheduled after biogas flows can be confirmed at over 100 scfm for a full week.

The engine generator requires some maintenance and a permit modification before it can be re-commissioned, as described previously. CleanWorld plans to install a new emissions control system and modify the air permit accordingly before re-commissioning the generator. The engine will also have to be checked by CleanWorld's maintenance crew and possibly adjusted before it can be run. A thorough inspection is being planned with a test run planned after the emissions control modifications are completed, as of the publication of this report. None of this work was within the scope of this grant. Furthermore, the engine will not be needed until the biogas production rate exceeds the capacity of the BioCNG units. This is not expected until sometime next year.

Chapter 9: Employee Training and Orientation

CleanWorld has developed an orientation program which introduces the anaerobic BioDigester system and its safe operation as well as the illness and injury prevention plan. The latter includes a brief introduction to general safety issues encountered at each CleanWorld location. This orientation is repeated annually for all employees as a refresher and any new employees hired within three months of the scheduled orientation session. The presentation is reviewed and updated before each presentation to reflect changes at the various CleanWorld operations. Employees who are hired more than three months before the orientation session are provided with the full Injury and Illness Prevention Program documentation and a brief one-on-one safety orientation is scheduled. They are then required to attend the full orientation at the regularly scheduled time. If several new hires require the orientation, a special session may be planned. In addition to the general orientation, detailed safety trainings are scheduled throughout the year.

The schedule for the orientation and safety trainings, both completed and planned for 2015 is shown in Table 13.

Table 13: Employee Training 2015

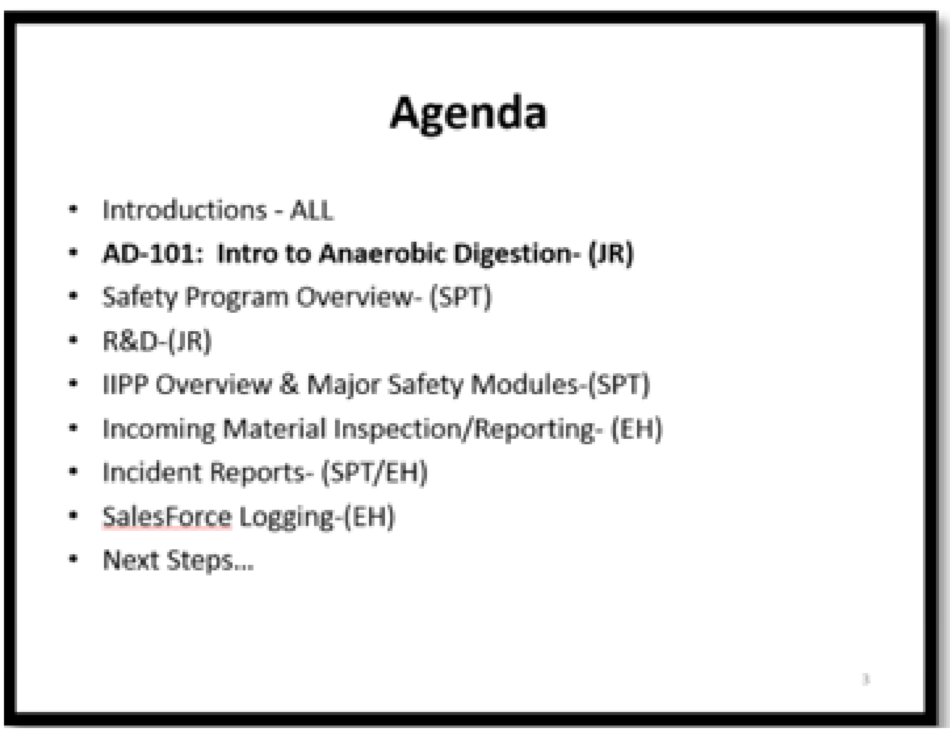
Date Planned	Training Module	Completed
Jan 2015	• Forklift Training	1/22/15
Mar 2015	• Annual Safety Training • Safety Program Overview • Injury and Illness Prevention Program Overview and Major Safety Modules • Incident Reports	3/5/15
Apr 2015	• Confined Space Training • Spill Prevention • Personal Protective Equipment for Emergency Response • Personal Protective Equipment - What employees need to know	4/2/15 8/28/15
May 2015	• Hazardous Waste Introductory Training • HAZWOPER Facility Operations	5/5/15
Jun 2015	• Storm Water Pollution Plan • Water Conservation	8/6/15 8/11/15
Jul 2015	• Working in Hot Conditions • Working Safely Outdoors	7/23/15
Aug 2015	• Respiratory Protection	8/7/15
Sep 2015	• Hazardous Communications and Globally Harmonized Systems requirements - What employees need to know • Hazard Communications and Globally Harmonized Systems requirements - What supervisors need to know	
Oct 2015	• Laboratory Safety • Safe Chemical Handling • Reactive Chemicals • Understanding Chemical Labels Under Globally Harmonized Systems requirements • Understanding the Safety Data Sheet	
Nov 2015	• Electrical Safety • Machine Guarding	
Dec 2015	• Back Safety • Basic First Aid for Medical Emergencies	

Source: CleanWorld

System Operations and Maintenance Training

Employees were trained in basic process, instrumentation, and safety. CleanWorld's Senior Vice President of Operations led the training in April 2015. Samples of the presentation are included in Figure 24 which also indicates the agenda for the training session. The session lasted about three hours and was mandatory for all CleanWorld employees who work in the field or in a lab setting.

Figure 24: Process and Safety Orientation Presentation Slide Examples



***Title (top) and agenda (bottom)**

Source: CleanWorld

Documentation

Standard operating procedures were documented and presented to site employees (e.g., checklists, data collection, and routine maintenance) at the time of the process orientation. The new standard operating procedures are developed whenever a new piece of equipment is received. Annual reviews of the standard operating procedures are routinely conducted by CleanWorld to ensure that the standard operating procedures meet current practices and the standard operating procedures are revised as needed.

Non-Standard operating procedures (e.g., troubleshooting, restarts, non-routing maintenance, and equipment changes) are still being collected as the system builds operating life. These will be documented and presented to site employees once complete. Site employees meet weekly to discuss site safety and non-operating procedures as challenges that the team faces are encountered.

A maintenance plan is being established and implemented to include:

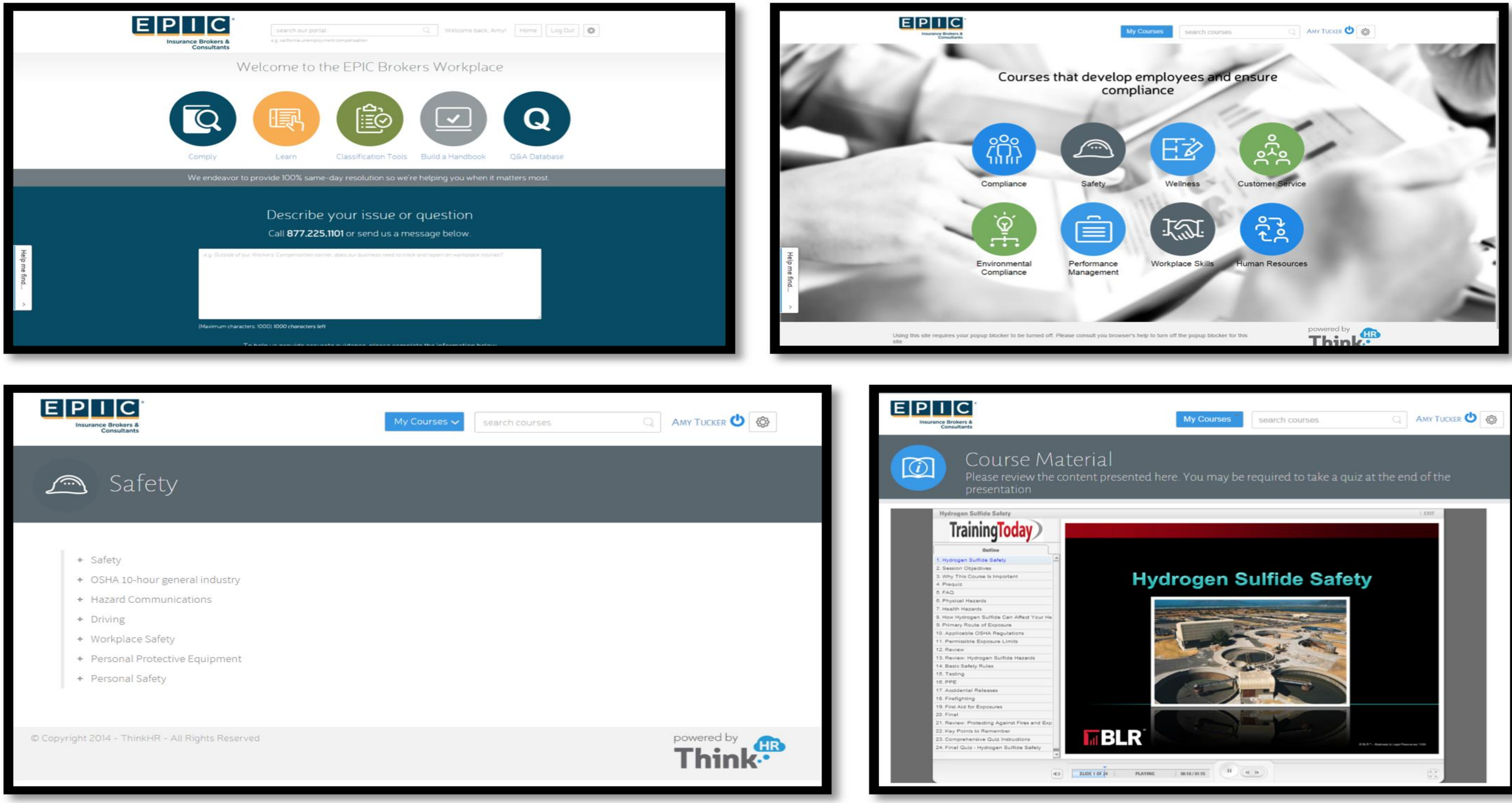
- PM Schedule
- Spare Parts and Consumables
- Contract Services

Safety Training

Employees are trained on injury and illness prevention programs, hygiene, and housekeeping requirements. In addition to the internal orientation and training sessions, which introduce the key topics, CleanWorld has access to detailed training modules online through its insurance provider. The online safety training courses are provided by Think HR. Each employee is assigned safety training modules specific to the hazards of their job and required to complete the modules through CleanWorld's online account. Employees have the option of completing modules in groups or as individuals. Once a module is completed, a certificate is generated, and the employees' records are updated.

The screen shots in Figure 25 show a glimpse inside the training courses.

Figure 25: Online Training System Screenshots



***(clockwise from top left) portal home page, course options, safety topics, and example online training session on hydrogen sulfide safety**

Source: CleanWorld

Some of the relevant available courses include the following:

- Forklift Operator Safety
- Forklift and Pedestrian Safety
- Hazard Communication and Globally Harmonized Systems requirements
- Understanding Chemical Labels Under Globally Harmonized Systems requirements
- Understanding the Safety Data Sheet
- Electrical Safety
- Hazard Communication
- Eye Protection
- Foot Protection
- Hand Protection
- Hearing Loss and Protection
- Noise and Hearing Conservation
- Personal Protection Equipment
- Hand Protection
- Respiratory Protection
- Back Safety
- Basic First Aid for Medical Emergencies
- Working in Hot Conditions
- Working Safely Outdoors
- Emergency Action and Fire Prevention
- Fire Extinguisher
- Job Hazard Analysis
- Laboratory Safety
- Lockout/Tag out
- Aerial Lift Safety
- Battery Safety
- Compressed Gases
- Crane Rigging
- Disaster Planning—What Employees Need to Know
- Hydrogen Sulfide Safety
- Mold Hazards and Prevention
- Permit-Required Conned Spaces Rescue—For Supervisors
- Permit-Required Conned Spaces—Attendant
- Permit-Required Conned Spaces—Entrant
- Portable Power Tool Safety

- Preparing for Weather Emergencies
- Respirator Fit Testing—What Supervisors Need to Know
- Scaffolds in Construction
- Trenching—The Competent Person
- Welding, Cutting, and Brazing

Chapter 10: Evaluation of Original Goals and Objectives

CleanWorld has evaluated the success of this project compared to the original goals and objectives. The overall program goals, technical goals, and economic goals were outlined in the project goals section of this report in Chapter 1. The following discussion details the ways in which the goals were met at the completion of the project.

Evaluation of Program Goals

CleanWorld demonstrated the scale-up of a commercial scale biofuel facility from 25 TPD to 100 TPD by installing the equipment and infrastructure described in this report. This increased the capacity of waste accepted and fuel produced by four times, which greatly increased revenue generation for the project.

CleanWorld reduced GHG emissions through efficiencies in scale-up because the larger system size has a smaller percentage of parasitic load, which reduces the GHG emissions per ton of feedstock processed. In addition, the overall volume of GHG reduction increased relative to the increased quantity of waste diverted from landfills and low-carbon biofuel. CleanWorld reduced petroleum dependence by displacing diesel fuel with the increased RNG volume sent to the natural gas vehicle fueling station that offers RNG to several companies, public municipalities, and schools.

CleanWorld stimulated economic development in California by developing a replicable plan for constructing phased AD projects. The demonstration of SATS as a phased AD project has become a great reference for other communities and companies looking for a scalable solution. The SATS model shows that there is a great economy of scale and business case for increasing a system's capacity, even when the scale-up occurs after the commissioning of the first phase. The SATS project has already demonstrated the benefits to waste collection companies of having CNG fleets that can fill up at the same location that they drop off feedstock. The marketing benefits of this renewable fuel have also been realized by these companies.

Evaluation of Technical Goals

Most of the technical goals were in the process of being met as the system continued to ramp up feedstock acceptance to full capacity. At the time of publication, the successful trends of the scale-up data indicated that we will be able to meet all these goals upon reaching full operational status.

The design, engineering and construction of the expansion were performed as described in the technical goals, and the new system components were all fully commissioned, except for the new biogas conversion unit which is currently planned when biogas production reaches the minimum required volume. At the time of publication, the scaled-up system was accepting approximately 35 tons per day of pre-landfill source separated waste, and plans were to continue to increase loading gradually until the 100 TPD capacity was reached. At the time of publication, the BioCNG 200 equipment was in the commissioning process. Gas flows indicated that a minimum of 100 scfm of biogas would be available for processing as soon as start-up was complete. The daily RNG production was expected to continue to increase from 440 DGE to 1,550 DGE to complete this goal in the next few months.

The goal of increasing useable heat production was dependent on our ability to run both our BioCNG units and the generator, which was predicated on reaching full capacity. Incorporating heat recovery will be revisited once it can be confirmed that the system is producing enough biogas to sustain operation of the co-generation unit. Plans were in place as of the date of publication to commission the generator in the next few months.

The maximum solid effluent volume at full capacity was estimated at 5-10 tons per day, which was less than the original goal of 20 tons per day. The volume decreased because the original goal included the addition of zeolite media to the BioDigester effluent, and the new effluent management plan did not. The products created using the new effluent management plan were expected to be more economically sustainable and have a greater market demand than the original concept of zeolite fertilizers. CleanWorld was actively testing several technologies that promised to produce high value fertilizer products from BioDigester residuals. Solid residuals have been removed from the BioDigester system and researched for their market potential. However, new technologies promised to also allow for creation of high value liquid fertilizer products. Implementation of these technologies should provide an increased volume of fertilizer products created over the Phase I's potential.

Currently, water recovered from food waste that would otherwise be destined for landfills was being redirected to local area rivers via the Sacramento County Regional Sanitation District's wastewater treatment plant. The volume of water redirected was expected to continue to increase as the feedstock acceptance increased to full capacity. At the time of publication, approximately 8,400 GPD were being recovered and CleanWorld anticipates exceeding the goal of 15,000 GPD once the system reaches full capacity. Furthermore, some of this water was being recycled through the BioDigester facility prior to discharge.

At the time of publication, GHG offsets from the scaled-up project had reached approximately 23 metric tons of CO2e per day. The net greenhouse gas offset will continue to increase as the feedstock acceptance increases to full capacity, and CleanWorld expects to meet the goal of 66 metric tons of CO2e equivalents per day of final GHG offset. As the RNG conversion equipment becomes available, CleanWorld will also resume registration of LCFS credits with The State at a rate of -15.29 g CO2e/MJ as well as Renewable Fuel Standard Renewable Identification Numbers.

Economic Impacts

Some of the economic goals were met while some were difficult to properly evaluate in this early stage after project completion. The expanded facility can now provide renewable fuel for all 20 trucks in Atlas's fleet and meet the goal of expanding the vehicles fueled for Atlas from 10 to 20. The short-term jobs projected were created in Marysville, California during the fabrication of the BioDigester skids. Construction jobs were also created in Sacramento, California during the construction and installation of the Phase II equipment onsite. Determining the precise number of jobs created was difficult because subcontractors hire new employees and redirect current employees based on the needs of the job at any given moment. CleanWorld estimated that the total number of short-term jobs created throughout the fabrication, construction, and installation of the facility was in the range of 100-140, which met the goal established to create 137 short-term jobs. CleanWorld created three new full-time material handler positions and one full-time administrative position as well as a new site lead position, a new operations director position, and two new maintenance positions, as well as a new field research position, a research engineer position, and two intern positions. This fell short of the original goal to create 16 long-term jobs (only 12 were created), but improvements in system automation allowed for less labor and increased economic viability for CleanWorld's systems. In addition, execution of this project employed over 20 CleanWorld staff throughout the project.

CleanWorld met its goal to generate more than $1.1 million in taxes to the benefit of the city, state, and county, with a current annual sum of approximately $1.15 million in taxes from the SATS project. This goal was evaluated by adding up several categories of tax revenue for the project. The first was the equipment purchased for SATS multiplied by the tax rate of 8.75 percent and annualized over the term of the grant. CleanWorld did utilize a California Alternative Energy and Advanced Transportation Financing Authority exemption, however the "lost tax" was still paid to the county by the state and was therefore included in the calculation. Taxes generated through payroll for design, engineering, environmental review, fabrication, construction, and installation were included and annualized over the life of the project. Taxes for payroll for operations, including management, marketing and sales were included on an annual basis for the system at full capacity. Fees paid for wastewater disposal costs were also included into the annual sum of taxes. CleanWorld did not include taxes paid for waste disposal by the hauling companies, vehicle taxes paid for new CNG vehicles purchased by Atlas, or taxes related to the sale of CNG at the Atlas ReFuel CNG station. CleanWorld did not pay any sales tax on the RNG sold to Atlas as this was considered a wholesale transaction and the tax was collected from Atlas when the fuel was re-sold to the end user. Even without including these sources of tax revenues, CleanWorld exceeded the tax generation goal. The tax benefits from the project will continue to accrue annually moving forward, generating additional revenue for the city, state, and county.

Final Conclusions

CleanWorld's scale-up of the SATS project was a great success for both the company as well as the State of California. The program, technology and economic goals that were established in the project's proposal were accomplished with a great degree of success. Most goals that had not yet been fully met were expected to reach full fruition when the Phase II system reaches full capacity. CleanWorld believes that this project will serve as a successful demonstration of a scalable BioDigester project that will be replicable throughout the state, especially for communities that have expanding organic waste collection programs.

Additional Research Needed

There were still two areas that needed further research and demonstration in CleanWorld's BioDigester system: pre-processing to allow acceptance of more heavily contaminated feedstocks and solids removal/effluent management. Creating innovative solutions in these two identified areas would allow future BioDigester projects to be more commercially relevant and economically feasible, which would greatly increase the number of BioDigesters constructed in California in the future. CleanWorld was actively researching, creating, and integrating technologies in these areas at the time of publication.

Feedstock Pre-Processing

CleanWorld employed a BioSeparator technology (Doda USA, Inc.) for pre-processing feedstocks to remove contaminants, but this technology had been found to have limitations. It did not remove glass, grit, or other brittle contaminants, and it passed many smaller contaminants such as light plastics. These contaminants accumulated in the digester over time and proved difficult to remove, but feedstocks are expected to become even more contaminated in the future.

In California, 25 percent – more than 6 million tons per year – of all landfilled waste is food and agricultural waste that could be used to make enough renewable biogas to displace nearly one billion gallons of biofuel per year.[1] However, most of this organic waste is not source separated. Local material recovery facilities have begun to incorporate a fine screening into their municipal solid waste treatment lines that recovers a largely organic stream to increase diversion. This mechanically separated organic fraction of municipal solid waste typically still contains 25-50 percent contamination by weight, making it unsuitable for digestion without additional pre-treatment to remove the contaminants prior to loading. CleanWorld tested their existing pre-treatment system on this material and found that it did not remove enough of the contaminants. CleanWorld began researching existing pre-treatment technologies and failed to find a system that, on its own, would effectively clean this stream. As a result, CleanWorld began developing a plan to integrate several different components that, together, would allow for acceptance of the organic fraction of municipal solid waste.

After extensive market research and visits to North American and European providers and operating facilities, CleanWorld identified the best probable solution and began planning to pilot a uniquely integrated combination of these technologies at the South Area Transfer Station. If successful, this would allow CleanWorld to accept highly contaminated material which would greatly improve the project’s economics as well as help local waste haulers meet California’s high waste diversion goals. The introduction of this technology into the commercial market could make over 6 million tons of feedstock per year available for digestion in California, which would accelerate the anaerobic digestion industry and stimulate economic development. This would greatly increase the quantity of renewable fuels available in California and reduce GHG emissions by diverting the organics from landfills and displacing petroleum-based fuels.

Effluent Management

Another major area of research for CleanWorld has been in the production of fertilizer products from anaerobic digester effluent. CleanWorld has developed and marketed several products based on digester effluent, but none has led to extensive wide-spread application of digester-based fertilizers in the marketplace. CleanWorld used another CEC grant (PIR-12-007) to review the market for digester effluent-based fertilizers and technologies for producing a variety of products. This led to the testing of many different pilot equipment options that has

[1] Bioenergy Association of California 2014

narrowed the search for the ideal combination of equipment needed to produce a cost effective and widely marketable fertilizer product.

Many of the technologies tested and reviewed were found not to be cost effective, but CleanWorld used the results of the grant to develop a novel integrated system that promises to create a concentrated liquid fertilizer with excellent market potential that can be stored and shipped to a wide range of customers. This technology would simultaneously generate a low strength wastewater that could be easily discharged into the local sewer system as well as a concentrated bacterial solution that could enhance digester stability, provide ready seed for new BioDigester systems, and potentially be turned into a secondary product. CleanWorld's initial testing and economic modeling suggests this system is technically and financially feasible. CleanWorld has tested all the components and is ready to demonstrate this technology at a larger scale. This technology will be widely applicable to any digester system accepting almost any feedstock which would allow CleanWorld to offer most new customers a complete solution for their waste streams that will greatly accelerate the dissemination of AD technology while further reducing GHG emissions by offsetting conventional fertilizer use.

GLOSSARY

ANAEROBIC DIGESTION (AD) Anaerobic digestion is the natural process in which microorganisms break down organic materials. In this instance, "organic" means coming from or made of plants or animals. Anaerobic digestion happens in closed spaces where there is no air (or oxygen). The initials "AD" may refer to the process of anaerobic digestion or the built system where anaerobic digestion takes place, also known as a digester.[2]

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 ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

1. Forecasting future statewide energy needs.
2. Licensing power plants sufficient to meet those needs.
3. Promoting energy conservation and efficiency measures.
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
5. Planning for and directing state response to energy emergencies.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.

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.

CARBON DIOXIDE (CO2)—A colorless, odorless, nonpoisonous 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. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 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.

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

[2] U.S. EPA (https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion-ad)

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

GALLONS PER DAY (GPD) — A measure of volume flow rate.

KILOWATT (kW)—One thousand 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 4 kW each hour.

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

LOW CARBON FUEL STANDARD (LCFS)—A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and therefore reduce greenhouse gas emissions. The LCFS standards are expressed in terms of the carbon intensity of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California that aim cut greenhouse gas emissions and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

MEGAJOULE (MJ)—A joule is a unit of work or energy equal to the amount of work done when the point of application of force of one newton is displaced one meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about one million joules to make a pot of coffee. A megajoule itself totals one million joules.

RENEWABLE NATURAL GAS (RNG)—Or biomethane, is a pipeline-quality gas that is fully interchangeable with conventional 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).[3]

COUNTY OF SACRAMENTO SOUTH AREA TRANSFER STRATION (SATS)—The South Area Transfer Station located at 8550 Fruitridge Road in Sacramento is a 12-acre COUNTY facility that is currently not used to transfer any material. SATS is an open-air transfer station. It is permitted to accept up to 348 tons per day.[4]

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.

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[3] U.S. Department of Energy (https://afdc.energy.gov/fuels/natural_gas_renewable.html)
[4] County of Sacramento (https://wmr.saccounty.net/Documents/2019%20Sacramento%20County%20Organics%20Diversion%20Services%20RFP.pdf)

STANDARD CUBIC FOOT (SCF)—One cubic foot of gas at standard temperature and pressure (60˚F [15.6˚C] at sea level). Since both temperature and air pressure affect the energy content of a cubic foot of natural gas, the SCF is a way of standardizing. One SCF = 1,020 BTUs.

THERM (THM)—A non-SI unit of heat energy equal to 100,000 Btu or 1.10 MMBtu.[5]

TONS PER DAY (TPD)—A measure of mass flow rate.

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[5] U.S. Energy Information Administration (https://www.eia.gov/)