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Integrated Algal Flow-Way, Digester, and Fuel Cell Demonstration Project

Prepared for: U.S. Department of Transportation Maritime Administration
Maryland Department of Transportation Maryland Port Administration
Maryland Environmental Service

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Contributors

This demonstration project is from the collaborative efforts of the following federal and state agencies, companies, and academic institutions:

- U.S. Department of Transportation Maritime Administration
- Maryland Department of Transportation Maryland Port Administration
- Maryland Environmental Service
- Anchor QEA, LLC
- University of Maryland
- Biohabitats, Inc.

In addition, the following subcontractors provided design and operational support:

- Tourgee & Associates, Inc.
- Atrex Energy, Inc.
- Reilly Electrical Services, Inc.
- Flanigan Consulting, Inc.
- HydroMentia Technologies, LLC
- Spectrum Environmental Sciences, Inc.

Major funding was provided by the U.S. Department of Transportation Maritime Administration and Maryland Department of Transportation Maryland Port Administration.

Executive Summary

In 2016 and 2017, an innovative demonstration project was designed, built, and operated to close the energy loop by producing on-site electricity for the Maryland Department of Transportation Maryland Port Administration (MDOT MPA) at its Dundalk Marine Terminal (DMT). The project successfully established the feasibility of integrating an algal flow-way, anaerobic algal digesters, a biogas collection and conditioning unit, and a fuel cell to convert algae to energy. This project incorporated multiple best management practices for improving water quality, reducing air emissions, and integrating alternative fuel sources at marine terminals.

Integrating several technologies (algal flow-way, digesters, biogas collection and conditioning unit, and fuel cell), the demonstration project operated as follows:

1. Water from the Patapsco River was pumped onto an algal flow-way (a long runway consisting of plastic sheeting covered by a screen where naturally occurring algae was allowed to grow). As the algae grew, it consumed undesirable nutrients (nitrogen and phosphorus) from the water, thereby improving water quality in the river.
2. The algae biomass was harvested and fed through a series of three anaerobic digesters—small, greenhouse-like structures—where microorganisms broke down the algae, producing biogas.
3. Water and hydrogen sulfide (H_2S) were removed from the biogas; the biogas was supplemented with natural gas; then it was fed into a fuel cell. This fuel cell generated electricity to power lights and a circulation pump, hence closing the energy loop.

The algal flow-way started-up in April and the digesters in August of 2017. The complete integrated system from algal flow-way to fuel cell ran from October to the first week of December of 2017, with testing of various percentage blends of biogas and supplemental gas in the fuel cell.

Phase 1 of the project began in the fall of 2016 with laboratory studies to characterize the biogas produced by digesting algae from the flow-way. Initial tests included batch digestion of algae grown at the DMT algal flow-way. The following studies were conducted for initial testing:

- Testing the impact of pre-treatment methods (level of drying, physical grinding, and chemical addition) on biogas quantity
- Determining biogas quality by measuring constituents in the gas (carbon dioxide, H_2S, and methane concentrations) at various times
- Estimating the overall production of biogas possible with digestion operations

Using the results from the batch digestion testing, a second laboratory study was conducted to mimic expected field operations (feeding every 3 days, with continuous removal of liquid waste and biogas) and to characterize the liquid waste and biogas produced from the digester. The results from the laboratory studies informed the need for and extent of H_2S removal, biogas storage necessary based on estimated biogas production, and effluent concentrations expected from the digestion process. In addition, based on the laboratory studies and past algal biomass productivity rates from the flow-way, the specifications and operating conditions for the demonstration project's algal digesters were developed.

Phase 2 of the project took place in 2017, with design, procurement, and construction of the operating system components followed by start-up and operations. One of the challenges in designing the system was integrating a weekly, batch-type algae harvest into a semi-continuous (Monday, Wednesday, and Friday) algae feed to the digesters and continuous operation of the fuel cell. To feed the digesters between harvests, a decant tank and feed tank system was designed. The decant tank allowed the harvest to settle to increase the solids content in the digester feedstock. A feed tank to hold at least a 1-week supply of algae for the digesters was installed with a pump and piping to allow for circulation and transfer of each tank. For the continuous operations of the fuel cell, biogas storage bags allowed for the produced biogas to be blended on a continuous basis for the fuel cell as needed. Another challenge was to purify the biogas to meet the fuel cell specifications. A biogas conditioning and compression unit reduced the water content and H_2S concentrations of the biogas. Sizing of the components of the conditioning unit was dependent on expected biogas production based on laboratory studies and digester sizing and the fuel cell inlet fuel pressure and flow requirements. A supplemental gas supply was needed to meet the minimum fuel cell feed rate.

This project demonstrated the integration of several innovative technologies in a marine industrial environment and supported the MDOT MPA's commitment to the environment by improving water quality, reducing air emissions, and incorporating alternative energy sources. The results from this project will provide researchers, engineers, and large-scale system designers information needed for future algal flow-way, digester, and fuel cell projects.

Major funding was provided by the U.S. Department of Transportation Maritime Administration through the Maritime Environmental and Technical Assistance (META) program, with support from the MDOT MPA.

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ABBREVIATIONS

AC	alternative current
amp	ampere
Anchor QEA	Anchor QEA, LLC
Atrex Energy	Atrex Energy, Inc.
Biohabitats	Biohabitats, Inc.
BMP	biochemical methane potential
CH_4	methane
CO_2	carbon dioxide
d	day
DC	direct current
demonstration project	Integrated Algal Flow-Way, Digester, and Fuel Cell Demonstration Project
DMT	Dundalk Marine Terminal
ft^3	cubic foot
gal	gallon
g DW/m^2/day	grams dry weight per square meter per day
H_2S	hydrogen sulfide
HDPE	high-density polyethylene
HP	horsepower
HydroMentia	HydroMentia Technologies, LLC
ISR	inoculum:substrate ratio
kg	kilogram
kg/L	kilograms per liter
L	liter
L/kg	liters per kilogram
L/L	liters per liter
L/min	liters per minute
m	meter
m^2	square meter
m^3	cubic meter
MARAD	U.S. Department of Transportation Maritime Administration
MDOT MPA	Maryland Department of Transportation Maryland Port Administration
MES	Maryland Environmental Service
MGD	million gallons per day
mL	milliliter
ppm	parts per million

ppmv	part per million by volume
psig	pounds per square inch gauge
RFP	request for proposal
Spectrum	Spectrum Environmental Sciences, Inc.
TAI Engineering	Tourgee & Associates, Inc.
TS	total solids
UMD	University of Maryland
USDA BARC	U.S. Department of Agriculture Beltsville Agricultural Research Center
VS	volatile solid
W	watt

1 Introduction

The U.S. Department of Transportation Maritime Administration (MARAD) and Maryland Department of Transportation Maryland Port Administration (MDOT MPA), through a cooperative agreement, provided funding for the Integrated Algal Flow-Way, Digester, and Fuel Cell Demonstration Project (demonstration project) at Dundalk Marine Terminal (DMT) in Baltimore, Maryland. This demonstration project is the first of its kind to link an algal flow-way[1] with an algal digester that produces biogas to fuel a fuel cell. The fuel cell provides power for lights at the site and a small flow-way recirculation pump. This project successfully demonstrated the use of innovative technologies in a marine industrial environment and supported MDOT MPA's commitment to the environment to improve water quality, reduce air emissions, and incorporate alternative energy sources.

1.1 Project Concept and Schedule

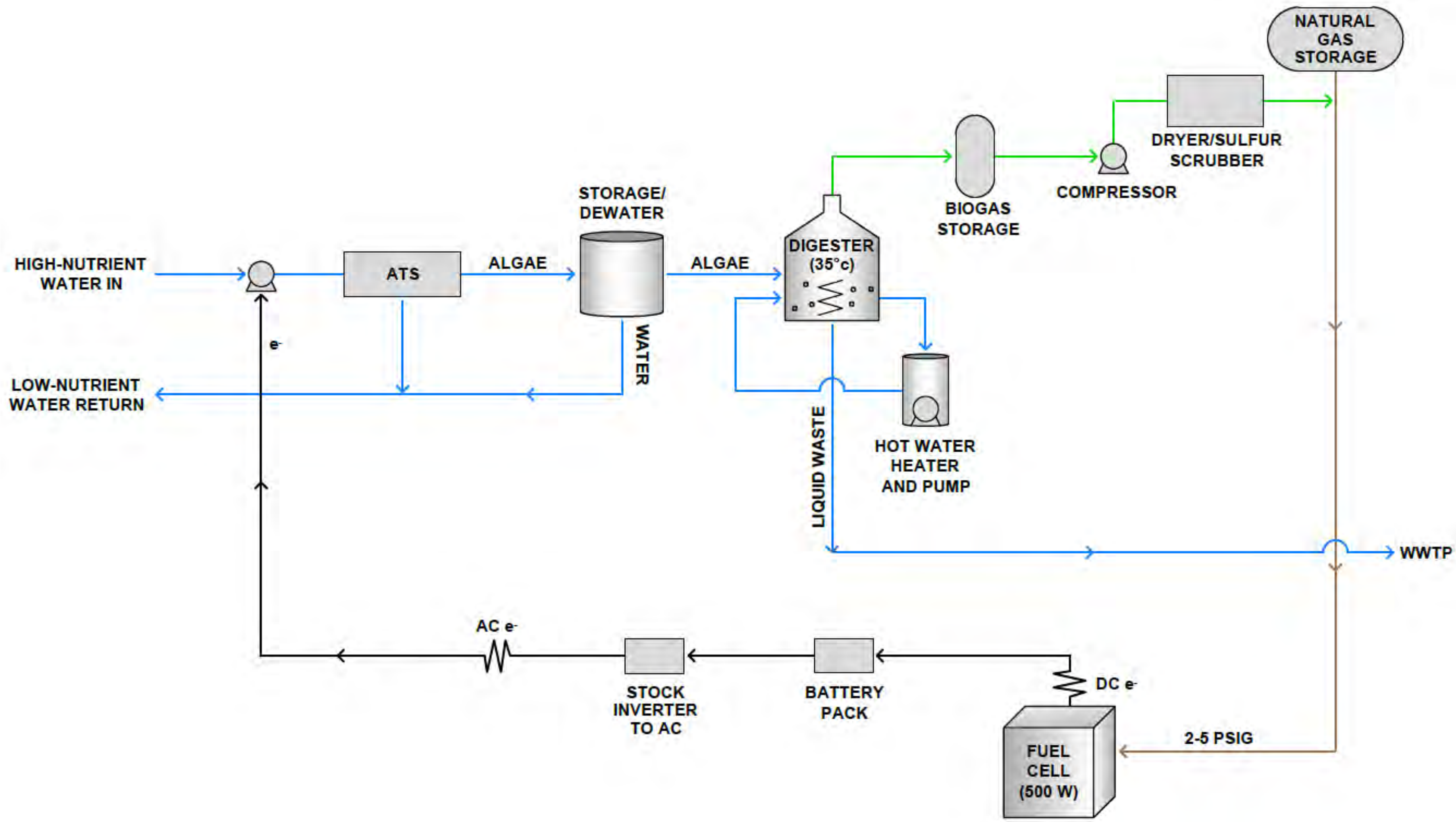
This project was designed to demonstrate the ability to produce electricity through a series of steps, starting with algae already being grown at the site as feedstock to an algal digester. The algal flow-way has been tested at MDOT MPA facilities for several years, demonstrating the ability to remove nutrients from Patapsco River surface waters (Selby et al. 2016).

In the demonstration project, harvested algae from the algal flow-way is fed through a series of three digesters—small, greenhouse-like structures with internal sealed bags—where microorganisms breakdown the algae and produce biogas. The generated biogas supplements natural gas as fuel to a fuel cell that produces electricity. Ideally, the electricity generated from the fuel cell would power the flow-way water intake pump, thereby reducing the energy footprint of the demonstration project and moving towards a completely sustainable system. However, the physical size of the algal flow-way limits biogas production, and the lowest wattage of a commercially available fuel cell (i.e., 500 watts [W]) was undersized to run the flow-way water intake pump. Instead, area lights and a small recirculation pump were powered by the fuel cell.

Figure 1-1 illustrates the demonstration project team's conceptual model of the integrated system. The demonstration project team consisted of individuals from MARAD, MDOT MPA, Maryland Environmental Service (MES), Anchor QEA, LLC (Anchor QEA), University of Maryland (UMD), and Biohabitats, Inc. (Biohabitats).

[1] Algal flow-ways are inclined (typically 1 to 2 degrees) systems designed to improve water quality by using natural algal assemblages that colonize on screens and assimilate nutrients from the overlying water into the algal biomass (Bott et al. 2015). The algae is then harvested, typically once every 7 to 14 days.

Figure 1-1
Conceptual Model of the Integrated System



The demonstration project was divided into two phases, allowing results from Phase 1 to inform the design, cost, and schedule of Phase 2. Phase 1 focused on laboratory-based studies to characterize the biogas produced from site-grown algae, estimate potential biogas production rates, and design the algal digester. Phase 2 of the demonstration project included the design, procurement, installation, testing, and operations of each of the components of the demonstration project and the integration of the components into an operating system. Integrating the operating system required addressing several operational and engineering elements that would move the algal mass from the flow-way through the digesters, separate and collect the biogas in an external storage system, remove water and hydrogen sulfide (H_2S) from the biogas, and compress the biogas to an appropriate pressure to blend with natural gas as feed to the fuel cell. The fuel cell was designed to include an inverter to provide the conversion from direct current (DC) to alternating current (AC) and a battery bank to store the generated electricity.

Funded in 2016 by MARAD with support from MDOT MPA, the demonstration project started in September 2016 with the laboratory studies. Design, procurement, and construction of the field components began in 2017, and operations ran through the first week of December 2017. Data analyses and documentation of results, including reporting, continued through the first quarter of 2018.

Figure 1-2 illustrates the initial project schedule, which was designed to take advantage of the prime growing season during the summer months. However, the initial project schedule was revised for the following reasons: 1) the Notice to Proceed for the demonstration project was delayed from July to September 2016 to facilitate contracting and grant administration and 2) identification of potential design/build firms for the gas conditioning unit and fuel cell took longer than expected. A no-cost, increased schedule extension was requested on April 20, 2017, and granted on April 24, 2017. The revised schedule reflected the start-up of the non-flow-way components in August 2017.

The revised schedule is shown in Figure 1-3. The revised schedule was met with one exception: the demonstration project team requested and received an extension of the start-up and testing period by 1 month, which extended operations into December 2017.

Figure 1-2
Initial Project Schedule

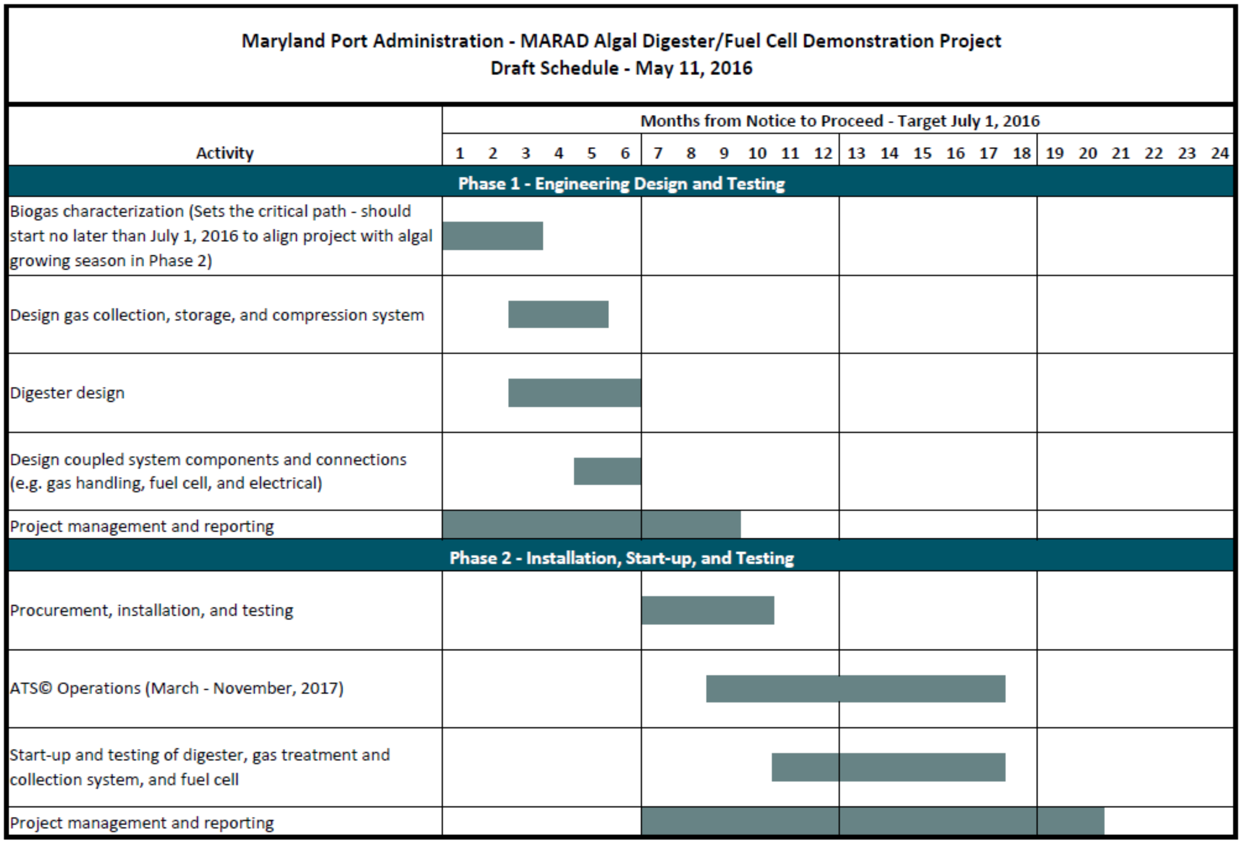
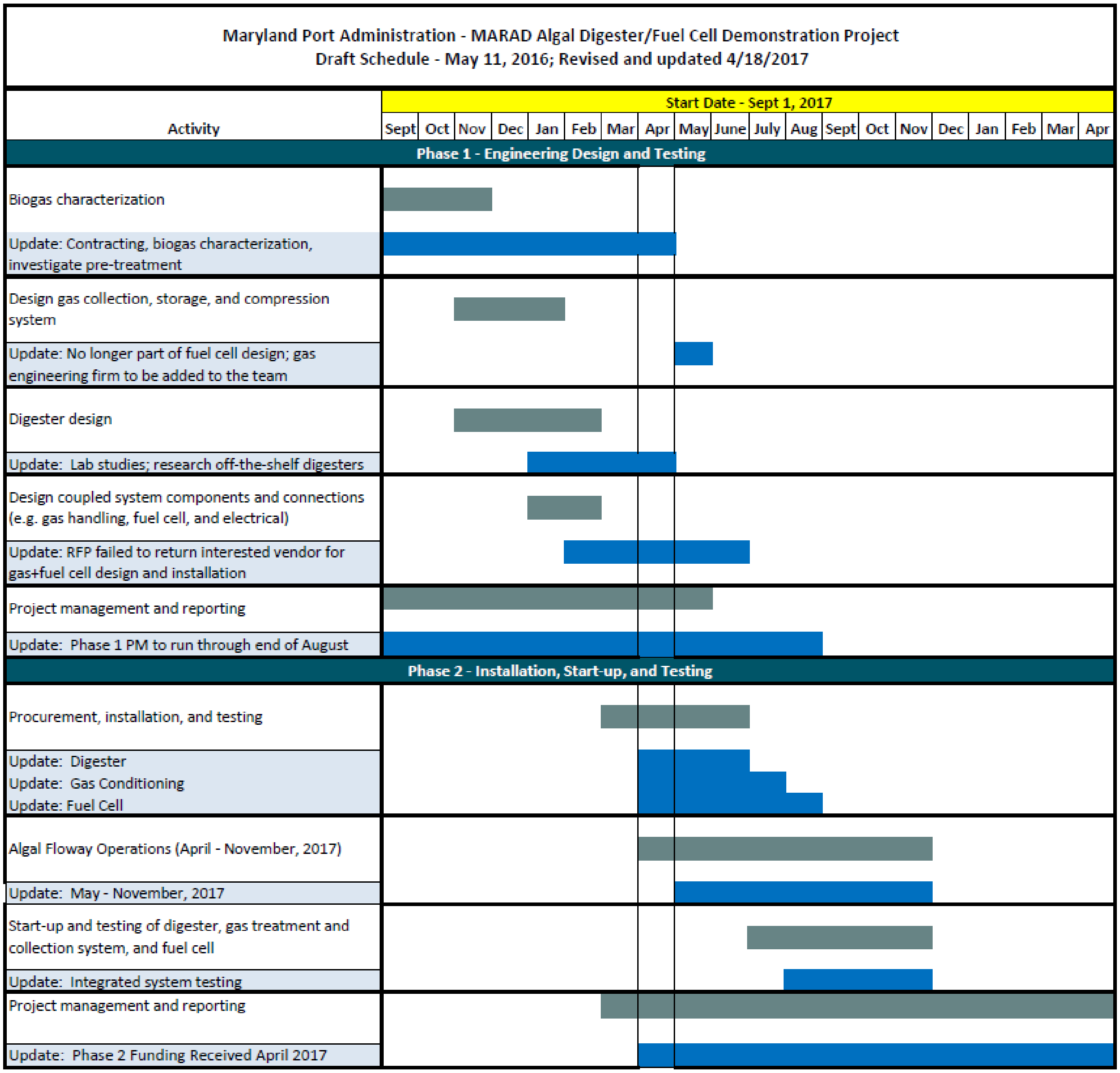


Figure 1-3
Revised Project Schedule



1.2 Existing Algal Flow-Way

An experimental algal flow-way was constructed at DMT in the summer of 2013 to assess the potential of this technology in mitigating nutrient and sediment runoff impacts from paved surfaces at the Port of Baltimore by removing nutrient and sediment from the Patapsco River (Selby et al. 2016). Each year from 2013 to 2016, water was pumped out of the Patapsco River and discharged to a runway (i.e., 61 to 100 meters [m] long and 2 m wide) that consisted of plastic sheeting covered by a screen. Tipping buckets were used to pulse the flow of water onto the runway in order to stimulate algal growth (Selby et al. 2016). The algae was manually harvested from the runway by scraping algal biomass off the screen into a sump located at the end of the flow-way. The algae and water in the sump were then vacuumed into a large tank truck. The algal mass from the flow-way at DMT was delivered to a drying pit and allowed to air-dry by evaporation. Dried solids were collected, weighed, and disposed of in a local landfill periodically. Water from the flow-way was returned to the Patapsco River.

Algal productivity rates and algal assemblage types from the experimental algal flow-way were studied from 2013 through 2016 (Smith et al. 2013; Smith et al. 2016; Selby et al. 2016). Average productivity rates—measured in grams dry weight per square meter per day (g DW/m^2/day)—from these studies of algae from the flow-way as well as 2017 operations of the flow-way provided the basis of design for the integrated system. Results from 2017 operations of the flow-way are provided in Appendix A.

1.3 Project Objectives

The use of fuel cells has been limited in industrial or marine environments largely due to the lack of availability of fuel, such as hydrogen or natural gas; however, by producing biogas on site for fuel provides opportunities for fuel cell deployment at waterfront facilities. This demonstration project addresses the feasibility of coupling an algal flow-way, algal digester, a biogas collection and storage system, and a fuel cell for continuous operations and the ability to run a fuel cell relatively maintenance-free using biogas feedstock produced on site at DMT. Coupling each of the technologies into an operational process and testing and operating individual unit operations were the objectives of the demonstration project. The key components needed to achieve these objectives were as follows:

- Characterization of biogas from site-grown algal assemblages
- Design and procurement of appropriately sized algal digesters
- Engineering and design of biomass handling system from the flow-way to the digesters
- Collection, storage, conditioning, and compression of biogas
- Design, procurement, and installation of a gas feed system to the fuel cell
- Engineering, design, and testing of a fuel cell
- Operations and testing of the integration system while defining operational parameters and constraints

Each of these key components was completed and the objectives of the demonstration project were successfully met.

1.4 Report Organization

This report focuses on the research, design, procurement, and operations of the integrated system. Section 2 provides a summary of the biogas characterization and digester investigations completed in the laboratory (i.e., a full report on those activities is provided in Appendix B). Section 3 presents the conceptual process and site model, design approach and parameters for each component, and design approach for integrating the individual process components into the system. Section 4 reviews the start-up and operations of the system, which began in May 2017 with the algal flow-way operations and ended in December 2017. Section 5 provides information on lessons learned, uncertainties and inefficiencies that were identified, recommendations for future studies, and conclusions and insights gained from this demonstration project. Separate reports detailing the algal flow-way productivity in 2017, laboratory studies of biogas production from algal digestion and data analyses and operations of the digesters in the field, standard operating procedures and information sheets, equipment specifications, and data logs are included in Appendices A, B, C, D, and E, respectively.

2 Phase 1: Laboratory Testing

Phase 1 of the demonstration project consisted of laboratory studies to characterize biogas and evaluate biogas production on a bench-scale to inform the pilot-scale digester design. This effort was led by the University of Maryland (Department of Environmental Science and Technology). Initial tests involved batch digestion of algae grown at the DMT algal flow-way. Studies focused on:

- Testing the impact of pre-treatment methods (i.e., level of drying, physical grinding, and chemical addition) on biogas quantity
- Determining biogas quality by measuring constituents in the gas (carbon dioxide [CO_2], H_2S, and methane [CH_4] concentrations) at various times
- Estimating the overall production of biogas possible with digestion operations

Using the results from the batch digestion testing, a second study was conducted to mimic expected field operations (i.e., feeding every 3 days with continuous removal of liquid waste and biogas) and to characterize the liquid waste and biogas produced from the digester. The results from the laboratory studies informed the need for and extent of H_2S removal, biogas storage necessary based on estimated biogas production, and effluent concentrations expected from the digestion process. In addition, based on the laboratory studies, the specifications and operating conditions for the field algal digesters were developed.

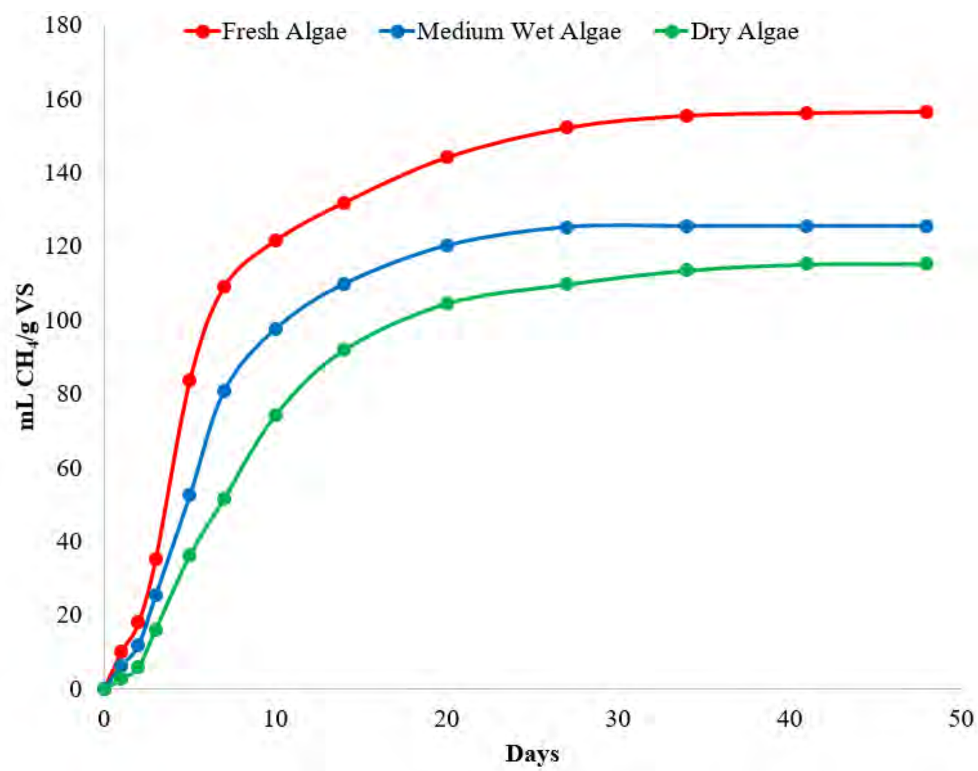
A detailed report is included in Appendix B. A summary of the results of the laboratory testing is provided in Sections 2.1, 2.2, and 2.3.

2.1 Batch Digester Study

A biochemical methane potential (BMP) study is a laboratory-scale batch experiment that measures the amount of CH_4 that can be produced when organic matter (in this case, algae) is anaerobically digested with an inoculum source that contains methanogens and the other groups of bacteria needed to digest the algae. The inoculum (i.e., liquid portion of dairy manure) for the BMP test was sourced from inside an operating anaerobic digester at the U.S. Department of Agriculture Beltsville Agricultural Research Center (USDA BARC). The first BMP test was conducted using three moisture contents of algae harvested from the algal flow-way: one sample of fresh algae (93% moisture content) and two samples of algae that were air-dried in the field for 1 week. The top portion of the algae mass, which was exposed to the sun and wind, had a 22% moisture content after 1 week of drying and was labeled as “dry” algae. The algae underlying the top layer had a moisture content of 62% and was labeled as “medium wet” algae. The first BMP study was completed on December 11, 2016, after 60 days of algal digestion in the laboratory.

The results showed that CH_4 production was most efficient for fresh algae, followed by medium wet and dry algae, on a per gram of volatile solids (VS) basis[2] (Figure 2-1). In terms of the total amount of CH_4 produced per gram of algae, which gives the total energy production possible based on the algae feed, dry algae and medium wet algae produced biogas with higher total CH_4 content than fresh algae (Figure 2-2). However, based on expected operations at the demonstration unit in the field, the demonstration project team decided that fresh algae, with a total solids (TS) content of 6% to 10%, should be used in the field algal digesters to eliminate the drying step and reduce potential clogging in the feed to the field digester.

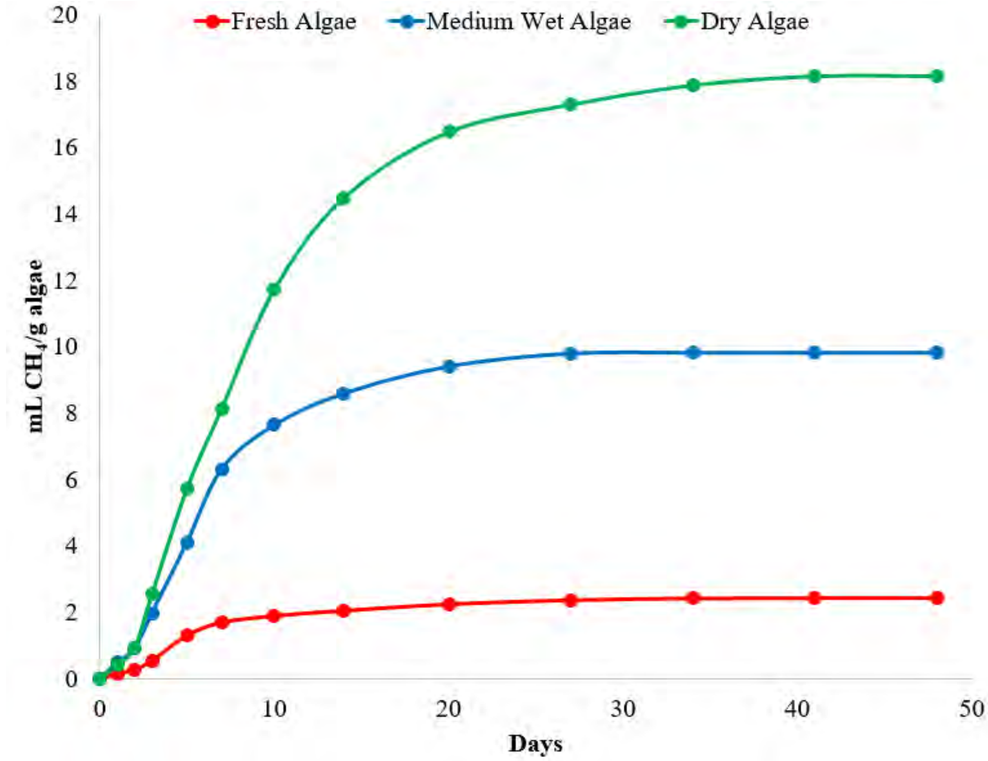
Figure 2-1
Cumulative Methane Production Per Gram of Volatile Solids During Batch Digestion of Algae at Three Moisture Contents



Note: Moisture contents of algae: 93% (fresh algae), 62% (medium wet algae), and 22% (dry algae)
Source: Lansing and Witarsa 2016

[2] Normalization to VS relates how efficiently the organic matter (i.e., VS) in the algae is converted into energy (e.g., CH_4).

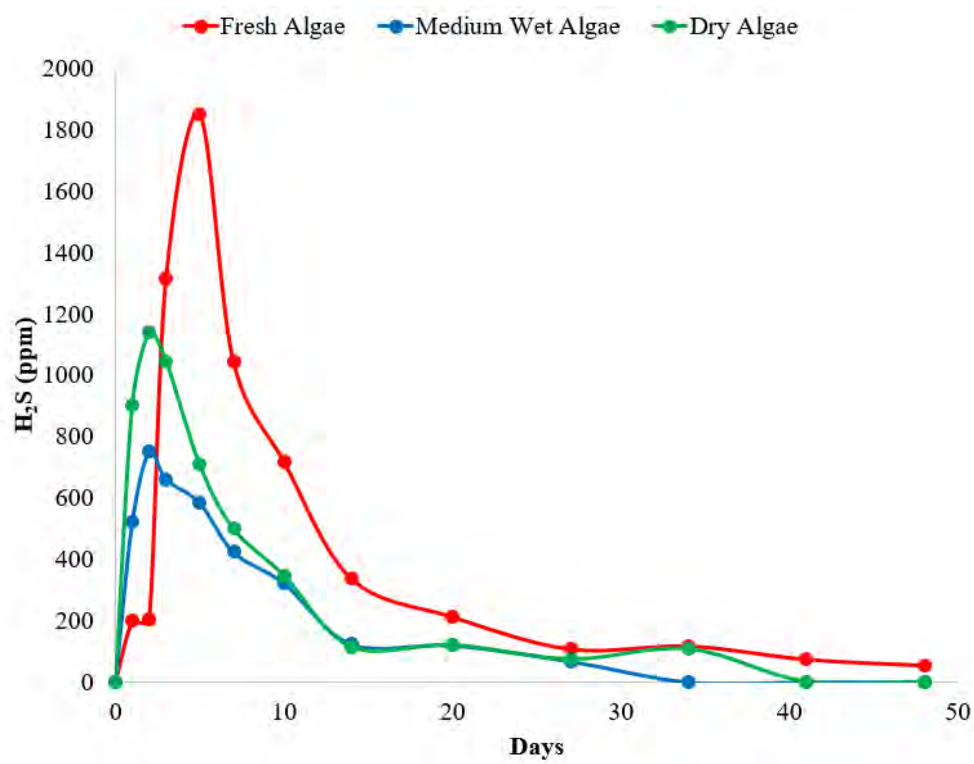
Figure 2-2
Cumulative Methane Production Per Gram of Algae Introduced During Batch Digestion of Algae at Three Moisture Contents



Note: Moisture contents of algae: 93% (fresh algae), 62% (medium wet algae), and 22% (dry algae)
Source: Lansing and Witarsa 2016

The H_2S production during the BMP test was monitored, with concentrations ranging from below detection limit (i.e., approximately 15 parts per million [ppm]) to 1,850 ppm in the fresh algae digestion. The algae with other moisture contents (medium wet and dry) produced lower H_2S levels that ranged from below detection limit to 750 ppm in the medium wet algae and 1,140 ppm in the dry algae treatment (Figure 2-3).

Figure 2-3
Hydrogen Sulfide Concentration in Biogas During Batch Digestion of Algae at Three Moisture Contents



Note: Moisture contents of algae: 93% (fresh algae), 62% (medium wet algae), and 22% (dry algae)
Source: Lansing and Witarsa 2016

2.2 Continuous Digestion Reactor Study

The objective of the continuous digestion reactor study was to quantify H_2S and CH_4 production when fresh algae are anaerobically digested in a continuous system (Lansing and Witarsa 2017a). Using recommendations based on the first BMP test (e.g., fresh algae and targeted solids content of 10%), the continuous digester reactor study employed a digester feeding regime closely following expected operations in the field.

Three continuous reactors (2 liters [L] each, with a working volume of 1.5 L) were constructed in the laboratory (Figure 2-4).

Figure 2-4
Laboratory Continuous Reactor and Multi-Foil Bag to Collect Biogas

Source: Lansing and Witarsa 2017a

Inoculum, obtained from the USDA BARC, was loaded and incubated in the reactors for 2 weeks to remove organic matter and sulfates, allowing for better differentiation between CH_4 and H_2S production from the inoculum and from the algae. Following inoculum incubation, algae[3] was loaded in a 2:1 inoculum to substrate ratio (ISR) based on VS. Small multi-foil bags were attached to the reactors to collect the biogas. Algae was then fed three times per week (i.e., Monday, Wednesday, and Friday), with a retention time of 20 days. The continuous reactors were run for 63 days.

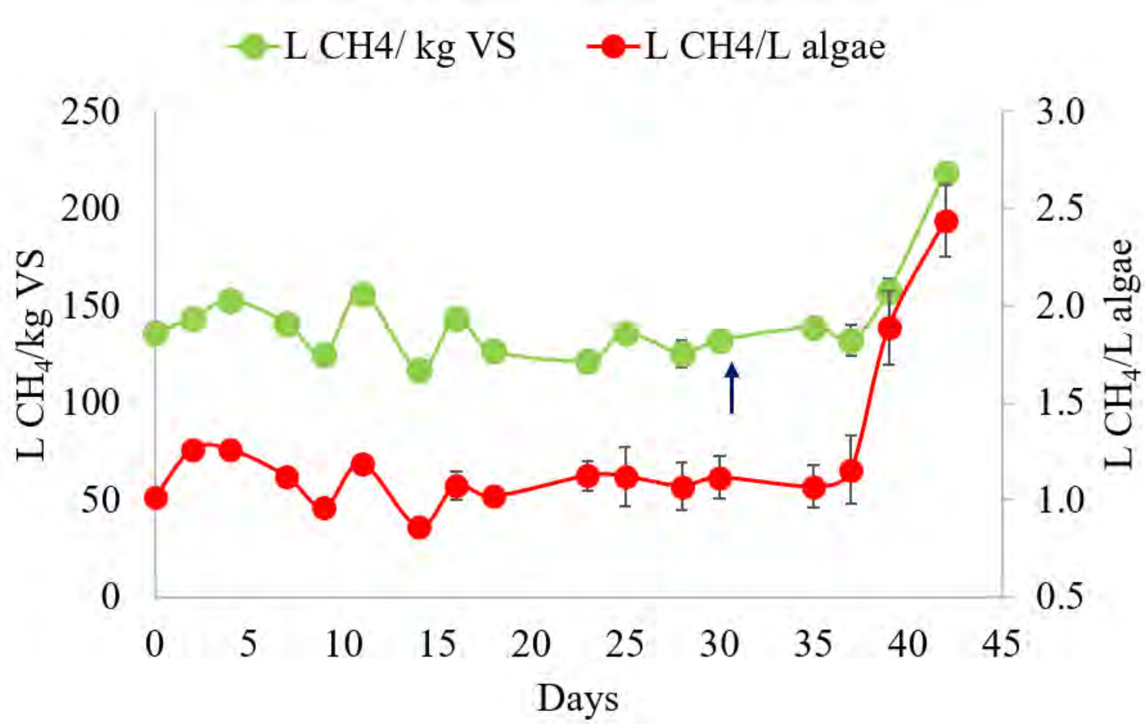
The algae fed to the reactors had a TS and VS of 6.30% and 1.24%, respectively. The results for the continuous reactors showed that average CH_4 content over 37 days of stable biogas production was 62.2%, while average H_2S concentration was 438 ppm, with a maximum H_2S value of 1,400 ppm observed for one of the reactors. On Day 37, a different algae feed batch (TS and VS of 7.28% and 1.77%, respectively) had to be introduced into the reactors due to exhaustion of the first batch of

[3] Since the total solids content in fresh algae collected over a 3-month period ranged from 2 to 7%, a settling and decanting process was developed in the laboratory to achieve the desired total solids content of 6 to 10%.

algae. The average CH_4 content over 5 days was similar at 62.8%, but the H_2S level was below detection limit over this period.

The average CH_4 produced by the continuous reactors was 135 L per kilogram (kg) VS and 1.09 L/L of algae over the 37-day period (See Figure 2-5), but this value increased to 188 L/kg VS and 2.16 L/L algae when the new feed was introduced.

Figure 2-5
Methane Production Per Kilogram of Volatile Solids and Per Liter of Algae for the Continuous Reactors



Note: The arrow refers to the introduction of new algae feed.
Source: Lansing and Witarsa 2017a

2.3 Results Influencing Design of the Algal Digesters

The laboratory-based studies provided the basis for the sizing, design, and operating conditions for the digesters in the integrated system at DMT (Section 2.1 and 2.2). The batch digester study demonstrated the ability to digest wet or fresh algae, which eliminated the following:

- Need for drying algae after harvest from the flow-way
- Extra step in biomass handling between the flow-way and decant tank

Additional pretreatment of the algae was not incorporated into the integrated unit at DMT for the following reasons:

- Efficiency of operations
- The continuous digestion reactor study indicated an efficient digestion of wet algae, producing low concentrations of H_2S in the biogas and a CH_4 content above 60%

As shown in Figures 2-1 and 2-2, the suggested retention time for algal digestion is 20 days, since this was when at least 90% of the total CH_4 was produced by the fresh algae. This result provided a target of 20 days of residence time for sizing the field digesters. The continuous digestion reactor study provided the operating parameters for field digester design and specifically the ISR for start-up of the field digesters. In addition, the measurement of H_2S in the laboratory provided valuable data for the design of the biogas conditioning and compression unit, since the maximum H_2S concentration allowable in the fuel into the fuel cell is 60 ppm by volume during normal operations.

Results of these studies were at presented at the annual meeting of the American Ecological Engineering Society in Athens, Georgia, in May 2017 (Witarsa et al. 2017; Maile-Moskowitz et al. 2017).

3 Phase 2: Design, Procurement, and Construction

Sizing and design of the operating system components (harvest and decant tanks, pumps, algal digesters, biogas storage, biogas conditioning and compression unit, and fuel cell) were constrained by the following: 1) flow-way algal production rate, 2) estimated biogas production rate, and 3) commercially available fuel cells. Based on laboratory results from Phase 1 and flow-way algal production rates from the demonstration unit flow-way at DMT obtained in previous years of operation, specifications for the algal digesters and biogas storage bags were developed. The remaining components were scoped and sized based on anticipated operations and fuel requirements for the lowest wattage, commercially available fuel cell.

Procurement of equipment was managed through requests for proposals (RFPs) as well as direct purchase for lower cost components.

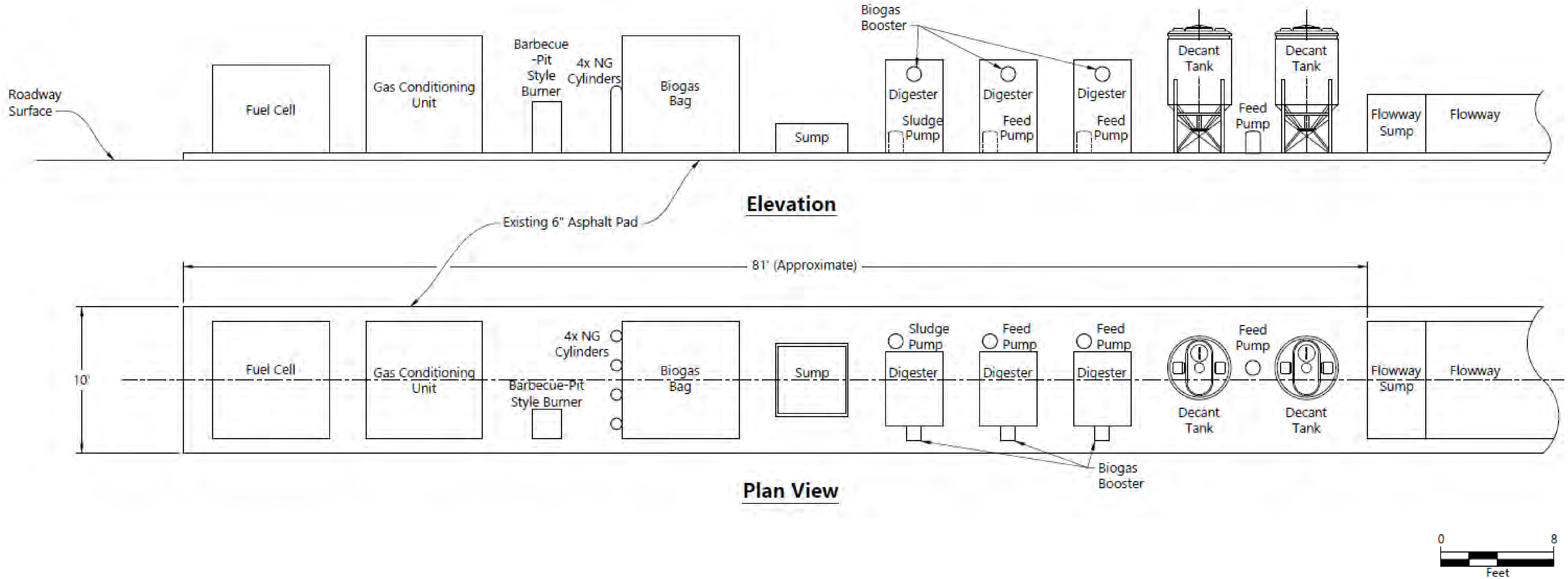
The following sections discuss the design basis, equipment specifications, and installation of each of the operating system components.

3.1 Site Layout and Design Challenges

The site layout was developed to take advantage of the physical space available at the end of the existing flow-way at DMT. As illustrated in Figure 3-1, the process followed sequentially from the flow-way (shown on the right) to the fuel cell (shown on the left).

One of the challenges in the system's design was integrating the weekly, batch-type algae harvest into a semi-continuous algae feed (Monday, Wednesday, and Friday) to the digesters and continuous operation of the fuel cell. This integration required feed tanks that could hold at least a week's supply of algae for the digester and biogas storage bags to store and supply biogas to the fuel cell. The biogas requires treatment to reduce the water content and H_2S concentrations to meet the fuel cell specifications for incoming fuel. A biogas conditioning and compression unit is shown in Figure 3-1 and is located between the biogas storage shed and the fuel cell. Sizing the biogas conditioning unit components depended on expected biogas throughput and the fuel cell inlet fuel pressure and flow requirements.

Figure 3-1
Conceptual Site Layout



Source: Anchor QEA, MDOT MPA, and MES Collaborative Design

3.2 Algal Flow-Way Operations and Modifications

The current flow-way is located at DMT and treats surface water from the Patapsco River. The headworks includes two tipping buckets to provide wave action across the surface of the flow-way, which stimulates algal growth (Figure 3-2). Algae attach and grow on the mesh screen atop the surface of the flow-way. On the surface of the flow-way is a mesh screen on which algae attach and grow. Once a week, algae is harvested by manually scraping the algae off the screen and collecting the algae into a sump located at the downstream end of the flow-way. The flow-way is approximately 61 m long by 2 m wide.

Process operations of the flow-way in 2017 were consistent with previous operating conditions, with one exception. The week of August 10, 2017, the existing mesh screen was replaced with 3D screen.[4,5] The screen was approximately 5 m shorter than the length of the flow-way (61 m); however, 56 m was all that was available from the vendor at the time. Algae was not harvested from the flow-way the week of August 17, 2017, to allow for the algae to re-establish on the new mesh. Based on visual observations, the new screen substantially increased the algal growth compared to the previous 2D screen.

A detailed report on flow-way operations and productivity is provided in Appendix A.

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[4] In July, the demonstration project team decided to test and then possibly replace the 2D mesh screen of the algal flow-way with a 3D screen to increase the growth of algae. The new screen arrived the week of July 27, 2017, and a small 8-inch by 8-inch test patch was installed to observe how quickly the algae would re-establish and if a discernable difference in productivity could be seen. Within 1 week, the test patch had significant and greater-density algal growth than the surrounding 2D mesh. The decision was made to shut down the flow-way after harvesting algae the week of August 10, 2017, and replace the entire 2D mesh screen. The timing worked well as the digesters were not scheduled to have inoculum loaded until the week of August 17, 2017, and would run only on inoculum for 2 weeks.

[5] The demonstration project team also discussed whether to replace the dump buckets at the headworks of the flow-way with a different surger system. As a result of these demonstration project team discussions, it was decided that the buckets should not be replaced due to their cost and the expected delivery time.

Figure 3-2
Algal Flow-Way Headworks Operating in October 2017

3.3 Decant and Feed Tanks and Transfer Pump

The demonstration project team discussed biomass handling and the need for decanting harvested algae to achieve 6% to 10% solids in the digester feedstock and determined that a two-tank system should be tested that would allow decanting in the first tank, while the second tank would act as the feed tank to the digesters. In previous years, the harvested material was collected in the sump, vacuumed into a vacuum truck, and transported to the drying pit approximately one-half mile from the flow-way. For this demonstration project, the vacuum truck was used collect the algae and water after the harvest. Plans were to use the truck's pressure system to move the wet-algae mixture from the vacuum truck to the decant tank through the top hatch using a flexible hose.

Based on harvest experience and discussions with the demonstration project team on June 2, 2017, the following information was used in the decant and feed tank sizing and design:

- Maximum harvest from the algal flow-way of 500 gallons (gal)
- Plan to load material to the decant tank through a top-loading hatch and allow material to settle

- Typical biomass settling time of 1 to 2 hours
- Plan to decant overlying water using a submergible pump or side drainage valves located at multiple heights
- Design piping and connections to minimize the potential for clogging by providing for recirculation of each tank and 2-inch piping

3.3.1 Tank and Pump Specifications

Based on the expected harvest volume and the desire to have at least a 1-week algae feedstock supply always available, two 550-gal, conical-bottom, high-density polyethylene (HDPE) tanks were purchased. These tanks were 48 inches in diameter and 86 inches in height and included a 3-inch bottom fitting designed for total drain and an 18-inch manhole at the top. The HDPE construction allowed for visual level observation of the liquid level in the tank. Tank specifications are included in Appendix D. Side valves were installed on the decant tank to allow sampling and decanting of water above the settled biomass after a week of settling time between harvests. To provide flexibility in decanting, three valves (top, middle, and bottom) were installed on the side of the tank based at approximate heights to decant one-fourth to one-half of a week's harvest after settling.

The transfer pump selected was an AMT Model 316A-95 cast iron sewage and trash pump designed for economical handling of solids-laden liquids and slurries. According to the manufacturer, this transfer pump can easily handle liquids containing sewage, stones, sticks, mud, and other solids, up to a maximum of 15% solids. Model 316A-95 has a 3-horsepower (HP) pump with 2-inch suction and discharge outlets. Pump specifications are included in Appendix D. The tank and pump system is shown in Figure 3-3.

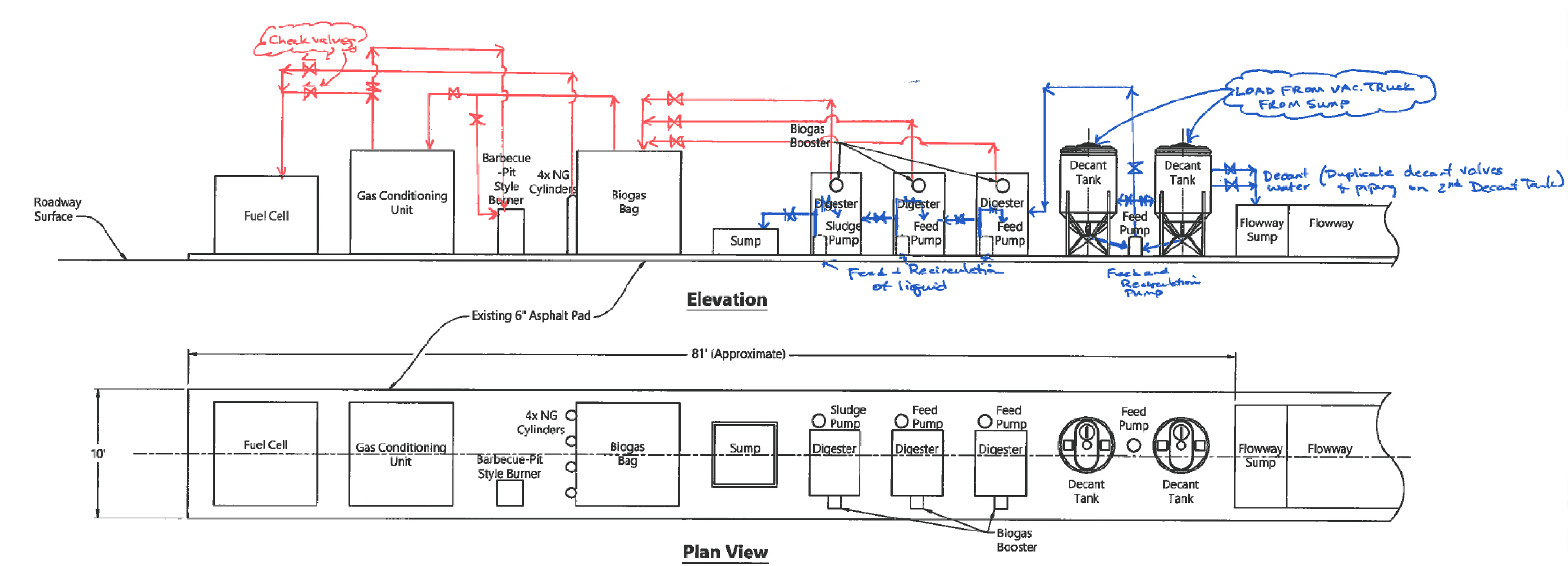
Figure 3-3
Decant and Feed Tanks and Transfer Pump

Note: The decant tank is on the left, with three valves that were installed to provide flexibility in decanting. The feed tank is in the middle, with the transfer pump connecting the two tanks via PVC piping.

3.3.2 Piping

The piping between the decant tank and the digester was designed and installed to allow for recirculation within the decant tank, transferal of biomass from the decant tank to the feed tank, and conveyance to the digester from the feed tank. Figure 3-4 illustrates the design of the piping layout.

Figure 3-4
System Piping



3.4 Algal Digesters and Supporting Equipment

Digester design was based on expected flow-way algal productivity and biogas production rates from the laboratory studies (Section 2). Based on various parameters, including maximum algal productivity measured historically at the flow-way, algal solids content of 10%, and algal density of 1 kg/L, the digester volume needed in the field was calculated to be 3,730 L (Table 3-1). The biogas storage volume needed in the field was calculated to be 4,570 L (Table 3-2); this was based on the maximum algae produced per day, algal solids content of 10%, and expected storage of 7 days.

Table 3-1
Calculation for Digester Volume Needed in the Field

	Quantity	Notes
Range of dry algal productivity in a day	0.008 to 0.071 kg DW/m^2/day	Calculated[1] using values in Smith et al. 2016
Surface area of algal flow-way	122 m^2	Surface area of flow-way (61 m long by 2 m wide)
Total dry algae per day	8.7 kg DW per day	Maximum productivity (0.071 kg) multiplied by surface area of flow-way
Algae with moisture content per day	87 kg wet weight per day	Total dry algae per day per solids content of 10% recommended for digester
Volume of wet algae per day	87 L per day	Assumed density of 1 kg/L
Volume of wet algae in 20 days	1,740 L	Volume of wet algae per day multiplied by 20-day retention time
Digester volume needed	3,730 L	Includes a safety factor of 1.5 and 30% head space

Notes:
Adapted from Lansing and Witarsa 2017b
1. This was calculated from total productivity values reported between June 8, 2014, and December 10, 2014, and between April 30, 2015, and July 9, 2015. The average of the values from the top and middle of the flow-way was taken because the flow-way in 2014 and 2015 was 100 m long, whereas the flow-way was 61 m long during the demonstration project. Total productivity measured in 2016 fell within this range (Selby et al. 2016).

Table 3-2
Calculation for Biogas Storage Bag Volume Needed in the Field

	Quantity	Notes
Maximum algae production per day	87 L wet algae per day	At 10% solids content
Biogas production	5 L biogas per 1 L wet algae	At 10% solids content
Total biogas volume per day	435 L per day	
Volume of biogas in 7 days	3,045 L	Assumed storage of 7 days
Biogas storage bag volume	4,570 L	Includes a safety factor of 1.5

Note:
Adapted from Lansing and Witarsa 2017b

Based on these volumes and research on commercially available designs, purchasing three digesters that would be run in series was recommended. This selection considered cost and ease of construction. An example of the selected digester is shown in Figure 3-5. The first two digesters each hold 1.7 cubic meters (m^3) liquid volume with 2 m^3 gas volume. The third digester holds 0.5 m^3 liquid volume with 0.7 m^3 gas volume. Accessories ordered with the digesters included the following: biogas pump, biogas desulfurization unit, biogas dehydrator, biogas stove, digester recirculation pumps, six electrical heating pads, and three external 2 m^3 biogas storage bags. The digesters and accessories were ordered on May 23, 2017, and shipped from Shenzhen, China, to Baltimore, Maryland, on May 29, 2017. The shipment arrived at DMT on July 14, 2017. Construction of the digesters began the week of July 17, 2017, and was completed the week of July 24, 2017. Piping, electrical, and gas tubing were installed between July 31 and August 7, 2017.

Figure 3-5
Puxin Anaerobic Digester

Photograph courtesy of Shenzhen Puxin Technology Co. Ltd (Puxin 2018)

The digesters were designed to maintain a constant liquid level with feed into one side of the digester and discharge at the opposite side. In Figure 3-5, the discharge is shown with a recirculation line and pump returning flow to the inlet. At the same height as the recycle line feeding into the front of the digester, an opening is shown on the discharge pipe that allows solids to leave the digester (overflow). In the system assembled at DMT, this overflow was a gravity flow feed to the next digester in the series. Effluent from the third digester in the series at DMT overflowed into an open tank, which was emptied using a vacuum truck once a week and disposed of through the terminal sewer system. The configuration of the three digesters and effluent receiving tank are shown in Figure 3-6. More details on the design of the digesters are included in Appendix B.

Figure 3-6
Three Algal Digesters and Open Digester Effluent Receiving Tank

Piping (e.g., plastic tubing) was installed so that gas from individual digesters could be transferred directly to the biogas storage bags through a flow meter, which allowed for measurement of gas production from each of the individual digesters. To create a sufficient quantity of fuel to run the fuel cell, the gas was collected and stored in three external biogas storage bags (Figure 3-7).

Figure 3-7
External Biogas Storage Bags

An Optima7 biogas monitor was purchased to sample the biogas for oxygen, CH_4, H_2S, and CO_2 content. The biogas system piping was designed for multiple sample points such that biogas collected in each digester could be tested for composition prior to transfer to an external storage bag. In addition, the biogas monitor was used manually to check H_2S removal in the biogas conditioning and compression unit. Concentrations of H_2S were measured along the piping from the digesters to the external storage bags; these measurements represent the H_2S concentration in each digester. Measurements were taken during each transfer of biogas from the digesters to the biogas external storage bags and on each day the digesters were fed. Equipment specifications for this monitor are provided in Appendix D. The collected data are provided in Appendix E.

3.5 Biogas Conditioning and Compression Unit

The fuel cell requires the inlet gas to contain less than 60 ppm H_2S and less than 500 ppm water. The inlet gas to the fuel cell must also be pressurized to 2 to 5 pounds per square inch gauge (psig). Therefore, a biogas conditioning and compression unit was designed and constructed to meet the gas conditions required by the fuel cell. The gas engineering firm provided a piping and instrumentation diagram, equipment specifications, instrument specifications, piping specifications, and a sequence of operations to support construction and operations of the unit.

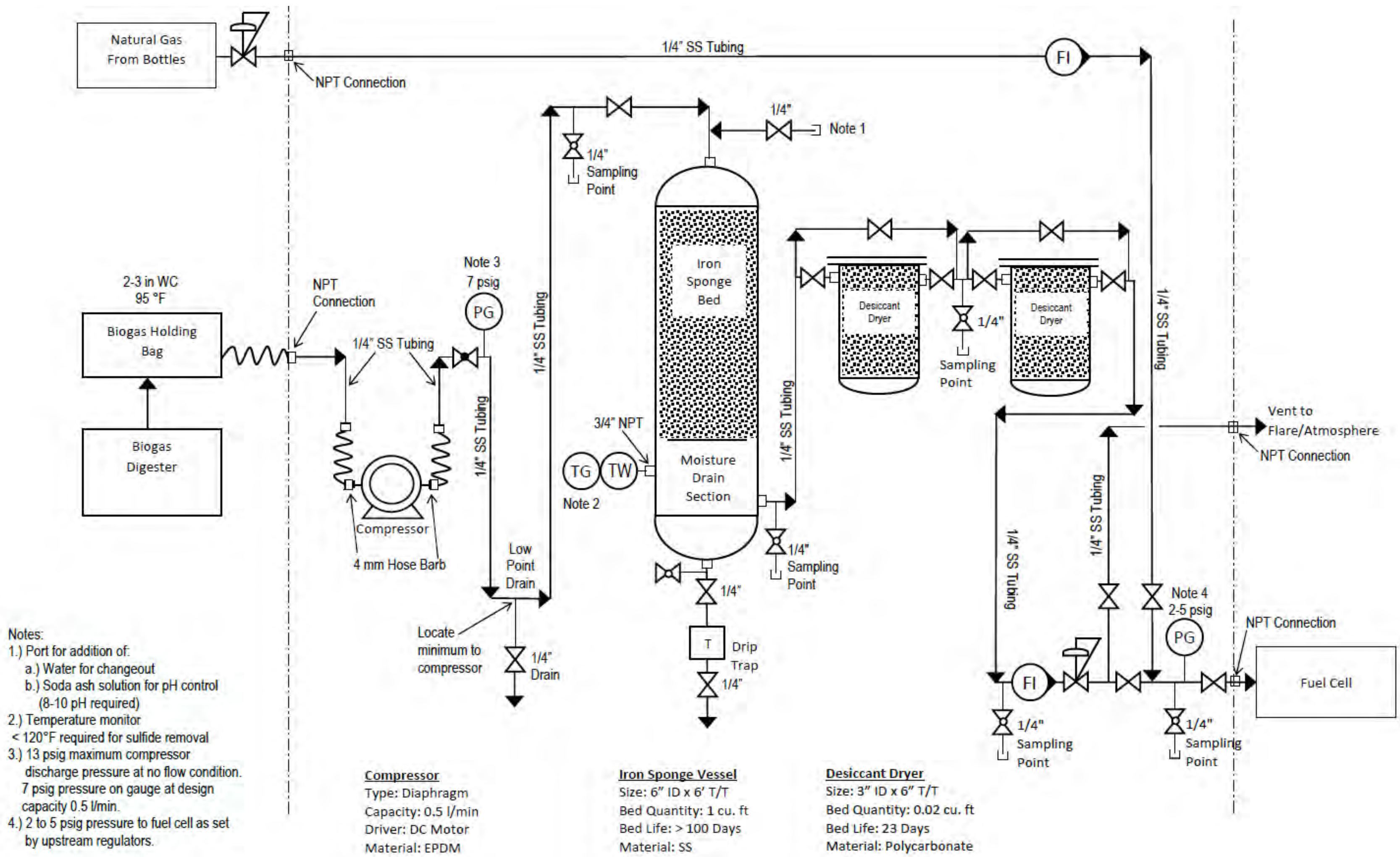
To remove water from the biogas, two desiccant beds were installed with a predicted life at full biogas production of 39 days per bed. The H_2S was removed by passing the biogas through an iron sponge, which reacts with the H_2S to form solid iron sulfide and water.[6] Other design criteria of the gas conditioning and compression unit included the following:

- Maximum biogas throughput at 0.5 L per minute (L/min)
- Ability to blend biogas into a regulated stream of CH_4

The piping and instrumentation diagram developed for the biogas conditioning and compression unit is shown in Figure 3-8.

[6] The reaction of H_2S with the iron sponge creates a system that when exposed to air can result in an exothermic reaction. The iron sponge supplier provided handling procedures for the spent iron sponge; these handling procedures were incorporated into job safety procedures for the system.

Figure 3-8
Biogas Conditioning and Compression Unit Piping and Instrumentation Diagram



The sequence of operations summarized each component of the unit and operation of the unit. The sequence of operations is included in Appendix D. Individual component specifications are included in the Gas Conditioning and Compression Unit Procurement List in Appendix D.

The biogas conditioning and compression unit was constructed and installed in August 2017 and is shown in Figures 3-9 and 3-10.

Figure 3-9
Side View of Biogas Conditioning and Compression Unit

Figure 3-10
Front View of Biogas Conditioning and Compression Unit

3.6 Supplemental Gas Supply

The lowest wattage for a commercially available fuel cell identified by the demonstration project team was 500 W. The fuel consumption of natural gas by the 500-W fuel cell is 3.7 L/min (Atrex Energy 2017). However, after discussions between the fuel cell vendor and the demonstration project team, the minimum flow rate was set at 2 L/min to allow for higher concentrations of biogas in the fuel mix, resulting in a lower output of the fuel cell (i.e., to approximately 300 W). The conceptual design of the system included supplemental gas to the biogas based on initial estimates of the biogas production rates and algal productivity from the flow-way. The gas conditioning and compression unit was designed and calibrated to provide 5% to 25% biogas in the fuel to the fuel cell and the ability to blend in a supplemental gas.

Delivery and cost options were investigated for compressed natural gas and CH_4 in the Baltimore area. Because natural gas vendors in the Baltimore area indicated that the concentration of CH_4 in natural gas can vary significantly, compressed natural gas was not selected as the supplemental fuel. The fuel cell vendor recommended using CH_4 with very low concentrations of other gases, such as CO_2, so that precise fuel-to-air ratios could be set and maintained in the fuel cell. The most economical and reliable supply of high-purity CH_4 was high-pressure size 300 (i.e., also known as T1) gas cylinders available from a local vendor. The fuel cell vendor estimated that an individual gas cylinder of this size would provide approximately 4 days of feed per cylinder at design rates. In coordination with a local gas vendor, a plan was developed to deliver four tanks per week during full biogas production.

Procurement of the CH_4 cylinders was challenging, as the local vendor failed to meet delivery dates. However, because of close monitoring of the demonstration project's daily status and frequent communications with the vendor, adequate CH_4 cylinders were procured and on-hand throughout the demonstration project. At least two extra cylinders were on site and available at all times. Further, a bracket system was designed and installed to secure a four-cylinder system to the side of the biogas storage bag shed. This bracket system is shown in Figure 3-11.

Figure 3-11
Four-Cylinder Bracket System

Also shown in Figure 3-11 is the pressure regulator (Concoa 526 Series Switchover). Because the fuel cell will shut down after experiencing a 15-second loss of inlet fuel, an automatic switching system is required to change the CH_4 source from empty to full cylinders. The system's design and procurement were based on recommendations from the fuel cell manufacturer. An automatic switching system is used by the fuel cell manufacturer in its laboratory during testing and calibration of fuel cells. The system has two CH_4 cylinders open at a time—when the pressure in those cylinders collectively drops to 50 psig, the regulator automatically switches to the other two cylinders. The empty cylinders are manually replaced with full cylinders that remain on standby for the next cylinder switch.

The system also requires high-pressure hoses and fittings. The equipment specification for the pressure regulator is provided in Appendix D.

3.7 Fuel Cell

A 500 W-fuel cell (Atrex Energy ARP500) was purchased for the demonstration project. This model is part of a line of remote power generators that provides continuous, unattended power for remote or off-grid applications. Using state-of-the-art solid oxide fuel cell technology, these generators use commercially available natural gas (e.g., CH_4) or propane to produce power without external reforming. The remote power generators convert the fuel's energy into direct current (DC) electricity using an electrochemical process. This process does not burn or combust fuel; therefore, the fuel cell only emits small amounts of water vapor and CO_2 (Atrex Energy 2017). The fuel cell constructed for this demonstration project is shown in Figures 3-12 and 3-13.

Figure 3-12
Fuel Cell Under Construction

Photograph courtesy of Atrex Energy

Figure 3-13
Fuel Cell on Site Adjacent to Gas Conditioning and Compression Unit

An inverter and battery bank were included with the fuel cell to provide conversion from DC to alternating current (AC) electricity. This allowed an on-site AC outlet to be used to run external lights and a small (1/4 HP) recirculation pump. The inverter also reduced the fuel cell output to 300 W, which lowered the fuel requirements to the fuel cell, allowing testing of higher concentrations of biogas for longer periods of time before exhausting the stored biogas.

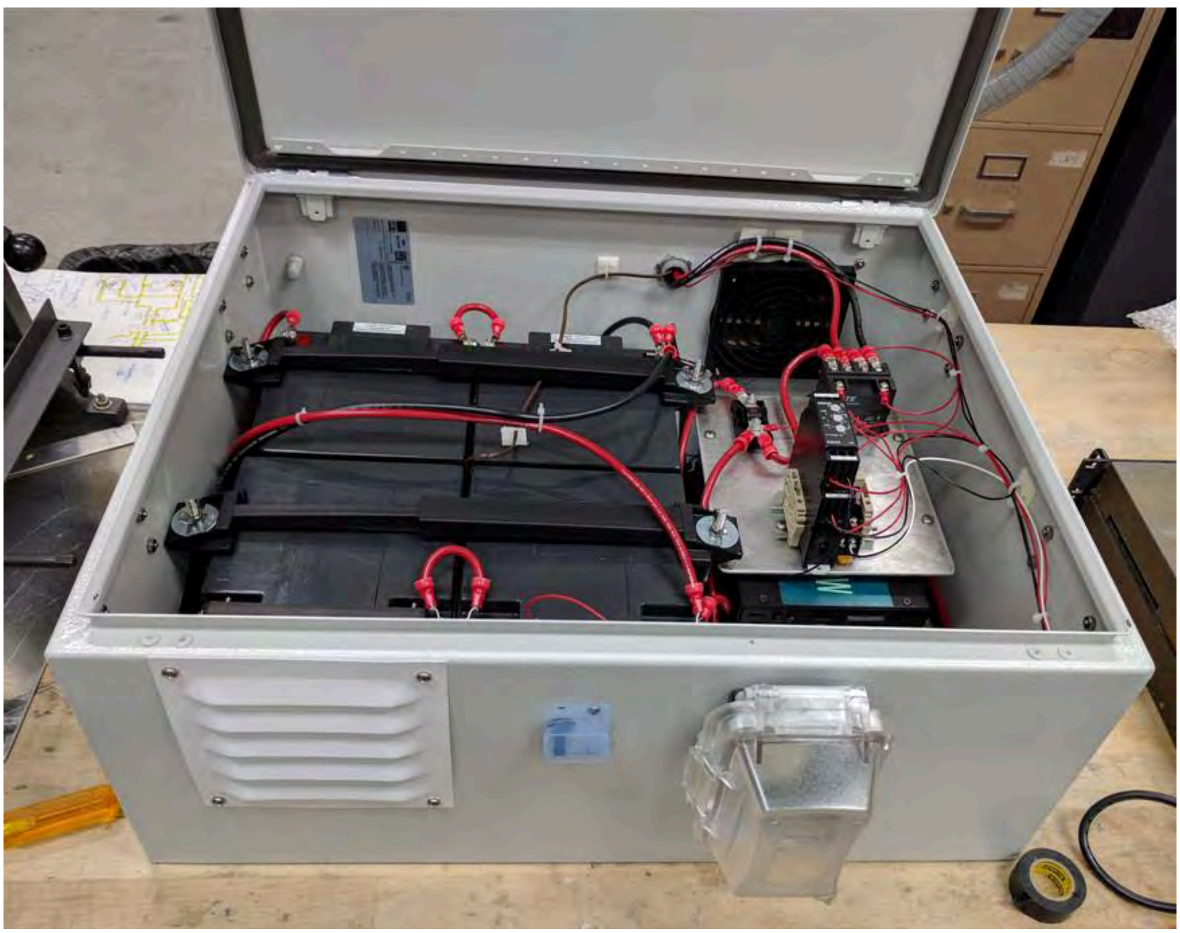
The percentage of biogas in the fuel mix to the fuel cell was calculated to be 15% based on a 300-W output and estimated biogas production rates (Table 3-3).

Table 3-3
Estimation of Percentage of Biogas in Fuel Mix to the Fuel Cell at Steady-State Operations

Parameter	Units	Value	Notes
Biogas production rate	L biogas per day	435	Lansing and Witarsa 2017b
	L biogas per minute	0.30	
Feed rate of fuel mix to fuel cell	L fuel per minute	2	Required minimum rate by manufacturer for 300-W output
Percentage of biogas in fuel mix	%	15%	Calculated by dividing biogas production rate by feed rate of fuel mix to fuel cell and multiplying by 100

The inverter and battery bank providing electrical storage of the energy from the fuel cell are shown in Figure 3-14.

Figure 3-14
Fuel Cell Battery Bank and Inverter Under Construction



Photograph courtesy of Atrex Energy

3.8 Integration of Biogas Conditioning and Compression Unit with Fuel Cell

At a meeting to discuss connecting the biogas conditioning and compression unit to the fuel cell, the following issues were identified and then resolved:

- Fuel cell external pressure regulator is set for 25 to 150 psig
  - Compressor on gas conditioning and compression unit has a maximum of 8 to 10 psig
  - With approval from fuel cell manufacturer, the external pressure regulator was removed
- Relief valve on the manifold is set at 20 psig; fuel cell relief valve is set at 10 psig
  - Installation of a relief valve after the biogas conditioning and compression unit but before the CH_4 tie-in was recommended to provide 10 psig of relief
- Connections between high-pressure CH_4 and low-pressure biogas
  - High-pressure hoses purchased and installed between gas tanks and pressure regulators and after the biogas conditioning and compression unit
  - CH_4 hose connected to the fuel cell feedline after the biogas conditioning and compression unit
- Control of gas blending and flow to the fuel cell: mixing of two gases was controlled at multiple points
  - Compressed biogas at 2 to 5 psig through a rotameter (calibration in the field using the internal fuel cell flow meter and pure CH_4)
  - Compressed CH_4 reduced from high pressure to 2 to 5 psig through the pressure regulator
  - Total gas to fuel cell (internal flow meter calibrated at fuel cell manufacturer's laboratory)

Connection details and operating sequences were reviewed and discussed. Supporting documentation to that discussion is included in Appendix C.

4 Phase 2: Start-Up and Operations

Prior to start-up of the non-flow-way components of the system, the demonstration project team had a one-page flyer of the demonstration project developed. On July 17, 2017, these flyers were distributed to Port of Baltimore tenants and neighbors to inform them of the project. This flyer is included in Appendix C.

4.1 Algal Flow-Way

Start-up of the flow-way began on May 1, 2017. The first harvest occurred on May 18, 2017, with weekly harvest continuing until December 7, 2017. Weekly harvests consisted of shutting down the flow-way water pump at the headworks and allowing the flow-way to drain by gravity. Once water flow slowed or stopped entering the sump located at the end of the flow-way, the outlet of the flow-way was blocked. The algae was manually scraped from the flow-way into the sump. The harvest, consisting of algae and water, was transferred from the sump to a vacuum truck using the suction of the vacuum truck.

On June 2, 2017, the algae was dominated by filamentous algae. Using algae from three harvests (May 18, May 25, and June 15, 2017), the settling of algae and its solids content was investigated after decanting overlying water. The initial solids content of the harvested algae ranged between 2% and 3%. After several hours of settling, the solids content rose to 6% to 9% after decanting the overlying water (Kangas 2017). This decanting study provided the basis for installing a decant tank to hold algae harvested from the flow-way and a second tank to hold the decanted algae prior to being fed into the algal digesters.

The flow-way continued to operate well throughout the summer and fall. The 2D mesh was replaced with the 3D screen (the full length delivered was approximately 5 m shorter than the length of the concrete flow-way). The 3D screen arrived the week of July 24, 2017, and a small 8-inch by 8-inch test patch was installed to observe how quickly the algae would re-establish and to see if a discernable difference in productivity was observed. Within 1 week, the test patch had significant and greater-density algal growth than the surrounding 2D mesh. As a result, the demonstration project team decided to shut down the flow-way after harvesting algae the week of August 7, 2017 and replace the 2D screen with the 3D screen. The timing worked well as the digesters were not scheduled to have inoculum loaded until the week of August 14, 2017 and would run only on inoculum for 2 weeks.

A detailed report on flow-way productivity is provided in Appendix A.

4.2 Decant and Feed Tanks and Pump Operations

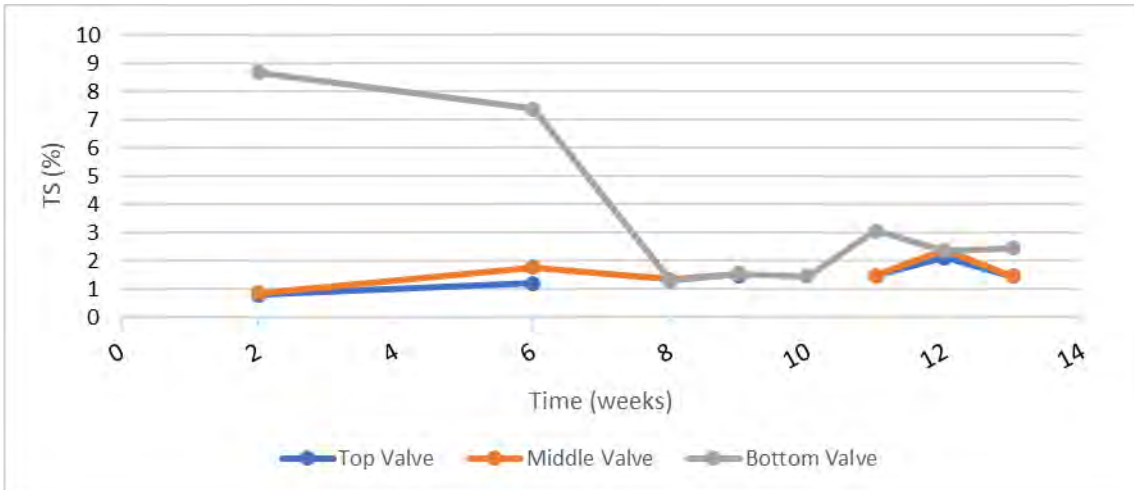
Based on results from biomass settling tests, a two-tank system was designed: 1) decant tank to allow biomass settling and thereby increase the percent solids in the biomass prior to transfer to a digester feed tank and 2) digester feed tank to store the biomass prior to being fed to the digesters. After each week's harvest and transfer of the algae from the sump to the vacuum truck, the algae was pumped out of the vacuum truck. Originally, the plan was to uses the vacuum truck's back pressure to transfer the algae to the decant tank; however, the vacuum truck's back-pressure system was not adequate to move the biomass. Therefore, the digester feed pump was piped to provide the following: 1) transfer from the vacuum truck to the decant tank; 2) recirculation of the decant or feed tank to prevent clogging and promote further settling if needed; and 3) transfer feed from the feed tank to Digester 1 (i.e., the first of three digesters in series).

To achieve a TS content of 6% to 10%, the material in the decant tank was allowed to settle from Thursday (i.e., typical day of harvest) to Monday. Based on previous observations of harvested biomass settling, initially the plan was to visually observe liquid density in the decant tank through its translucent sides to determine the interface between the higher percent solids and overlying water. However, immediately after the first transfer of the biomass to the decant tank, the tank sides became covered with algae and visual observation of a clear liquid layer was not possible. Thus, the standard operating procedure was as follows:

- Settling of the harvested material from Thursday to Monday (or to Friday when low on harvested material)
- Decanting of liquid from the top valve and then the middle valve
- Transferring the remaining decant tank volume to the feed tank via the port at the bottom of the decant tank

The decant process worked well for the first few weeks of operations (i.e., August 25 through September 18, 2017), achieving 7% to 8% TS in the lowest portion of the decant tank. However, as seen in Figure 4-1, less settling occurred after September 18, 2017; TS at the three sampling points along the side of the decant tank ranged from 1.3% to 2.4% from October 22 to October 30, 2017.

Figure 4-1
Percent Total Solids in Decant Tank



Note: Samples were collected at three fixed-height sampling valves. Samples were not always available at the top valve due to varying heights of tank contents.
Source: Lansing and Yarberry 2018

Figure 4-2
View of Algae in Decant Tank on October 4, 2017

With one exception, the feed tank and transfer pump operated as planned throughout the demonstration project. The volume of feedstock to Digester 1 was calculated based on the difference between the levels of the material in the decant tank before and after transfer of material into the digester. The transfer pump seal failed on Friday, September 1, 2017, for unknown reasons (perhaps solids in the feedstock or a bad seal given the short amount of time the pump operated prior to seal failure). A submersible pump was used to continue scheduled feedings to Digester 1 until the transfer pump was replaced on September 17, 2017.

4.3 Algal Digesters

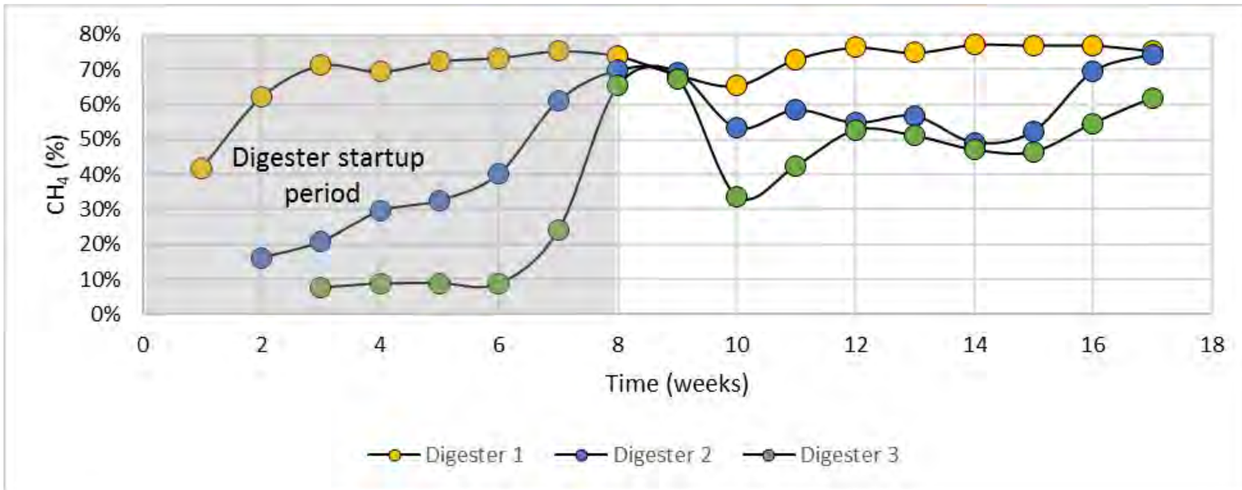
Construction and installation of the digesters was completed the week of August 14, 2017. Leak testing commenced by completely filling the digesters with water so that each digester overflowed into the next, and the third digester overflowed into the effluent receiving tank. This provided gas seals between the inlet and outlet of the digesters. Air was then added to the digesters to test for air tightness; a few minor leaks were noted and repaired. Prior to adding the inoculum, air was removed from each digester using the biogas transfer pump so that only water remained in the interior of the digester. Inoculum from USDA BARC was delivered to the DMT on August 16, 2017 and loaded into the digesters. Overall, the digesters operated as designed; however, the electrical heating pads did not provide adequate heat to keep the digesters above 30°C. This may have been due to the heating pads being installed on the sides instead of underneath the digesters and heat escaping along the sides of the digesters. Additional heating pads were installed on September 18, 2017, and external insulation was added in November 2017. Plugging issues were encountered in November and December in Digester 1's effluent pipe, and it had to be cleaned after every feed event. Digester 2 also developed clogging issues in the effluent line during the last 2 weeks of operations. Additional information about operations of the digesters and a detailed data analysis are provided in Appendix B.

Wet algae was loaded into the digester every Monday, Wednesday, and Friday, with approximately 53.8 gal of algae from the feed tank every Monday and Wednesday and between 75 and 85 gal every Friday to provide enough algae for digestion through the weekend (Lansing 2017). The percent of CH_4 in the biogas was very high for a digester (i.e., greater than the 60% to 65% expected based on laboratory results), and it remained relatively constant throughout the digestion period (Figures 4-3, 4-4, and 4-5). When the digesters were not being heated properly, the loading rate decreased to 25 gal every day and 50 gal on Fridays to keep the system running through the weekend.

At the start of operation on August 16, 2017, inoculum was added to each digester at the following rates: 1,300 L to Digester 1; 450 L to Digester 2, and 50 L to Digester 3. The remaining volumes of the digesters were filled with water.

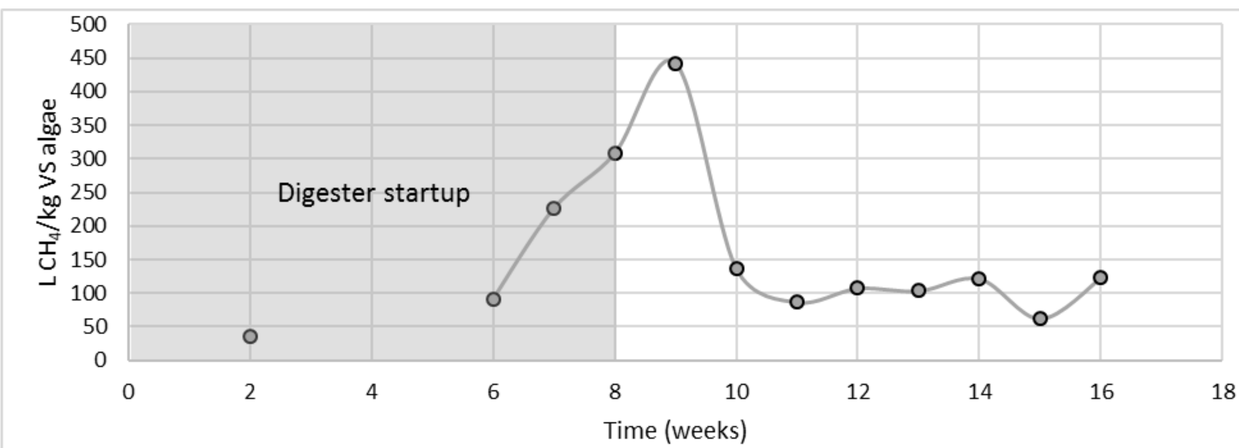
The total weekly H_2S concentration in the biogas did not exceed 3,600 ppm (Figure 4-6). The production of biogas gradually increased until October 3 (Week 8, which is when the digesters reached optimal temperature and additional inoculum was added) with the total biogas production increasing to 1,430 L per week (Figures 4-4 and 4-7). In addition, the CH_4 production (which is calculated from the biogas production multiplied by the percent CH_4 in the biogas) also increased.

Figure 4-3
Percent Methane in Digesters Over Time



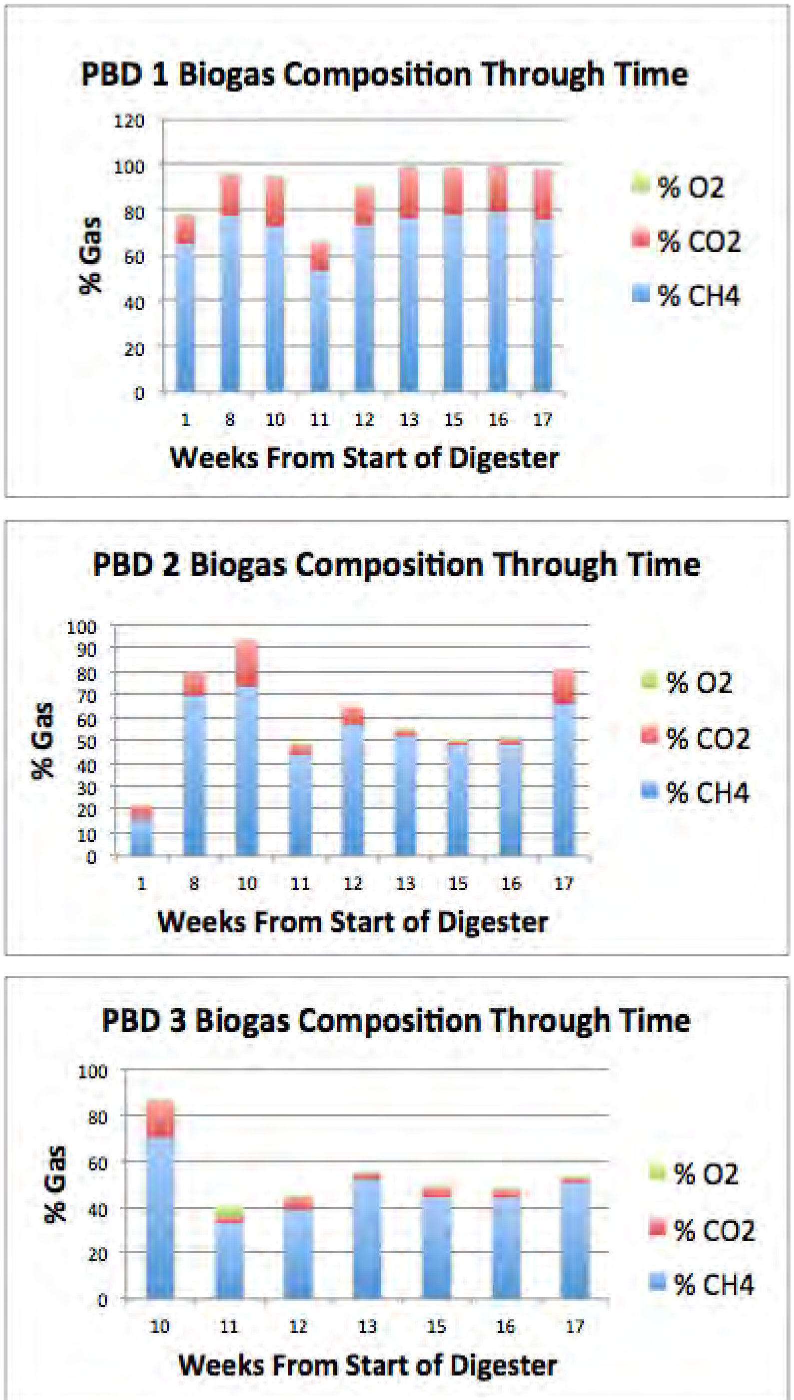
Source: Lansing and Yarberry 2018

Figure 4-4
Total Weekly Methane Production Per Kilogram of Volatile Solids



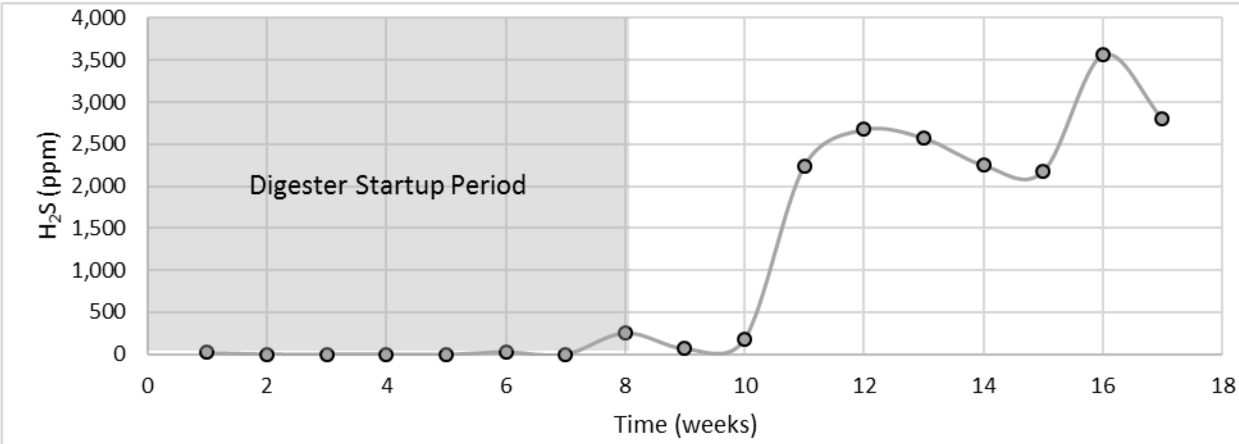
Note: Increases in biogas production are shown as the temperature of the digesters increased and additional inoculum was added.
Source: Lansing and Yarberry 2018

Figure 4-5
Average Percent Methane, Carbon Dioxide, and Oxygen in Biogas from Digesters Over Time



Note: PBD 1 – Digester 1, PBD 2 – Digester 2, PBD 3 – Digester 3; Digester 3 sampling began when algae reached this final digester after a 44-day hydraulic retention time
Source: Lansing 2017

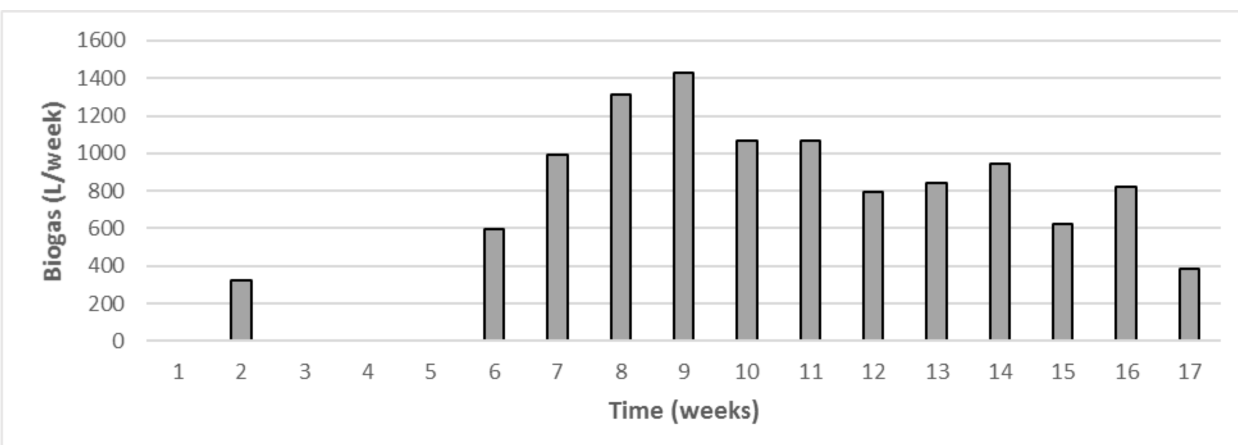
Figure 4-6
Total Weekly H_2S Production in the Algal Digesters



Source: Lansing and Yarberry 2018

It should be noted that the biogas production in the digesters varied over time (Figure 4-7). The start-up phase took approximately 8 weeks; in Week 2, the total biogas produced was 321 L per week. Biogas production during Week 9 was 1,430 L. The digesters maintained production between 625 and 1,067 L per week for the remaining 7 weeks of operation. The total biogas produced during the period of operation was 11,200 L. The total CH_4 produced during the period of operation was 7,500 L, averaging 612 L per week.

Figure 4-7
Total Weekly Biogas Production



Source: Lansing and Yarberry 2018

4.3.1 *Addition of Inoculum*

In addition to the inoculum loading in August 2017 to begin the system processing, an additional 264 gal of inoculum was added into Digester 2 and 66 gal into Digester 3 on October 2, 2017. The inoculum added to the digester was the liquid portion of anaerobically digested cow manure obtained from the USDA BARC. The quantity of CH_4 production appears to have increased substantially since this inoculum was added (Week 8 in Figure 4-7). Other factors—such as adding in heating blankets, installing the plastic cover for each digester, and adding external insulation—seem to have aided in the increase of CH_4 produced in each digester.

4.3.2 *Sampling*

Sample collection from the digester was done bi-monthly on Mondays before the algae was fed into the digesters. Samples were collected from the metal box at the inlet of each digester after the feed pump was turned on for a few seconds so that the algal feed was flowing through Digesters 1, 2, and 3, consecutively. Two samples were collected from the digesters during each sampling trip, with one sample acidified on site to run nutrient tests. The feedstock took about 10 minutes to circulate through the three digesters, making the sampling process take about 10 to 15 minutes. Starting November 6, acidified samples were also collected from Digester 3 and the effluent outlet.

When acidifying the samples on site, approximately 10 milliliters (mL) of 5.25 normal sulfuric acid was used. Beginning on October 2, 2017, samples were collected every week to run TS, VS, chemical oxygen demand, and nutrients and to observe biogas changes more closely. Tests were also conducted for NH_4, volatile fatty acids, carbon to nitrogen ratio, total kjeldahl nitrogen, and total kjeldahl phosphorus.

Detailed data analyses and additional assessment of digester performance are included in Appendix B.

4.4 Biogas Conditioning and Compression Unit

The biogas conditioning and compression unit was delivered to DMT on August 30, 2017. A small diaphragm pump providing compression of the biogas from atmospheric pressure in the external biogas storage bags to 2 to 5 psig was the only component in the system requiring electrical supply. During testing, the diaphragm pump failed, so the back-up pump was installed. A slightly larger back-up pump (rated to 16 psig) was ordered, as this pump is a critical component of the system and a pump failure would shut down the system from the biogas external storage bags to the fuel cell.

During an on-site inspection of the biogas conditioning and compression unit, one of the desiccant units was found to be installed backwards; the desiccant unit was reversed prior to leak testing. The system was tested for leaks using compressed air prior to delivery and again after installation at DMT. Biogas was processed through the unit starting on October 11, 2017. The diaphragm pump provided adequate flow between 5 to 7 psig through the conditioning and compression unit for successful blending with the supplemental CH_4.

The desulfurization unit provided with the digesters was installed, successfully reducing the H_2S in biogas prior to the external biogas storage bags. This allowed the biogas conditioning and compression unit to act primarily as a H_2S polishing and water-removal step. One desiccant bed was replaced after the initial week-long run of the biogas conditioning and compression unit as the bed indicated, by color change, that it was becoming saturated with water.

The biogas conditioning and compression unit operated from October 11 through October 16, 2017, when the stored biogas supply was exhausted. The fuel cell continued to operate on pure CH_4 until additional biogas was collected in the external biogas storage bags. On October 27, 2017, the biogas conditioning and compression unit was brought back online and resumed supplying the fuel cell with a biogas:CH_4 mix. The biogas conditioning and compression unit ran until November 1, 2017, when the biogas external storage bags were again emptied. The final run of the system occurred from November 29 through December 1, 2017, successfully removing water and H_2S from the biogas and compressing the biogas to 5 to 7 psig. Varying concentrations of biogas—5% to 35%—were mixed with CH_4 for fuel cell testing. Manual control of the mix was achieved by controlling the flow of biogas through the biogas conditioning and compression unit's rotameter and of CH_4 through the pressure regulator on the gas manifold.

4.5 Supplemental Gas Supply

Based on the flow-way productivity and the laboratory results for anaerobic digestion, under continuous operations, the expected concentration of biogas in the fuel to the fuel cell was 5% biogas at a fuel cell feed rate of 3.3 L/min. The supplemental fuel, CH_4, was supplied from high-pressure cylinders. After discussions with the fuel cell manufacturer, the fuel cell inverter was set to 300 W, which allowed a lower fuel cell feed rate (2 L/min) and thereby reduced the amount of supplemental gas (methane) in the fuel mix.

The pressure regulator operated as planned and designed. As the CH_4 cylinders approached 50 psig, the regulator automatically switched from empty to full cylinders without interrupting the CH_4 supply to the fuel cell. The empty cylinders were manually replaced with full cylinders on the bracket system. Typically, two cylinders lasted 3 to 5 days.

4.6 Fuel Cell, Inverter, and Battery Bank

Though flow-way algal productivity rates increased due to the installation of the 3D screen, the digester design basis of 71 g DW/m^2/day algal mass was not achieved in October and November 2017 (Appendix A) when the fuel cell was brought online. This may be due to the shorter growing days and cooler fall temperatures in October and November. In addition, the targeted 6% to

10% solids in the digester feedstock was not achieved in the decant tank, resulting in less total biogas production than design estimates (Section 4.2). Therefore, instead of running the fuel cell continuously, fuel cell testing was completed through short runs of 5 to 7 days when enough biogas accumulated in the external biogas storage bags to run at compositions of 5% to 35% biogas in the fuel (enough to the fuel cell for several days at a time).

The fuel cell, inverter, and battery bank were delivered to DMT on August 22, 2017, and placed at the site on September 7, 2017. During this time, multiple conference calls were held to ensure that the biogas conditioning and compression unit and fuel cell fittings matched, adequate pressure controls and relief valves were in place, and flow metering could be achieved using meters on the CH_4 regulators, biogas conditioning and compression unit, and the fuel cell. One of the biggest hurdles was safeguarding the fuel cell if the CH_4 gas regulator failed. The pressure regulator relief value is set at 25 psig; however, the fuel cell needed protection at 10 psig. After exploring options, it was determined that a 10 psig relief value could be added before the fuel cell.

The fuel cell was commissioned on site on September 11 and 12, 2017. The commissioning involved placing the fuel cell on site, installing the fuel cell reactor core, connecting the inverter and battery box, and testing the electrical components and remote sensing capabilities. After commissioning, start-up of the fuel cell was postponed because of delayed delivery of the high-pressure hoses to connect the pressure regulator to the biogas conditioning and compression unit. The hoses arrived on September 14, 2017. Based on an assessment of available stored biogas and the current biogas production rate, the demonstration project team decided to delay the fuel cell's start-up until more stored biogas was available in October 2017.

On October 10, 2017, the fuel cell was started up on CH_4 only. On October 11, 2017, biogas was introduced to the fuel cell at 5% of the total feed, with the remaining 95% being supplemental CH_4. Based on a visual observation of the external biogas storage bags (the first bag was approximately 66% full, and second and third bags were approximately 50% full), the biogas supply was estimated to last approximately 6 days at a 0.3 L of biogas per minute feed rate. The fuel cell was run with the biogas mixture from October 11 through October 16, 2017, at which point the fuel cell fuel was changed to pure CH_4. During this first week of fuel cell operations, the biogas proportion in the fuel mix ranged from 5% to 20%.

The fuel cell manufacturer supported the start-up and operations of the fuel cell on site and remotely. Prior to start-up of the fuel cell, additional calibration of the biogas conditioning and compression unit rotameter was necessary as the rotameter was originally calibrated using air. The gas properties of biogas would have caused a shift in the air-based calibration. Therefore, the rotameter was recalibrated using bottled CH_4 and the internal fuel cell flow meter. The results from the calibration provided the ability to set flow to achieve a specific biogas concentration in the fuel to the fuel cell. The results of the calibration and percent biogas in a 2 L/min total flow to the fuel cell are shown in Table 4-1.

Table 4-1
Biogas Conditioning and Compression Unit Rotameter Calibration Results

Biogas Rotameter Setting (liters per hour)	Biogas Rotameter Setting (liters per minute)	Biogas Measured Flow (liters per minute)	% Biogas in Fuel to Fuel Cell
4	0.07	0.1	5
10	0.17	0.25	12.5
20	0.33	0.55	27.5
30	0.50	0.8	40
40	0.67	1	50

Note:
Total feed rate to the fuel cell was set at 2 L/min.

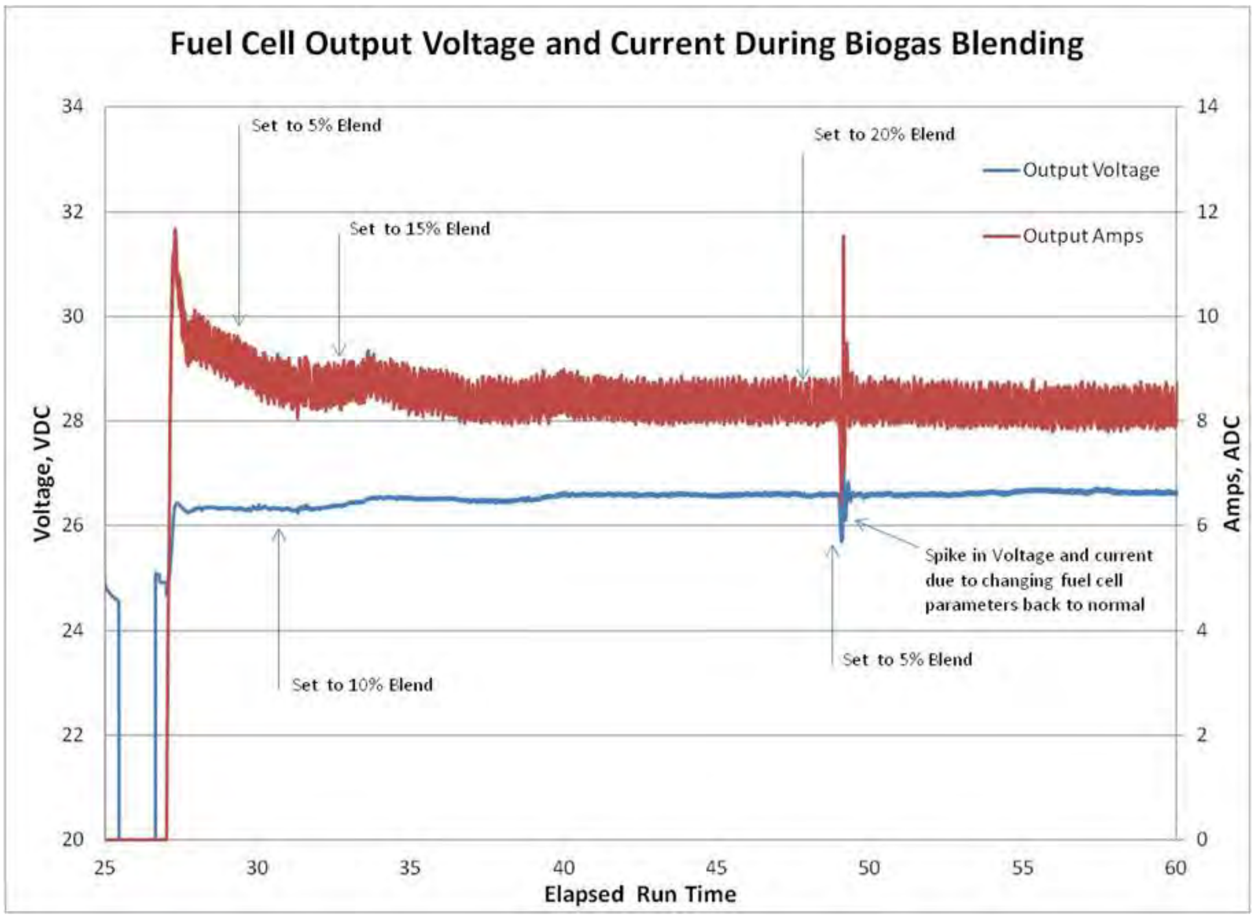
On October 11, 2017, the fuel blend to the fuel cell started at 5% biogas and 95% methane, and the fuel cell ran for 2 hours. The biogas concentration was then increased to 10%— equivalent to a 7.5-L per hour setting on the rotameter—and performance of the fuel cell was monitored for an additional 2 hours. Prior to leaving for the day, the biogas concentration was set to 15%, equivalent to an 11.5-L per hour setting on the rotameter. During remote monitoring by the fuel cell manufacturer, it was noted that as the fuel cell regulated its temperature by adjusting the inlet fuel flow rate, the inlet pressure also changed, which affected the biogas flow rate through the rotameter. The software-controlled conditions affecting the fuel flow rate were modified to eliminate these flow rate fluctuations. The fuel cell ran at a slightly higher flow rate overall.

The fuel cell ran on the 15% biogas blend through the night of October 11, 2017. The fuel cell manufacturer remotely monitored and adjusted the biogas rotameter the next morning, increasing the biogas in the blend to 20%. The fuel cell ran on the 20% biogas blend for an hour without any change in performance. After an hour, the fuel was reset to a 5% biogas mixture to monitor longer term performance. At a 5% biogas blend, no changes would be needed to the fuel cell programming if the biogas fuel was depleted and the fuel switched to 100% CH_4. By design, the fuel cell would be able to restart on biogas seamlessly as the biogas becomes available. Given that the fuel cell was calibrated at 5% biogas and 95% CH_4, when a significant deviation in the fuel mix is made, the fuel cell manufacturer should be notified to modify internal air-to-fuel ratios to maintain the performance and health of the fuel cell.

The energy output from the fuel cell powered area lights for the site and a small water recirculation pump at the algal flow-way. The fuel cell ran continuously from October 10 through October 30, 2017, and then again from November 29 through December 1, 2017. Biogas availability controlled the number of days the biogas conditioning and compression unit and the fuel cell were operated.

Figure 4-10 illustrates the fuel cell output voltage and current when various biogas mixtures were tested. Output voltage ranged between 26 and 27 volts, with output amperage ranging from 8 to 10 amperes (amps). The spikes in voltage and current at approximately 48 hours were due to resetting of the fuel cell operating parameters for a 5% biogas blend.

Figure 4-10
Fuel Cell Output from October 11 to 12, 2017

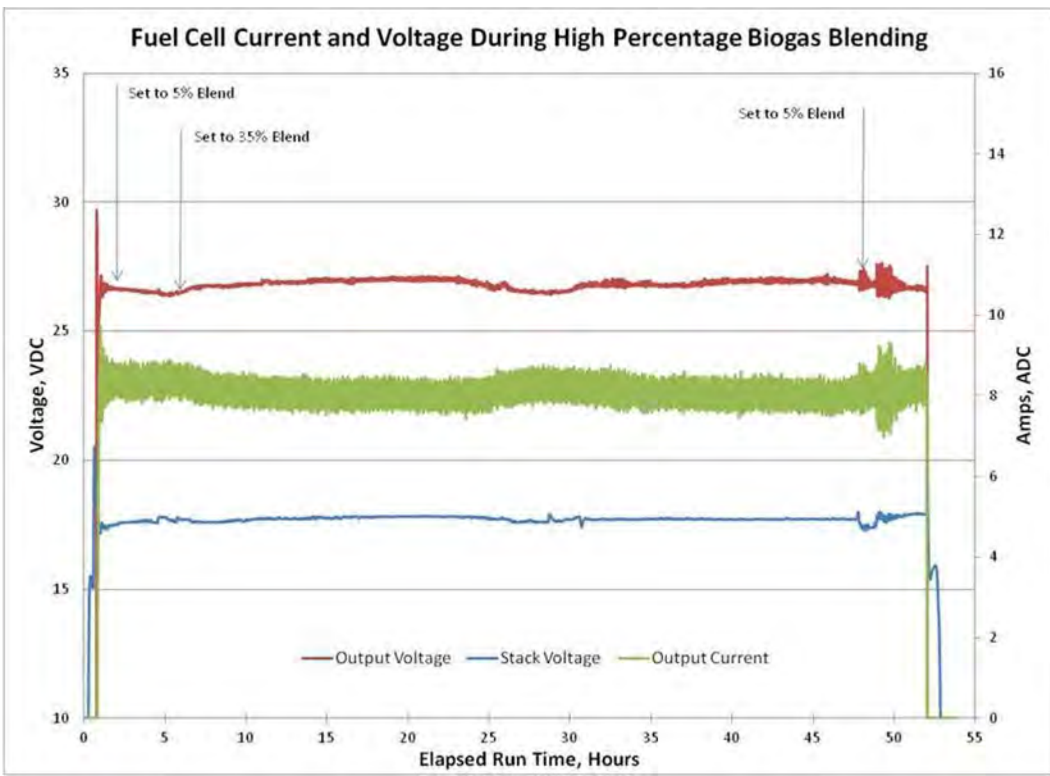


Source: Atrex Energy

Between October 17 and October 24, 2017, the fuel cell ran on 100% CH_4. On October 25, 2017, enough biogas had been collected in the external biogas storage bags to begin testing as fuel to the fuel cell. With the fuel cell manufacturer monitoring the fuel cell performance remotely, biogas was blended into the fuel mix; the blend started at 5% biogas in the fuel mix and was increased in increments of 5% until 20%. The fuel cell was stable throughout the ramp-up to 20% biogas in the fuel mix. Due to concerns that biogas would be depleted over the weekend, the mix was reset to 5% at the end of the day on Friday and the fuel cell was run at 5% biogas through October 30, 2017, when the fuel cell and biogas conditioning and compression unit were shut down to allow for collection and storage of biogas from the digesters.

The fuel cell started up again on November 29, 2017, and it ran through December 1, 2017, shutting down when the stored biogas was depleted on December 1, 2017. The goal of this run was to increase the percent biogas in the fuel mix to 35% and monitor the fuel cell's performance. As seen in Figure 4-11, biogas blends of 5% and 35% produced similar output voltages between 27 and 28 volts and output amperages between 7 and 9 amps.

Figure 4-11
Fuel Cell Output from November 29 to December 1, 2017



Source: Atrex Energy

The stack voltage measured during this final run is shown in Figure 4-11. This is the voltage of the fuel cell stack itself. Stack voltage provides information about the cell's health: a decline in this voltage during operations indicates that the cells are possibly being damaged or degrading. As seen in Figure 4-11, the stack voltage did not change when biogas was added, and it remained steady over the course of the testing. However, this voltage changed slightly around hour 47 due to the following:

- Exhaustion of biogas
- Fuel cell programming was set back to the original values for a 5% biogas blend

The fuel cell then stabilized and did not show any sign of damage.

4.7 Decommissioning

Decommissioning of the flow-way, decant and feed tanks, digesters, biogas conditioning and compression unit, supplemental gas, and fuel cell began on November 30, 2017. The flow-way pumps were shut down and drained, and a final harvest was completed on November 30, 2017. No further winterizing or decommissioning of the flow-way was required.

The decant and feed tanks were emptied on December 6, 2017. After collection of final biogas samples, the three digester bags were emptied, and the algal digesters were cleaned by pumping water through them to remove residual algae. After the digesters were decommissioned, the piping and transfer pump were drained. Waste was collected in the effluent tank and disposed of in the terminal's sewer system.

The biogas conditioning and compression unit was drained, and all valves were closed for the winter. The demonstration project team determined that the iron sponge would be left in place for continued use; it did not require removal and disposal because the concentrations of H_2S and total amount of biogas processed through the system were well below design.

The pressure regulator and associated high-pressure hoses were removed from the site and placed in storage for safekeeping.

The fuel cell was designed for outdoor deployment and thus was shut down and left on site. The inverter was also left on site. The battery bank was removed and stored in a nearby warehouse.

5 Summary and Conclusions

The demonstration project investigated the feasibility of integrating an algal flow-way, anaerobic algal digesters, a biogas collection and conditioning unit, and a fuel cell to convert algae to energy. Each of the system components were tested independently and then integrated into one operating system. As a demonstration project based on laboratory research and first-time integration of each component into an integrated system, project management and team collaboration were extremely important in problem-solving, scheduling, and testing of operational options. In summary, the key lessons learned and uncertainties identified, design constraints and scale-up considerations, recommendations for future studies, and conclusions are discussed below.

5.1 Project Management and Team Collaboration

The demonstration project team structure, management, and clearly identified roles and responsibilities contributed to the success of this demonstration project. Expectations were laid out in paperwork, such as: 1) a cooperative agreement between MARAD and MDOT MPA, 2) a contract between MES and Anchor QEA for project management, and 3) a contract between MDOT MPA and UMD for biogas characterization and digester design in Phase 1 and operations support, data analyses, and reporting in Phase 2. Subject matter experts from UMD and Biohabitats completed the demonstration project team. Tourgee & Associates, Inc. (TAI Engineering), Atrex Energy (Atrex Energy, Inc.), HydroMentia Technologies, LLC (HydroMentia), Spectrum Environmental Sciences (Spectrum), and Reilly Electrical Services supported the project as subconsultants. MES provided financial tracking, procurement of all equipment, and day-to-day operations at DMT. Close communications and regular budget tracking reviews with MES project managers throughout the demonstration project kept the project within budget and on schedule. As expected, with a large demonstration project team, effective and regular communication throughout the demonstration project was critical. During Phase 1, monthly calls were held, and detailed bi-monthly reports were provided by UMD researchers. In Phase 2, monthly calls were supplemented with sub-team calls (e.g., UMD, Biohabitats, MES, and Anchor QEA on the algal digesters; TAI Engineering, MES, and Anchor QEA on the biogas conditioning and compression unit; TAI Engineering, Atrex Energy, and Anchor QEA on the fuel cell). HydroMentia provided flow-way assessment and insights to operations during the data analyses, focusing on productivity and algal community development. Spectrum provided technical review of project documentation. Collaboration amongst demonstration project team members and subconsultants allowed for real-time problem solving and solution-driven brainstorming when problems arose.

5.2 Lessons Learned and Uncertainties Identified

Overall, the integrated system operated as designed and planned. Having a dedicated and committed on-site MES staff who collaborated with component teams (e.g., UMD and Biohabitats on the flow-way; UMD on the digesters; Anchor QEA and TAI Engineering on the biogas conditioning and compression unit and supplemental gas manifold and supply; and Anchor QEA and Atrex Energy on the fuel cell unit) contributed significantly to successful start-up and operation of the system. Integration of each component into a process system was successful but required a higher level of daily support and management than anticipated due to operational troubleshooting, including the following:

- Flow-way water pump failure and replacement
- Digester transfer pump failure and replacement
- Plugging of recycle and overflow lines from digesters
- Heating elements adjustments and trial-and-error settings on thermostats
- Manual biogas transfer from digester internal storage to external biogas storage bags
- Monitoring pressure and switching of CH_4 cylinders

For large-scale or future demonstration unit design, spares of equipment (e.g., transfer pumps and compression pumps) should be installed to provide back-up, as failures in these pumps will result in a system shutdown. In addition, monitoring biogas production and controlling biogas transfers remotely will reduce labor requirements.

The algal flow-way portion of the demonstration project benefited from team's multi-year experience in start-up, operations, and harvesting of the algal flow-way at DMT. Replacement of the 2D mesh screen with a 3D mesh screen increased the growth of algae. Otherwise, the flow-way performed as anticipated; no operational lessons were learned during Phase 2 of this demonstration project.

Harvest methods of the algae from the flow-way were adequate, but perhaps there is an opportunity for better biomass handling during harvest that could increase the percent solids in the feedstock of algae to the digesters. Ideas include draining the harvest longer, harvesting and transferring in sections, and keeping the vacuum truck stationary between harvest and transfer to decant tank.

Decanting methods for increasing the TS in algae prior to the digester worked well for the first few weeks of operations, but they did not meet the targeted level of solids thereafter. More study is needed on operations to provide better settling. Suggestions include cleaning out the decant tanks on a routine basis, draining more water from the sump before transferring algae to the vacuum truck, and identifying less disruptive methods of transferring biomass from the sump to the decant tank.

The digesters produced a higher quality biogas than expected; biogas was generated with a higher percentage of CH_4 and lower percentage of H_2S than was measured in the laboratory. Biogas quantity, however, was lower than anticipated. While the biogas quantity was influenced by other factors external to the digesters (e.g., flow-way productivity), several operations involving the digesters have the potential to be optimized, including the following:

- Running the digesters under warmer conditions (e.g., during summer or with better heating pads and insulation) would produce more biogas.
- Metering of feedstock to the digesters could be improved as follows: readings from the inline flow meter were not accurate, and the feedstock volume was estimated from differences in algae levels in the decant tank.
- The piping design could be improved to allow for routine clean out (as sludge aged and became thick, piping between digesters and in the recirculation lines became clogged).

The external biogas collection system worked well. Tubing and valves were installed between each digester and external biogas bag pair so biogas volume from individual digesters could be measured through the biogas flow meter. The biogas bags needed to be continually monitored for leaks.

The biogas compression and conditioning unit worked as designed. Removal of water and H_2S did not saturate the desiccant beds or iron sponge. Future designs need close collaboration between design engineers and fuel cell engineers to ensure that fittings match, pressure relief systems are in place, and flow meters are calibrated with some redundancy. The larger diaphragm pump was superior to the smaller, initially installed pump.

For the supplemental gas supply, bottled CH_4 worked well in this demonstration project. However, for long-term deployment, a more economical and reliable delivery of CH_4 or natural gas (perhaps by pipeline or via a larger fuel tank) is recommended.

The fuel cell operated as designed. On-site and remote monitoring by the manufacturer provided guidance and safeguards during the demonstration project. MES staff led start-up and operations on site after commissioning by the fuel cell engineer. Through excellent communication with Atrex Energy, MES staff successfully and safely started up, operated, and shut down the fuel cell.

5.3 Design Constraints and Scale-Up Considerations

Using laboratory and field estimates of biogas and algae production rates, the maximum energy production from the existing flow-way can be estimated. In addition, using the same rates, the necessary size for an algal flow-way to continuously power a 500-W fuel cell can be determined.

5.3.1 Maximum Energy Production from Existing Algal Flow-Way

The biogas being converted to electricity by the fuel cell was constrained by the algal flow-way size and the biogas production rate from site-grown algae. When this demonstration project began, the flow-way was approximately 2 m wide by 61 m long, resulting in 122 square meters (m^2) of algae growing area (Lansing and Witarsa 2017b). At a maximum algal production rate of 71 g of algae

DW/m^2/day, the flow-way can produce a maximum of 8,700 g DW algae per day. Using an assumed 10% solids and a density of 1 kg/L for the algae harvested from the flow-way, 87 L per day of wet algae can be expected at maximum algal production (Table 5-1).

Table 5-1
Calculation of Daily Volume of Wet Algae Based on Maximum Algal Production Rate at DMT Flow-Way

Parameter	Unit	Value	Notes
Dry-weight algae production at the flow-way			
Maximum algal production rate measured at DMT flow-way from 2014 to 2016	g DW/m^2/day	71	Calculated[1] using values in Smith et al. 2016
Algae growing surface area	m^2	122	Original area of flow-way (2 m wide by 61 m long)
Dry-weight algae production rate	g DW per day	8,700	Calculated by multiplying maximum algal production rate by area of algal growing surface
Wet-weight algae production at the flow-way			
Algal solids	%	10	Assumed 10% solids to 90% water
	g DW per g wet algae	0.1	
Density of algae	kg wet algae per L wet algae	1	Assumed
Production rate of wet algae on a mass basis	kg wet algae per day	87	Calculated by dividing dry-weight algae production rate by algal solids
Production rate of wet algae on a volume basis	L wet algae per day	87	Calculated by dividing production rate of wet algae on a mass basis by density of algae

Note:
1. This was calculated from total productivity values reported between June 8, 2014, and December 10, 2014, and between April 30, 2015, and July 9, 2015. The average of the values from the top and middle of the flow-way was taken because the flow-way in 2014 and 2015 was 100 m long, whereas the flow-way was 61 m long during the demonstration project. Total productivity measured in 2016 was below this maximum (Selby et al. 2016).

In laboratory studies, digestion of fresh (i.e., wet) algae produced about 3 mL of CH_4 per gram of fresh algae, with approximately 60% CH_4 content (Lansing and Witarsa 2017b). Based on these parameters, 5 L of biogas per 1 L of wet algae (or 435 L of biogas per day) can be produced from algae grown on the existing flow-way (Table 5-2).

Table 5-2
Calculation of Volume of Biogas Produced Per Day

Parameter	Unit	Value	Notes
CH_4 production rate for wet algae	mL CH_4 per g wet algae	3	Estimated for wet algae from Figure 2 of Lansing and Witarsa 2017b

Parameter	Unit	Value	Notes
Proportion of CH_4 to biogas	ratio of CH_4 to biogas	0.6	Average CH_4 in continuous reactors laboratory study was 62% (Lansing and Witarsa 2017a)
Biogas produced per weight of wet algae	mL biogas per g wet algae	5	Calculated by dividing biogas production rate for wet algae by proportion of CH_4 to algae
Biogas produced per volume of wet algae	L biogas per L wet algae	5	Calculated by multiplying biogas produced per mass of wet algae by density of algae, assuming 1 kg/L density
Biogas production	L biogas per day	435	Calculated by multiplying production rate of wet algae on a volume basis (see Table 5-1) by biogas produced per volume of wet algae

Based on the biogas production rates estimated from the Phase 1 laboratory studies—with measured 60% CH_4 content and a CH_4 heating value of 1,011 British thermal units per cubic foot (ft^3) as well as maximum algal production on the flow-way and 10% algal solids to the digester—the integrated system could continuously produce 114 W without energy losses (Table 5-3).

Table 5-3
Calculation of Maximum Energy Content of Biogas Produced

Parameter	Unit	Value	Notes
Production rate of CH_4	ft^3 per day	9.2	Calculated by multiplying total biogas production (see Table 5-2) by proportion of CH_4 to biogas (see Table 5-2); 1 L equals 0.0353 ft^3
Heating value of CH_4	BTU per ft^3	1,011	Engineering ToolBox 2018
Energy rate based on CH_4 produced	BTU per hour	388	Calculated by multiplying production rate of CH_4 by heating value of CH_4
Conversion between W and BTU per hour	W per (BTU per hour)	0.29	1 W equals 3.412 BTU per hour
Maximum energy system could produce continuously (without energy losses)	W	114	Calculated by converting the energy rate based on CH_4 in BTU per hour to W

Note:
BTU: British thermal unit

With an energy equivalence of 114 W, biogas produced from site-grown algae (i.e., at the maximum measured algal production rate) would have been able to supply approximately 50% of the fuel needed to continuously power a 250-W fuel cell, the size that was originally scoped for this demonstration project.[7]

As discussed in Section 3.7, the lowest wattage of a commercially available fuel cell was 500 W at the time of the RFPs in spring 2017; therefore, a greater percentage of supplemental gas was needed to continuously power the fuel cell than anticipated. As an operational adjustment, the demonstration project team decided to collect and store biogas in the external biogas storage bags until enough biogas was available to run the fuel cell for at least 5 to 7 days at a time, allowing for the testing of up to 35% biogas in the fuel mix to the fuel cell.

The energy from biogas generated by the digestion of algae was greatly impacted by the TS content of the algae. Using the maximum productivity of the flow-way at DMT measured in 2017 of 55 g DW/m^2/day (Kangas 2018), the maximum calculated biogas production rate—based on Phase 1 laboratory results and assuming 10% solids—is 367 L of biogas per day (see Tables 5-1 and 5-2 for calculation approach). However, for algae with 2% to 4% solids entering the digesters on site at DMT, the calculated biogas production rate would be proportionately reduced to 67 and 135 L biogas per day at 2% and 4% solids, respectively.[8] The average biogas production rate measured at the DMT digesters was 30.3 L of biogas per day (Lansing 2017[9]), with an average of 73.1% CH_4 (see Appendix E). The impact of the low percent solids in the algae digesters on the biogas produced and resulting energy produced is considerable. Using field averages for biogas production and CH_4 content of biogas from Digester 1 (i.e., averaged for weeks 8 through 17), the energy value of the CH_4 produced continuously is 9.6 W (Table 5-4).

Table 5-4
Calculation of Maximum Energy Content Using Average Rate of Biogas Produced in Phase 2

Parameter	Unit	Value	Notes
Average measured biogas production rate	L biogas per day	30.3	Lansing 2017
Measured proportion of CH_4 in biogas	ratio of CH_4 to biogas	0.731	See Appendix E
Volume of CH_4 produced per day	ft^3 CH_4 per day	0.78	Calculated by multiplying average measured biogas production rate by proportion of CH_4 to biogas and converting from L to ft^3 (1 L equals 0.0353 ft^3)
Heating value of CH_4	BTU per ft^3	1,011	Engineering ToolBox 2018
Energy rate based on CH_4 produced	BTU per hour	32.9	Calculated by multiplying volume of CH_4 produced per day by energy density of CH_4

[7] Production of the 250-W fuel cell was discontinued in 2016.
[8] These values are conservatively high assuming a linear and direct relationship between percent solids and a biogas production rate between 10% solids and 2% solids.
[9] Lansing (2017) reported an average biogas production rate of 212 L of biogas per week for weeks 9 through 17.

Parameter	Unit	Value	Notes
Conversion between W and BTU per hour	W/(BTU per hour)	0.29	1 W equals 3.412 BTU per hour
Maximum energy system could produce continuously (without energy losses)	W	9.6	Calculated by multiplying energy rate based on CH_4 produced by relationship between W and energy rate

5.3.2 *Flow-Way Sizing and Scale-Up Considerations*

Using the maximum measured algae production of 55 g DW/m^2/day in the field in 2017 and the average measured concentration of 73.1% CH_4 in the produced biogas, the algal flow-way size to produce 500 W of energy content in the produced biogas can be calculated as a function of percent solids to the digester. For example, at 10% solids, the flow-way would need to be 571 m^2 to produce 500 W of energy continuously from the biogas produced (Table 5-5); this is approximately 4.7 times the size of the current flow-way.

Table 5-5
Calculation of Algal Flow-Way Size to Produce 500 W of Energy from Biogas

Parameter	Unit	Value	Notes
CH_4 need to produce 500 W of energy			
Energy desired	W	500	Lowest wattage of commercially available fuel cell
Conversion between W and BTU per hour	W per (BTU per hour)	0.29	1 W equals 3.412 BTU per hour
Heating value of CH_4	BTU per ft^3	1,011	Engineering ToolBox 2018
CH_4 needed to produce 500 W of energy	L CH_4 per day	1,147	Converting W to BTU per hour, using the heating value of CH_4, converting ft^3 to L and hours to day
Biogas need to produce desired rate of CH_4			
Proportion of CH_4 to biogas	Ratio of CH_4 to biogas	0.731	Lansing 2017
Biogas needed to produce desired rate of CH_4	L biogas per day	1,570	Converted L CH_4 per day to L biogas per day by dividing by proportion of CH_4 to biogas
Algae growth needed to produce desired rate of biogas			
Proportion of volumes of biogas to wet algae	L biogas per L wet algae	5	See Table 5-2
Density of algae	kg wet algae per L wet algae	1	Assumed density (1 L equals 1 kg)
Algal solids	kg DW per kg wet algae	0.1	10% solids

Parameter	Unit	Value	Notes
Algal growth needed to produce desired rate of biogas	kg DW per day	31.4	Biogas rate (1,570 L per day) converted to kg DW per day
Algal flow-way surface area to support algal growth needed to produce desired rate of biogas			
Maximum measured field algal productivity in 2017	g DW/m^2/day	55	Kangas 2018
Surface area of algal flow-way needed to produce 500 W	m^2	571	Calculated by converting 31.4 kg DW per day to g DW per day and dividing the maximum measured field algal productivity (g DW/m^2/day) in 2017

The energy requirements for an integrated system include power for the flow-way water pump, decant and feed pump, heating elements for digesters, biogas transfer pump, and biogas compression pump. The flow-way water pump (currently a 5-HP pump at the DMT flow-way) and the heating elements for the digesters account for the majority of the energy used at the site. Based on the assessment above for which a 571 m^2 of flow-way was estimated to provide enough algae for 500-W energy production, scaling to 3,729 W (equivalent to 5 HP) would require 4,259 m^2 (approximately 1 acre) of flow-way growing surface.

Additional scale-up considerations include the following:

- Optimize system component design sizing.
  - Size individual components based on algal flow-way size and productivity to reach a level of biogas production that can facilitate continuous fuel cell operations.
- Improve the biomass handling system.
  - Reduce biomass manipulation so decanting is effective.
  - Recover algae solids currently too fine to recover.
- Reduce external energy and gas supplies.
  - Design for power output to provide energy to digesters and minimize pumping requirements.
  - Identify and secure a reliable, economical source of natural gas as supplemental gas.

5.4 Recommendations for Additional Studies

The following are specific areas of improvements and further investigations identified by the demonstration project team:

- Improve biomass handling, separation, and recovery.
- Optimize digester operations.
- Assess fuel cell deployment opportunities at the Port of Baltimore.

Addressing these items will provide critical design and scaling information for future algal flow-ways and coupled digester and fuel cell installations at marine terminals and ports.

MDOT MPA's commitment to the environment is demonstrated through its GreenPort initiatives, implementing sound environmental practices and supporting innovative approaches to improving air and water quality. Currently, MDOT MPA and MES are completing a 30% design for the 3 million gallons-per-day (MGD) algal flow-way that will cover approximately 0.5 acre at the Port of Baltimore. The design team for the 0.5-acre algal flow-way project identified biomass handling, storage, and recovery as an area of uncertainty. The results from this demonstration project as well as potential future studies will inform the design as well as future designs of flow-ways and integrated units;

One area of uncertainty and operational difficulty for the demonstration project was transporting and decanting the biomass after harvest from the flow-way to the digesters. Based on the laboratory investigation completed for this demonstration project, a 6% to 10% solids content (% algae) in the feedstock to the digesters was targeted. After the first month of operations, the feedstock to Digester 1 ranged from 2% to 4% solids and from 1% to 2% solids in Digesters 2 and 3 (which were placed in series behind Digester 1). While this demonstration project met and exceeded the laboratory biogas quality and production rate on a per-VS basis, the total biogas production rates were lower due to the lower VS in the feedstock. Further optimization and investigation of innovative biomass handling, separation, and recovery will improve digester operations and increase biogas production and fill a significant data gap in the 30% design of the 3-MGD flow-way. Future studies should focus on identifying and testing dewatering and recovery systems that can be used in the demonstration unit to supply the digesters with a consistent and higher solids content feedstock and to identify cost-effective and operationally effective biomass handling systems for the 3 MGD flow-way.

The digesters were constructed and operated from August to December 2017. Some key operational questions that were addressed included how to inoculate the digesters with bacteria (e.g. manure), quantify the biogas quality and production, track solids content through the digester unit, determine the efficacy of the decanting tank, and compare the field-scale system to results seen in the laboratory. Recommendations for future digester modifications include the following:

- Re-pipe the recirculation and outflow piping to reduce and clear sludge build up.
- Install adequate heating blankets and improve the digester insulation, if possible.
- Run the digesters for longer periods to gain further insight through operational and sampling data analyses.
- Run the digesters during the summer months when algal productivity is highest.

Optimizing operations and further testing of the digesters will provide design parameters for future digesters associated with algal flow-ways.

A 500-W fuel cell was installed, tested, and operated in October and November 2017, using a biogas and CH_4-blended feedstock. The target was 5% biogas based on estimated biogas production rates from the laboratory studies. Due to the lower total biogas production rates in the field, the biogas was allowed to build up in the biogas storage bags, and the fuel cell ran at varying rates of biogas mixtures until the supply was exhausted, at which point the fuel cell was shut down. Final testing of the fuel cell ran a fuel mix as high as 35% biogas and 65% CH_4. Any higher concentrations of biogas in the fuel mix to the fuel cell would require recalibration of the fuel-to-air control mechanisms of the fuel cell (Cheektamarla 2017). This demonstration project successfully demonstrated the ability to produce electricity using a biogas-blended fuel to a fuel cell.

Further investigation of the implementation and installation of fuel cells on marine terminals and ports should focus on Port of Baltimore-specific opportunities to deploy 500 W or larger fuel cells as alternatives to diesel or electric power supplies. At any marine terminal or port, gas availability is a limiting factor to deployment of a fuel cell if gas is required to supplement the biogas. At the Port of Baltimore, natural gas lines exist, which could serve as a supplemental fuel supply.

5.5 Conclusions

This demonstration project successfully validated the ability to couple an algal flow-way, digester, biogas conditioning and compression unit, and fuel cell into an integrated system producing electricity from algae grown on site. The demonstration project team designed and operated an integrated system to convert algae—already being grown on an algal flow-way to remove nutrients from a nutrient-rich surface water—into biogas for fuel to a fuel cell. This demonstration project showed that electricity could be produced using a non-fossil fuel energy source and, thereby, could reduce air emissions. With financial support and project oversight from MARAD and MDOT MPA, the demonstration project answered many questions on the feasibility and success potential of coupling independent units into a system that could produce electricity from site-grown algae. Several design and operational uncertainties were answered and others identified during the design, start-up, and operations of the system. These include the following:

- The flow-way demonstrated consistent algal productivity from a water source with varying salinity (e.g., 4.9 to 12.9 parts per thousand) and temperature (e.g., 8.7°C to 31.2°C).
- The design and sizing of the decant and feed tanks and transfer pump prevented anticipated clogging of tank outlets and piping to the digesters. However, decanting of the algae in the decant tank fell short of the targeted 6% to 10% solids in the algal biomass after the first month of operations.
    - Further investigation is needed into alternative biomass handling, separation, and recovery methods to ensure consistent, higher solids in the digester feedstock.
- The digesters operated well, but more optimization for biogas production through operational and design modification is needed.

- Recirculation pumps failed, and recycle and overflow piping clogged.
  - Additional heating elements and insulation may enhance biogas production.
- The external biogas collection and storage bag system was well-designed and maintained its integrity throughout the demonstration project. Long-term integrity of the bags and connective tubing will need to be monitored and assessed.
- The biogas conditioning and compression unit operated as designed and performed better with the higher-capacity diaphragm compression pump. A higher-capacity diaphragm pump would be needed to meet the flow demands of higher biogas blends.
- The gas supplement system operated as designed; however, a specialized pressure manifold and high-pressure hoses were required to connect the supplemental CH_4 to the biogas conditioning and compression unit.
- The fuel cell, inverter, and battery bank started up and operated as designed. Early involvement and regular communications between the biogas conditioning and compression unit and fuel cell engineers and technicians were critical to couple the units in a manner that provided safeguards and supplied the required flow and pressure of biogas-blended fuel to the fuel cell.

The results from this demonstration project and the identification of uncertainties in the design and operations will provide researchers, engineers, and large-scale system designers with the information needed for future projects.

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Appendix A
Results from Algal Flow-Way Operations in 2017

ALGAL BIOMASS PRODUCTIVITY AT THE PORT OF BALTIMORE ALGAL TURF SCRUBBER: 2017

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Introduction

An experimental algal turf scrubber (ATS) has been studied at the Port of Baltimore from the summer of 2013 through the fall of 2017 to assess the potential of this technology for mitigating nutrient and sediment runoff impacts from the paved surfaces at the Port (May et al. 2014, Selby et al. 2016, Smith et al. 2013, 2016). The system was operated in 2017 as part of a new project to study the biofuel potential of algal biomass harvested from the ATS. The major change in 2017 at the ATS was the switch between the use of the traditional two-dimensional (2D) screen for growing algae during the first part of the study period, to a three-dimensional (3D) screen that was used in the second part of the study period. The 2D screen had been used in all previous years of operation; the 3D screen was tested in 2017 because it was predicted to increase algal productivity. Increased productivity would come from the increased surface area available in the matrix of the screen for attachment of the algae. The present report describes algal biomass productivity data from the ATS during the 2017 growing season during late spring to late fall.

Site Description

The ATS is located at the extreme eastern edge of the Port of Baltimore property in Dundalk, Maryland on a paved roadbed. The length of the system is approximately 61 meters and the width is 2 meters. The system is lined with plastic (0.045 mil EPDM) pond fabric to contain water flow. The slope of the system is approximately 1 %. Water pumped from the Patapsco River adjacent to the Port is input at the top of the raceways into 10 liter tipping buckets that pulse the water flow in order to stimulate algal growth. Water flows by gravity from the top of the system to the bottom, where it flows back into the river. A nylon mesh screen is placed in the bottom surface of the ATS raceway on which the algae grows as attached periphyton.

Environmental parameters at the site for 2017 are shown in Table 1. The average flow rate was 75 gallons/minute, but there was much variability in flow over the study period. The values ranged from 43 GPM to 108 GPM. Variability was due to some extent to a continual fouling of the intake pump, which reduced flow. Once the pump was cleaned, the flow rate was relatively high, but would decline over time as fouling built up at the intake and in the lines. Using the average of 75 GPM, the relative flow rate to the raceway was 11.4 GPM/foot at the top of the ATS.

The water temperature data portrays a typical seasonal pattern. The values were in the mid- to high 20s through the summer with a high of 31.2 degrees C on August 17. Temperature started to decline through the fall in to early winter.

Salinity values were brackish but they changed during the study period. During the summer (June – August) the values ranged from 4.1 to 7.4 with an average of 5.8. During the fall (September – November) the values increased (essentially doubled) to an average of 11.5 with a range of 8.9 to 12.8. This pattern may reflect relatively higher precipitation in the late spring and early summer which diluted salts, followed by relatively increased evaporation in the late summer and early fall which concentrated salts.

Methods

Biomass productivity

Algal productivity was estimated when the biomass was harvested, typically on a weekly basis during the growing season. The harvest method involves turning off the water flow to the ATS and allowing the raceway to drain between ½ and 1 hour. After drainage, some water remains within the algal biomass, but most has drained out the bottom of the system back into the Patapsco River. The entire raceway was harvested by scraping algal biomass with a squeegee into piles that were vacuumed into a large tank truck for processing.

Drying Pit Method

During the first part of the study period the tank truck was driven to a drying pit where the algal biomass slurry (termed "greenwater") was dumped and allowed to air-dry by evaporation. This pit is an enclosed area of paved parking lot that has been used for drying materials collected during storm drain clean-outs. The truck greenwater that was dumped in the drying pit was allowed to air-dry typically for a week between harvests. After this time, the solids were shoveled into plastic trash bags and weighed on a portable balance.

Subsamples of solids were taken from the trash bags to establish a dry to fresh weight ratio. These subsamples were taken to the lab and weighed to establish their fresh weight, then were air-dried with the aid of an electric fan. The subsamples were dried in an oven at 60-degree C for 24 hours and reweighed to establish their dry weight. The ratio was found by dividing the dry weight by the fresh weight. This dry/fresh weight ratio was then multiplied by the weight of material in the trash bags to estimate algal biomass. Because the surface of the drying pit is uneven, the solids in the truck greenwater do not dry uniformly   Thus, solids were sorted into wetter and drier categories before being shoveled into the trash bags. Subsamples were then taken from each bag. Algal biomass productivity, in units of grams dry weight/m2/day, was calculated by multiplying the fresh weight in the bags by the dry/fresh weight ratios and dividing by the area of the raceway (120 m2) and harvest time interval (typically 7 days).

Truck Weight Method

An alternative method of estimating algal biomass productivity was based on the mass of greenwater in the tank truck. After the algal biomass slurry was vacuumed into the tank truck, the truck was driven to a vehicle scale where it was weighed. The weight of the empty truck had been established prior to the harvest. The weight of the harvested algae was found as the difference in weights between the full and empty truck. After weighing, the truck was driven to a drying pit where the truck greenwater was dumped and allowed to air dry by evaporation. Three small samples (each 220 ml) of the truck greenwater were taken as the contents of the tank truck was being emptied into the pit. These samples were used to convert the weight of the truck greenwater into units of algal biomass. An initial weight was taken of each fresh greenwater sample. The solids (e.g., biomass) in the samples quickly settled to the bottom of the sample jars. The overlying water in the sample jars was then decanted to facilitate drying. The remaining slurry of biomass and water was placed in a shallow aluminum pan and allowed to evaporate to an air-dried solid. An electric fan was used to accelerate drying. The solids were then dried for 24 hours at 60 degrees C and weighed on an electronic balance. The ratio of this weight to the weight of the initial full sample jar establishes a biomass concentration conversion factor for the truck greenwater in units of grams dry weight/kilogram of fresh greenwater. The weight of the greenwater in the truck (kilograms) was then multiplied by the biomass concentration (grams dry weight/kilogram) to estimate the total biomass produced by the raceway (grams dry weight) since the previous harvest date. This estimated total biomass was divided by the area of the raceway (120 m2) and the harvest interval (typically 7 days) to calculate algal biomass productivity in units of grams dry weight/m2/day.

Greenwater Volume Method

An additional method of estimating algal biomass productivity was based on the volume of harvested greenwater. In this approach after harvesting, total volume of the harvest was assessed and multiplied by a biomass concentration in terms of grams dry weight per unit volume of the samples acquired when the tank truck was emptied (see the Truck Weight Method description above for biomass concentration).

During the first part of the study, the tank truck was dumped into the drying pit as described above. In this case the total volume was estimated geometrically by measuring dimensions of area and depth of the greenwater in the pit after harvest.

In the second part of the study, the contents of the tank truck were pumped into a large plastic holding tank which was used to feed an anaerobic digester constructed to assess the biofuel potential of the algal production. This holding tank was transparent and had volume levels marked on the outside of the tank, allowing easy measurement of total volume harvested.

In this method the volume of harvested greenwater (liters) was then multiplied by the biomass concentration (grams dry weight/liter) to estimate the total biomass produced by the raceway (grams dry weight) since the previous harvest date. This estimated total biomass was divided by the area of the raceway (120 m2) and the harvest interval (typically 7 days) to calculated algal biomass productivity in units of grams dry weight/m2/day.

Results

Biomass productivity

Table 2 compares weekly algal production rates for the 2-D screen during the first part of the study period. The ATS was started on May 1, 2017. There was a general pattern of increase from late May to July. The averages for the drying pit and volume based methods were relatively similar at 26.0 and 24.1 grams/m2/day respectively but the estimate from the truck weight methods was much higher, somewhat inexplicably, at 36.1 grams/m2/day.

Table 3 compares algal production rates for the 3D screen during the second part of the study period. Basic data used in the calculation of the values in Table 3 are given in Appendix 1. No data was taken with the drying pit method as the harvested algae was placed in the anaerobic digester settling tank rather than the drying pit where it could be physically weighed. Data from the volume based and truck weight methods were similar throughout this portion of the study period. This similarity may have been caused by the ability to more accurately measure the total volume of harvested algae in the settling tank as compared with the drying pit. Since both methods are based on similar basic data in terms of the biomass concentrations factors, it is not unexpected that the different methods would yield similar productivity values.

There is a general trend of declining values of algal productivity over time in Table 3. This decline is especially apparent by mid-October, and was probably caused by limiting factors such as declining sunlight inputs and lower temperatures at the end of the growing season. The average values of algal biomass productivity, through 11/16/17 when both methods were used and could be compared, was 38.9 grams/m2/day for the volume based method and 38.7 grams/m2/day for the truck weight method.

Discussion

Estimating algal productivity

In this report and in several of the earlier reports on the ATS at the Port of Baltimore different methods of estimating algal biomass productivity have been tested and compared. This has been a necessary activity as algal productivity is a critical parameter in assessing the functioning of an ATS in removing nutrients from a water body. In general, nutrient removal rate by an ATS is estimated by multiplying the algal productivity rate (in units of grams dry weight per unit time) by the concentration of nutrients in the algal biomass (in units of % N or P). This calculation yields the grams of N or P removed by the ATS over time.

The variability in data on algal productivity rate derived from different methods illustrate that there is no objective reality in this important parameter. Likely, operators of an ATS will advocate for the method that is easiest to measure and that yields the highest absolute values for productivity. However, regulators who will give credit for ATS performance at nutrient removal may require different methods that meet their goals of transparency and certainty that nutrients have been removed from the input waters. Thus, more ground must be covered before a method of choice is established.

Continuing research on algal productivity measurement methods is also needed as the ATS is scaled up to acre-size. The methods developed and studied in the five years of research at the pilot-scale ATS at the Port of Baltimore will need to be re-envisioned as a scaled-up system is being planned and constructed. How well will the estimates of algal productivity from the pilot-scale system translate to the larger scale? It may be unwise to assume a one-to-one relationship.

3D screen productivity

It is not possible to know how much greater algal biomass productivity occurred on the 3D screen once it was installed midway through the study period because simultaneous, direct comparison with the 2D screen was not possible. However, inferences can be made based on indirect comparisons.

The productivity from the first part of the study period, when the system utilized a 2D screen, can be compared with productivity from the second part of the study period, when the 3D screen was utilized. Thus, for the volume based method the 3D screen had higher productivity (average of 38.9 grams/m2/day; data from Table 3) in comparison with the 2D screen (average of 24.1 grams/m2/day; data from Table 2) and for the truck weight method the 3D screen also had higher productivity (average of 38.7 grams/m2/day; data from Table 3) in comparison with the 2D screen (average of 36.1 grams/m2/day; data from Table 2). Additionally, the productivity in 2017 of the 3D screen (averages of 38.9 and 38.7 grams/m2/day; data from Table 3) was greater than the productivity of the 2D screen over the same calendar period in 2016 (average of 27.2 grams/m2/day from Table 4). None of these comparisons are scientifically valid because of the differences between the contexts under which the productivity took place, but it seems clear that algal biomass productivity increased when the 3D screen was installed. Based on the performance of the 3D screen in 2017, its use in future iterations of the Port of Baltimore ATS can be recommended.

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Table 1. Environmental data for the Port of Baltimore ATS during 2017. Water temperature and salinity data are for the outflow of the ATS.

Date	water flow rate, gallons/minute	water temperature, degrees C	salinity
6/15/17	108	25.9	4.9
6/22/17	102	26.2	5.1
6/29/17	70	24.3	6.5
7/6/17	47	26.3	5.1
7/13/17	82	27.4	6.4
7/20/17	77	29.4	5.7
8/3/17	73	26.3	4.1
8/10/17	72	25.8	6.1
8/17/17	68	31.2	5.9
8/24/17	43	25.2	6.6
8/31/17	87	23.6	7.4
9/4/17	71	22.7	8.9
9/21/17	---	23.2	10.6
9/28/17	74	24.0	11.3
10/5/17	71	21.3	12.8
10/12/17	59	20.3	12.8
10/19/17	98	17.8	12.9
10/26/17	91	15.0	12.7
11/2/17	73	16.8	12.9
11/9/17	77	14.6	12.2
11/16/17	74	8.6	9.0
11/30/17	49	8.7	10.7

Table 2. Comparison of productivity estimates of the 2D screen at the Port of Baltimore ATS, late spring/early summer 2017. All data are in units of grams dry algae/m2/day.

Date	drying pit	volume-based	truck weight-based
5/25/17	24.2	23.8	26.7
6/15/17	20.6	17.2	28.3
6/22/17	16.6	21.1	39.3
6/29/17	32.6	30.5	42.5
7/13/17	35.9	28.0	43.8

Table 3. Productivity of the 3D screen at the Port of Baltimore ATS, late Summer/Fall 2017. All data are expressed in units of grams dry weight algae/m2/day.

Date	volume-based	truck weight-based
8/31/17	46.6	49.2
9/21/17	42.8	47.0
9/28/17	53.7	57.1
10/5/17	46.4	44.2*
10/12/17	43.0	37.2*
10/19/17	27.9	28.5
10/26/17	34.9	33.7*
11/2/17	38.3	35.1
11/16/17	16.0	16.2
11/30/17	------	13.7

*An underestimate because the harvested greenwater volume exceeded the capacity of the vac truck and therefore a relatively small amount of greenwater was not included in the truck weight, though the total greenwater was included in the volume-based estimate.

Table 4. Productivity of the Port of Baltimore ATS in fall 2016 using a 2D screen (from Selby et al. 2016). All data are in units of grams dry weight/m2/day. Data was gathered with the drying pit method.

Date	productivity
9/9/16	43.9
9/15/16	33.5
9/22/16	26.8
10/6/16	28.0
10/13/16	21.8
10/20/16	20.6
10/28/16	27.1
11/3/16	18.3
11/10/16	21.2
11/22/16	30.5
Average	27.2

Appendix Table 1. Basic data from harvested greenwater (GW) used for estimating algal productivity of the 3D screen at the Port of Baltimore ATS, late summer/fall 2017.

Date	algal biomass concentration		truck weight	greenwater volume
	(g dry wt./liter GW)	(g dry wt./kg GW)	(kilograms GW)	(liters GW)
8/31/17	34.3	33.6	1332	1235
9/21/17	27.0	25.8	1656	1444
9/28/17	33.0	31.9	1629	1482
10/5/17	23.9	22.9	1755	1767
10/12/17	20.0	19.2	1764	1957
10/19/17	19.1	18.6	1395	1330
10/26/17	17.8	17.3	1773	1786
11/2/17	18.7	18.1	1764	1862
11/16/17	10.4	10.1	2916	2793
11/30/17	11.3	11.1	2250	-------

Appendix B
Laboratory Report

Appendix B-1: Results from Algal Flow-way Operations in 2017

The goal of this project was to design a pilot-scale anaerobic digestion system that would digest algae from an algal turf scrubber. Prior to the pilot-scale digester installation, two laboratory-scale experiments were conducted to determine the design and operation parameters for the pilot-scale anaerobic digestion system. The first laboratory study was a batch digestion experiment, while the second study was a semi-continuously fed system. The results of the laboratory testing are detailed in Appendix B-2.

Based on the laboratory results, it was expected that after the digester start-up period, the biogas would average 60 to 62% CH_4, with a normalized CH_4 production value between 81 and 146 L CH_4/kg VS based on the hydraulic retention time (HRT) of 20 days and 35°C used in laboratory testing. In the pilot-scale digester, after the stabilization period (Weeks 1-8), the biogas had a higher percent CH_4 than expected (66.4 ± 1.6%), with CH_4 production of 137 ± 34 L CH_4/kg VS, which was near the higher end of the expected range from laboratory testing. When normalized by volume of algae added, the pilot-scale system produced an average of 1.13 ± 0.33 L CH_4/L algae, which was near the lower end of the expected range from the laboratory study (1.09 to 2.69 L CH_4/L algae), likely due to the lower operating temperature of the pilot-scale system. Average weekly biogas production from the pilot-scale system was 588 ± 68 L CH_4, which was within 4% of the expected weekly production from the laboratory study.

Decant Tank and Total Solids of the Algae Feedstock

In order to achieve the recommended total solids percentage of 6-10% (moisture content of 90-94%) in the influent to the pilot-scale anaerobic digester, the algae from the algal turf scrubber was pumped into a decant tank for solids separation and thickening. The thickened algae feedstock was then pumped into a separate feed tank to use as the digester substrate.

During normal operations, the algae were pumped into the decant tank on a Thursday and allowed to settle until Monday when sampling and digester feeding occurred. The decant tank had three sampling ports at three different heights from the effluent valve for flexibility in decanting and testing (Figure 3-3 in Main Report). In order to determine the effectiveness of the decant tank, algae samples were taken from each of the decant sampling valves (labeled Top, Middle, and Bottom), as well as from the algae feed tank, which was used as the influent to Digester 1. Sampling of the decant tank occurred Weeks 2, 6, and 8-13. The percent total solids (TS) in the bottom of the decant tank did not reach the design of 6 to 10% TS after Week 6, with the feed tank effluent, which serves as the influent to the first digester, reaching a maximum TS of 4.57% (Table B1-1).

From Week 2 to Week 8, the TS sampled from the bottom valve of the decant tank was higher than the TS in the algal feed tank by 29 to 66%, which means that the volume of algae being transferred into the feed tank was greater than the volume of the thickened algae from the bottom of the decant tank. Starting Week 9, however, the algae in the feed tank had an equal or higher percent TS (up to 69% more TS) than the bottom level in the decant tank, which could be a result of further settling in the feed tank prior to being pumped into the digester (Figure B1-1). The efficiency of the decant tank should be further explored and design changes proposed to ensure that the algae entering the digester is closer to the design parameters.

Table B1-1: Percent total solids (TS) in the decant and feed tanks.

Week	Decant Tank Top Valve TS (%)	Decant Tank Middle Valve TS (%)	Decant Tank Bottom Valve TS (%)	Algal Feed Tank TS (%)
2	0.78 ± 0.01	0.86 ± 0.01	8.66 ± 0.02	2.96 ± 0.05
6	1.21 ± 0.02	1.78 ± 0.04	7.39 ± 0.01	4.57 ± 0.00
8	N.S.[a]	1.34 ± 0.01	1.30 ± 0.003	0.92 ± 0.01
9	1.47 ± 0.01	1.53 ± 0.01	1.54 ± 0.01	4.26 ± 0.001
10	N.S.[a]	N.S.[a]	1.46 ± 0.01	2.65 ± 0.00
11	1.47 ± 0.004	1.47 ± 0.01	3.07 ± 0.99	3.07 ± 0.01
12	2.11 ± 0.05	2.39 ± 0.06	2.35 ± 0.17	2.52 ± 0.01
13	1.45 ± 0.001	1.44 ± 0.01	2.45 ± 0.03	3.46 ± 0.04

[a] N.S. = not sampled.

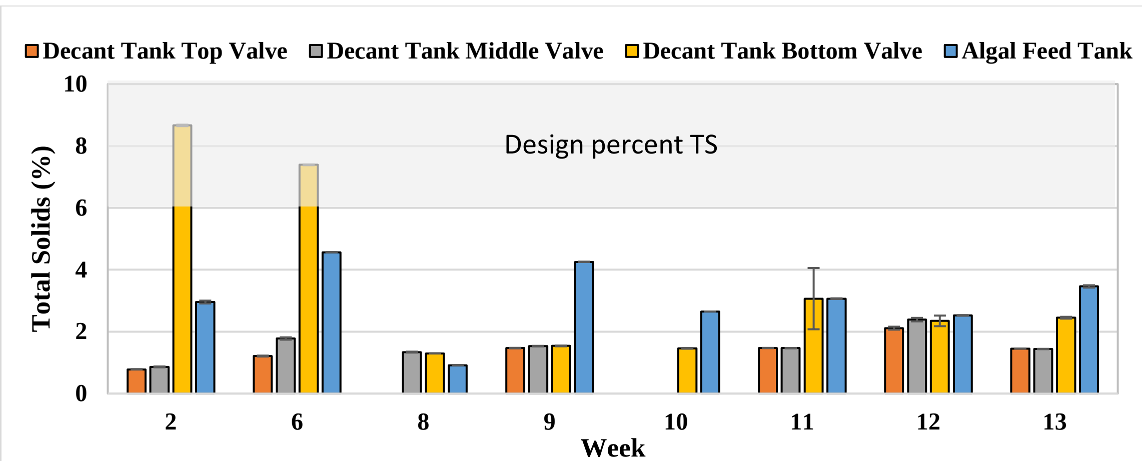

Figure B1-1: Total solids (%) at the three levels in the decant tank and the algal feed tank.

Temperature

The heating units ordered for the digesters were not placed under the digesters and did not have direct contact with the digesters, and therefore, were not adequately heating the digesters until Week 6. Additional heating units from Dr. Lansing's lab were installed during Week 6 (Figure B1-2). Even after the new heating units were installed, the temperature units were not able to dependably overcome the lower outside temperatures in the first two, larger, digesters. Digester 2 was always warmer than Digester 1 due to the higher influent temperature into Digester 2 compared to the cold algal feedstock coming into Digester 1. Ideally, anaerobic digesters should be kept in the mesophilic temperature range, which is 30 to 35°C. After Week 9, when temperatures decreased below the ideal range in the pilot-scale digesters, the average weekly CH_4 production also decreased (Figure B1-2). In the future, it is recommended that the feed tank also have the capability of being heated, which would increase the temperature of the digesters, thus increasing CH_4 production. In addition, the heating blankets should be installed to have direct contact with the digesters.

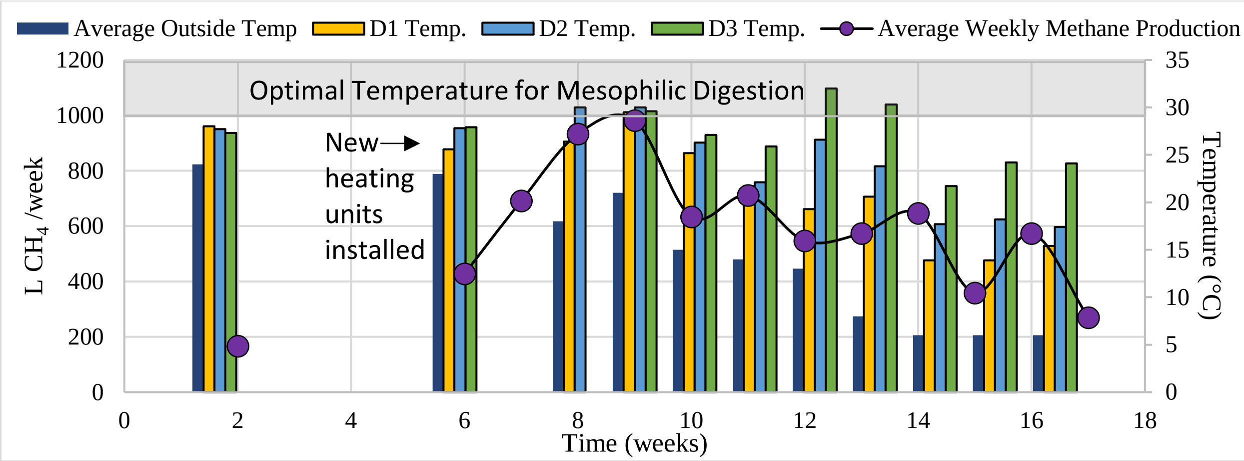

Figure B1-2: Weekly average methane production (L CH_4/week) of the pilot-scale digesters, with average weekly temperatures in the three digesters and the outside temperature shown.

Nutrients Dynamics

The purpose of the algae in the algal turf scrubber was to assimilate dissolved, inorganic nitrogen and phosphorus from the Patapsco River into the harvested algae biomass before the nutrients could reach the Chesapeake Bay. The algal biomass was then utilized as a substrate for anaerobic digestion, where the concentrated nutrients in the biomass were re-mineralized into a form favorable for potential use directly as a fertilizer or to be processed for nutrient recovery.

It was not expected that the total nitrogen (TN) or total phosphorus (TP) concentrations would change between the influent and effluent of the digestion system, as digesters do not significantly remove nutrients. The TN and TP concentrations in the influent to Digester 1 ranged from 595 to 1,180 mg N/L and 79 to 145 mg P/L, respectively. Due to a variable feeding schedule, the hydraulic retention time of the system fluctuated. The average HRT of Digesters 1 and 2 from Week 11 to 17 was 16 days, which means that the effluent of Digester 2 on Week 16 contained the nutrients that entered Digester 1 on Week 11. The TN and TP concentrations in the effluent of Digester 2 on Week 16 were within 5 and 25% of the influent concentrations from Week 11, respectively (Figure B1-3). During Week 16 and Week 17, solids were accumulating in Digester 1, which may have led to a decrease in nutrients concentrations in the effluent of Digester 2 (Figure B1-3). Overall, the TN was 7 to 8 times the concentration of TP, which was similar to the N:P ratio in the digested samples from the batch laboratory test, and also matches the N:P ratio needed for plant uptake, i.e. corn crops require a N:P ratio of 7:1. It is possible that the phosphorus in the system was less soluble than the nitrogen (25% reduction compared to 5% in TN) due to precipitation of the phosphorus with iron present in the algae, which could lead to higher retention of phosphorus in the precipitated solids in the system.

As the algae moved from the feed tank through Digesters 1, 2, and 3, the nitrogen in the algae was mineralized to ammonium. The ammonium concentrations increased on average 33% from the influent of Digester 1 to the effluent of Digester 2, with an average ammonium concentration in the influent to Digester 1 of 194 ± 22 mg NH_4-N/L and an average effluent ammonium concentration from Digester 2 of 288 ± 51 mg NH_4-N/L. The increase in ammonium between the influent and effluent resulted in a decrease in organically bound nitrogen on average from 77 to 27% from the influent of Digester 1 to the effluent of Digester 3, respectively.

As the algae moves through the digestion system, the organics in the biomass are converted to CH_4, which results in decreased carbon in the system and mineralization of nutrients from the algae biomass. The carbon to nitrogen ratio (C:N) increased from 6.01 in the influent of the decant tank to 6.28 after passing through Digester 1 (Figure B1-4), which was not expected. It should be noted that the C:N ratio was not regularly tested, as it was not part of the original scope of work. Based on the long HRT of the system, a sample taken in the influent of one day cannot be necessarily correlated with a sample taken from the effluent of the digesters. In order to better understand the potential for nutrients recovery, the nutrients, and the C:N ratio should be tracked more regularly in future operations.

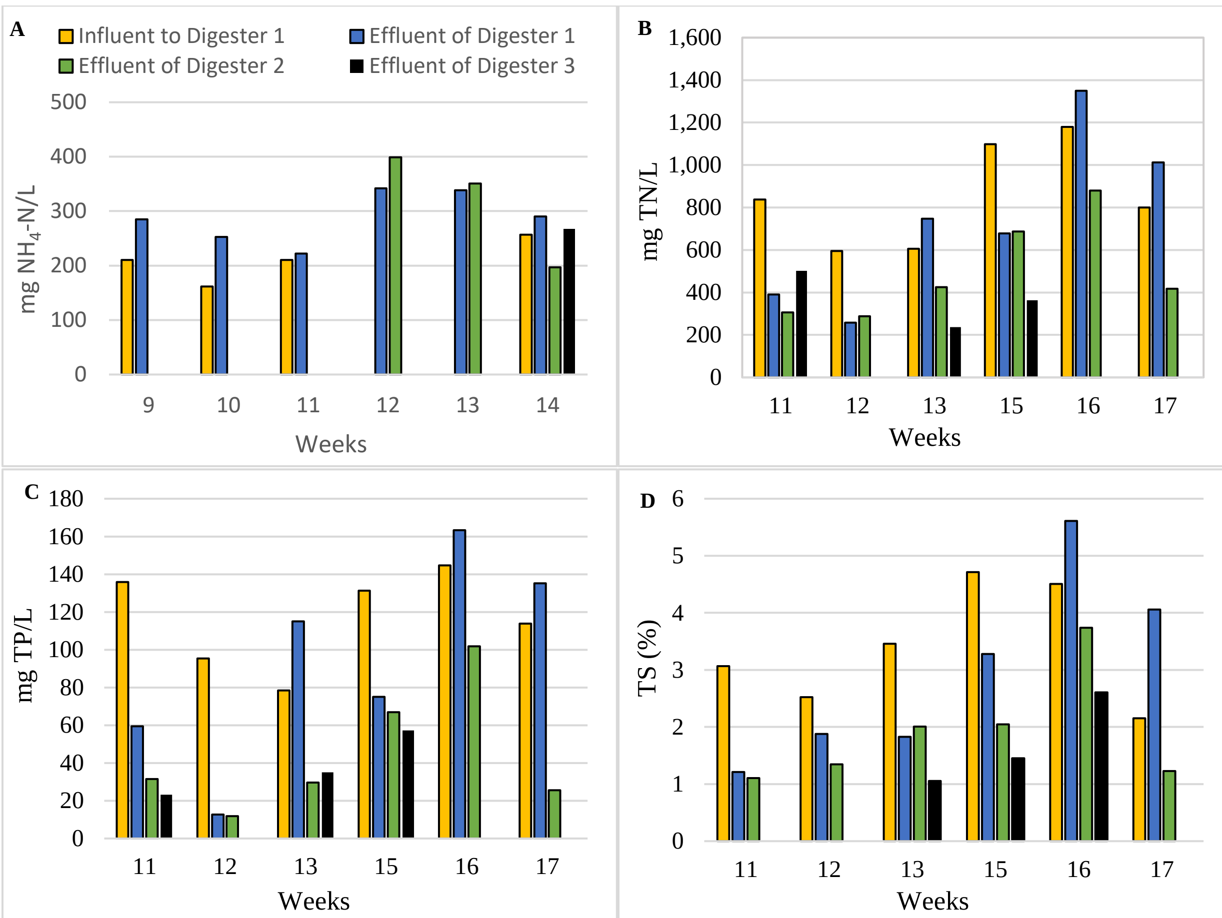

Figure B1-3: Nutrients and solids in the pilot-scale digestion system, with A) ammonium-nitrogen (NH_4-N) concentrations, B) total nitrogen (TN) concentration, C) total phosphorus (TP) concentrations, and D) percent total solids (TS).

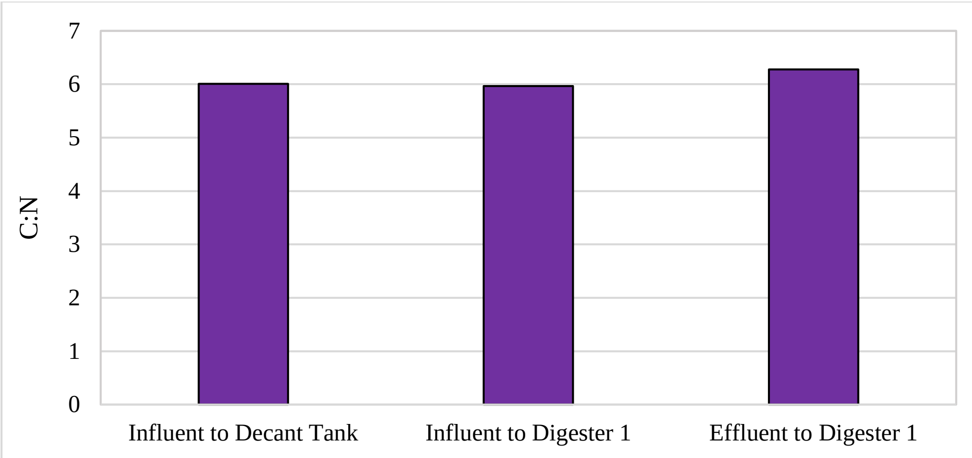

Figure B1-4: Carbon to nitrogen ratio (C:N) of the algae from the decant tank through Digester 1.

Appendix B-2: Laboratory Report

Batch Methane Production Testing

The first laboratory experiment was a batch methane (CH_4) production test designed to determine the preparation requirements for the algal feedstock to increase CH_4 production during anaerobic digestion. The algae substrate from the ATS was tested using three different percent total solids (TS) values, including algae directly from the ATS with a TS of 8% (TS-8) and algae that was air dried for a week and divided into two layers: the bottom layer with a TS of 38% MC (TS-38) and the top, dried layer with a TS of 78% (TS-78).

The batch test followed the biochemical methane potential (BMP) testing procedure (Moody et al., 2007), with the results expressed as: L CH_4/g VS (volatile solids) added, which relates the conversion efficiency of the organic material in the algae to CH_4, and by L CH_4/g substrate added, which gives the total CH_4 production for that substrate. The first normalization (L CH_4/g VS) does not account for the moisture content in the substrate, as water does not contribute to organic matter. After collection, the algae substrates were placed into 250 mL glass bottles with a microbial seed (inoculum) from a continuously fed full-scale anaerobic digester at USDA Beltsville Agricultural Research Center (BARC)in Beltsville, MD USA.

After the 60-day batch digestion, the results showed that CH_4 production was most efficient for fresh algae, TS-8 (158 ± 13 L CH_4/kg VS), followed by the medium-wet algae, TS-38 (127 ± 2 L CH_4/kg VS) and dry algae, TS-78 (117 ± 17 L CH_4/kg VS) (Figure B2-1). In terms of the total amount of CH_4 produced per gram of substrate; however, digesting dry algae, TS-78 (19 ± 2 L CH_4/kg algae) and medium-wet algae, TS-38 (10 ± 0.1 L CH_4/kg algae) had higher total CH_4 content compared to fresh algae, TS-8 (2 ± 0.1 L CH_4/kg algae). While digesting TS-78 and TS-38 could reduce the digester volume by 91% and 30%, respectively, compared the volume of digester needed to contain the fresh algae (TS-8), use of fresh algae eliminates a pre-drying process and reduces clogging potential in the digester. It was recommended that fresh algae should be concentrated to a TS content of 6-10% before digestion.

Overall, the BMP performed as expected. The pH of the treatments ranged from 7.98 to 8.13, which was within the preferred range for methanogenesis (6.5 to 8.2.) (Table B2-1). The total and volatile solids destruction over the 60-day batch test ranged from 11 to 15% and 16 to 20%, respectively (Table B2-1). While TS and VS destruction was low, this is a common occurrence in batch testing due to the high volume of inoculum in the bottles, which is pre-digested material and microorganisms. The post-digestion TN and TP ranged from 1,590 to 2,160 mg N/L and 200 to 308 mg P/L, respectively, with the average TN eight times the concentration of TP, as was expected.

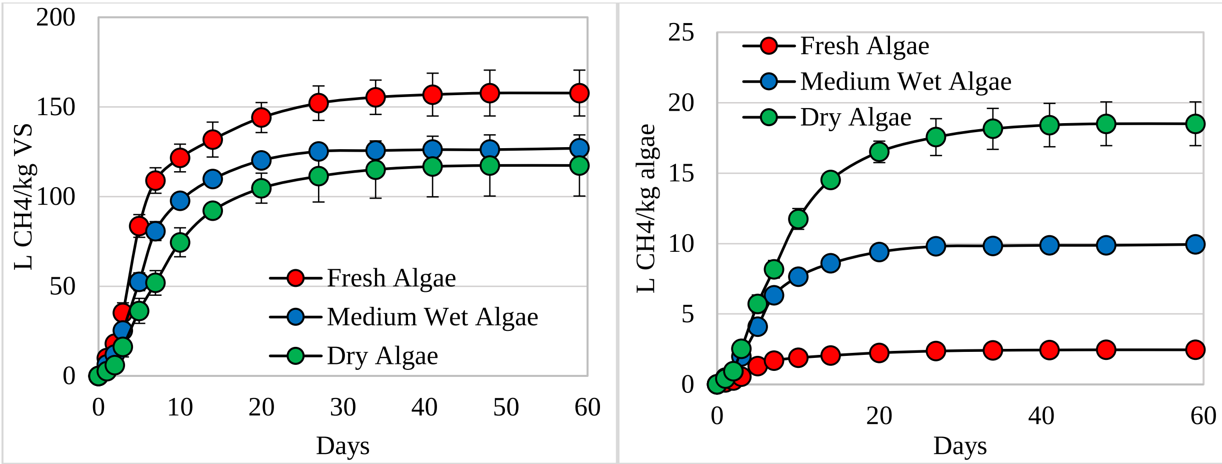

Figure B2-1: Cummulative CH_4 production based on volatile solids in the algae (L CH4/g VS) on the left and total algae addition (L CH4/kg algae) on the right) at three total solids content: fresh algae (TS 8%) medium-wet algae (TS 38%) and dry algae (TS 78%).

Table B2-1: Pre- and post-batch digestion parameters data of triplicate treatments ± standard error.

Sample	pH		TS (%)		VS (%)		TN (mg N/L)	TP (mg P/L)
	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP	Post-BMP	Post-BMP
TS 8%	7.98 ± 0.04	7.38 ± 0.01	3.43[a]	3.05 ± 0.14	1.33[a]	1.07 ± 0.04	1,590 ± 8	200 ± 4
TS 38%	8.09 ± 0.02	7.47 ± 0.01	4.81[a]	4.07 ± 0.12	1.73[a]	1.41 ± 0.01	2,070 ± 36	281 ± 4
TS 78%	8.13 ± 0.03	7.46 ± 0.01	5.09[a]	4.50 ± 0.30	1.81[a]	1.52 ± 0.04	2,160 ± 70	308 ± 9
Inoculum	8.04 ± 0.01	7.46 ± 0.01	2.12 ± 0.01	1.92 ± 0.02	1.27 ± 0.01	1.10 ± 0.01	1,770 ± 12	210 ± 2

[a] Sample values were calculated, so there is no standard error to report

Semi-Continuous-Fed Methane Production Testing

The findings from the batch testing were utilized to determine the feed rate for a semi-continuously fed system. In this study, two reactors (2 L each, with a working liquid volume of 1 L) were constructed (Figure 2-4 in Main Report) and fed algae that was decanted in the laboratory to achieve the desired total solids content of 6-10%. The inoculum was the same inoculum source used for the batch digestion test at a 2:1 inoculum to algae ratio, by VS. The inoculum was incubated in the reactors before substrate loading for two weeks to reduce residual organic matter and sulfates present in the inoculum.

Multi-foil bags were attached to the reactors to collect the biogas. Algae was fed three times per week (Mon, Wed, Fri), with a retention time of 20 days. The feeding rate was 100 mL on Monday and Wednesday and 150 mL on Friday to achieve an overall feeding rate of 50 mL/day. The experiment ran for 63 days, which was a total of 3 HRTs. A magnetic stir bar was placed in each of the reactors and was used during sampling to evenly distribute the material. The effluent was removed before each feeding session. The TS and VS of the algae substrate for the first 37 days was 6.30% and 1.24%, respectively (wet mass basis). On Day 37, a different algae feed was utilized, with a TS and VS of 7.28% and 1.77%.

Based on the batch test results digesting fresh algae, it was expected that the continuous reactors would produce biogas with a percent CH_4 of 65.8 ± 0.9% and 158 L CH_4/kg VS. The overall average CH_4 concentration was 61.4 ± 0.8%, which was within 7% of the expected concentration. Over the first 37 days of testing, the average CH_4 concentration was 62.2 ± 1.1%. After Day 37 when the new algae feed was introduced with a higher percent TS (7.27 vs 6.30%), the biogas averaged 60.2 ± 1.1% CH_4 for the remainder of the experiment (25 days).

The average CH_4 production normalized by VS over the 63-day study was 110 ± 7 L CH_4/kg VS, which was 30% less than expected; however, CH_4 production averaged 146 ± 7 L CH_4/kg VS when the new feedstock, with the higher TS value was introduced on Day 37 (Figure B2-2), which was within 7% of the CH_4 produced during the batch test. The average CH_4 production for the first 37 days was only 84.1 ± 2.1 L CH_4/kg VS, which illustrates the effect of the algal feed composition on CH_4 production. When normalized by volume of algae added, the semi-continuous reactors averaged 1.77 ± 0.17 L CH_4/L algae, which was 31% less than expected, given the batch digestion production of 2.57 ± 0.12 L CH_4/L algae; however, after the new algal feed was used as the influent after Day 37, the continuous reactors produced 2.69 ± 0.14 L CH_4/L algae, which was 5% more than produced in batch testing.

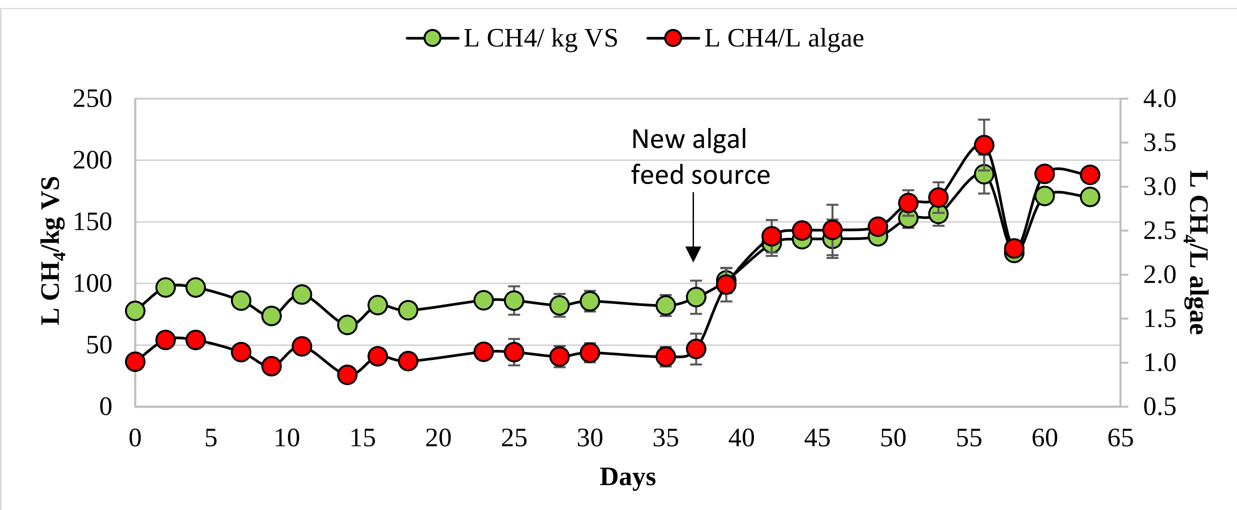

Figure B2-2: Methane (CH_4) production per kg volatile solids (VS) and per liter of algae for the continuous reactors during the 64-day testing period.

Hydrogen Sulfide Production in the Laboratory and Pilot Reactors

Hydrogen sulfide (H_2S) production during the batch test ranged from below detection limit (approximately 15 ppm) to 1,850 ppm in the fresh algae treatment of the batch digesters (Figure B2-3). Similarly, the semi-continuous reactors had H_2S concentration ranging from below the detection limit to 1,400 ppm, with an average H_2S concentration of 438 ± 78 ppm, which was within the range observed in the batch test. Scale-up from the laboratory to the pilot-scale system; however, resulted in an average weekly H_2S concentration of 2,860 ± 671 ppm after stabilization (Figure B2-3). The increase in H_2S production of 51% from the 2 L reactors to the 3,900 L reactor was most likely due to the increased HRT of the pilot system from 20 days to 50 days, allowing for almost twice the amount of time for the VS in the system to be converted to H_2S. Additionally, as the temperature dropped in the pilot-scale digesters, the H_2S concentration increased, likely due to out-competition by the sulfide reducing bacteria compared to the methanogens at this decreased temperature range. Keeping the temperature higher may result in lower relative H_2S concentrations in the biogas.

While the choice was made to use fresh algae as the substrate for the pilot-scale anaerobic digesters, digestion of dry and medium wet-algae with inoculum reduced the amount of H_2S expected from the inoculum in the batch testing by 39 to 50%, indicating that these two types of algae did not contribute to H_2S production and could potentially be used as an additive to reduce H_2S levels during digestion. Digestion using fresh algae, however, contributed to additional H_2S level (Figure B2-4), although this was only 22% more than the amount expected to be produced by the inoculum. Algae substrates (fresh, medium wet, and fresh algae) and inoculum from the batch test were sent to AgroLab for analysis. The results showed high iron content in all the algae samples (1,490 – 29,400 ppm iron/dry weight). This was 32 - 640 times higher than the inoculum and 7.5 - 147 times higher than dairy manure that had approximately 200 ppm iron (analyzed outside this experiment). Since iron has been known to precipitate sulfide, the high iron content within the algae could explain the low H_2S production observed in the batch digestion.

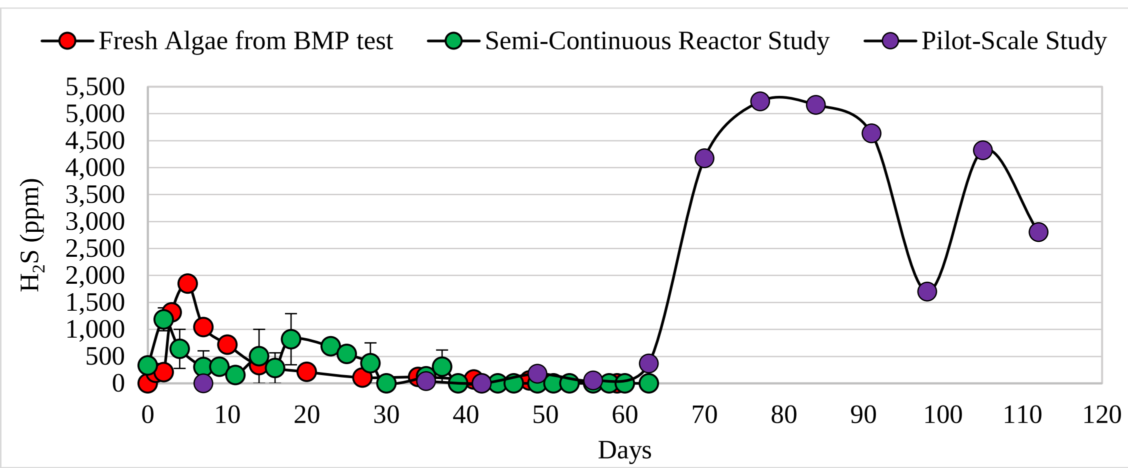

Figure B2-3: Hydrogen sulfide (H_2S) concentration in biogas during batch digestion, semi-continuous laboratory-scale digestion, and semi-continuous pilot-scale digestion of fresh algae.

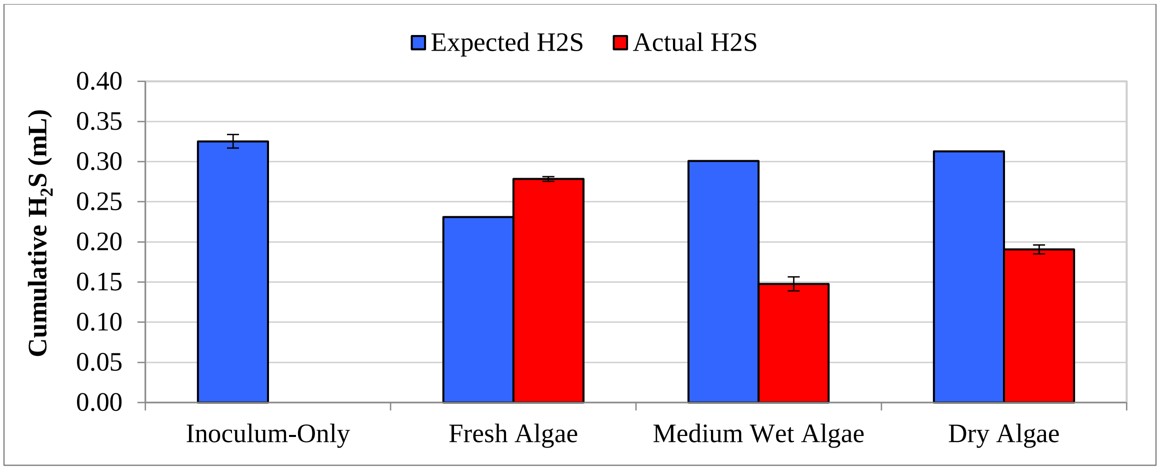

Figure B2-4: Comparison of the expected cumulative H_2S (mL) from the inoculum in each treatment based on the inoculum-only treatment, and the actual quantity of H_2S (mL) produced during batch digestion of fresh algae (TS-8), medium-wet algae (TS-38) and dry algae (TS-78).

Volatile Solids Destruction in the Laboratory and Pilot Reactors

Volatile solids destruction in the semi-continuous reactors averaged 23.9 ± 3.5%, which was low for anaerobic digestion (Table B2-2). One possibility for the low reduction in VS in the semi-continuous laboratory study was the high average organic loading rate (OLR) of 734 ± 43 g VS/m^3-day, with only a 20-day HRT. The pilot-scale reactor had a HRT of 50 days and an OLR of 193 ± 36 g VS/m^3-day, which allowed for a higher, more expected VS reduction of 65.0 ± 6.1% after the stabilization period of 8 weeks.

Table B2-2: Influent and effluent characteristics of the semi-continuous laboratory reactors, with effluent samples conducted in triplicate with ± standard error shown.

Week	**pH**		**sCOD (mg/L)**		**TS (%)**		**VS (%)**	
	Influent[a]	Effluent	Influent[a]	Effluent	Influent[a]	Effluent	Influent[a]	Effluent
1	6.99	7.21 ± 0.01	2,550	1,220 ± 104	6.49	5.80 ± 0.01	1.27	1.04 ± 0.01
2	6.89	7.09 ± 0.02	2,710	1,320 ± 120	6.16	5.93 ± 0.03	1.23	1.08 ± 0.01
3	6.89	7.16 ± 0.00	2,510	874 ± 25	6.47	5.91 ± 0.01	1.29	1.05 ± 0.00
4	6.90	7.05 ± 0.04	1,990	818 ± 19	5.76	5.81 ± 0.01	1.15	1.03 ± 0.00
5	N.S.[b]	7.19 ± 0.04	2,200	838 ± 19	6.56	5.67 ± 0.04	1.29	0.999 ± 0.006
6	6.88	7.26 ± 0.02	1,820	803 ± 17	7.29	5.93 ± 0.04	1.69	1.01 ± 0.01
7	6.76	7.13 ± 0.03	1,780	601 ± 6	7.17	6.14 ± 0.04	1.66	1.10 ± 0.02
8	6.92	6.94 ± 0.01	2,980	385 ± 14	7.49	6.32 ± 0.03	1.80	1.22 ± 0.00
9	6.78	7.00 ± 0.00	3,010	490 ± 30	7.40	6.45 ± 0.06	1.68	1.16 ± 0.02

[a] Only one sample, no standard error
[b] N.S. = Not Sampled

Pre-Treatment Study:
A batch methane production test was conducted using the following pre-treatments; 1) 1% enzyme addition (cellulose, protease, alpha amylase, lipase, and pectinase) at 37 ºC; 2) blended; 3) blended + 1% enzymes (at 37 ºC); 4) sodium hydroxide (5M); 5) 120 ºC; and 6) sodium hydroxide (5 M) and 120 ºC. There were four controls: 1) 1% enzymes (no algae); 2) algae stored at 4 ºC); 3) inoculum-only; and 4) algae pre-heated to 37 ºC. The experiment was conducted in triplicates, except for the control algae at 37 ºC, which was conducted in duplicate, resulting in a total of 29 reactors. The batch test followed the biochemical methane potential (BMP) testing procedure (Moody et al., 2007), with the results normalized by L CH_4/kg VS added. After the pre-treatments were conducted, the treated algal feedstocks were placed into 250 mL glass bottles with inoculum from a continuously fed full-scale anaerobic digester at USDA Beltsville Agricultural Research Center (BARC) in Beltsville, MD USA.

The two pretreatment methods that yielded the highest CH_4 production values were: 1) the combined pretreatment method of blending the algae and adding enzymes, and 2) the 5M sodium hydroxide (NaOH) treatment at 37 ºC. The blended and enzyme treatment produced the highest amount of CH_4 (615 ± 144 L CH_4/kg VS) which was 56% higher than the algal control (i.e. no pretreatment). The sodium hydroxide treatment produced 420 ± 165 L CH_4/kg VS, which was 35 % more CH_4 than was produced by the algal control (Figure B2-5). While the pre-treatment study results were not used in the pilot-scale study, a scale-up analysis of the results should be conducted to determine if the energy (blending), cost (enzyme or NaOH cost), and time devoted to pre-treatment would be worth the increase in methane production shown.

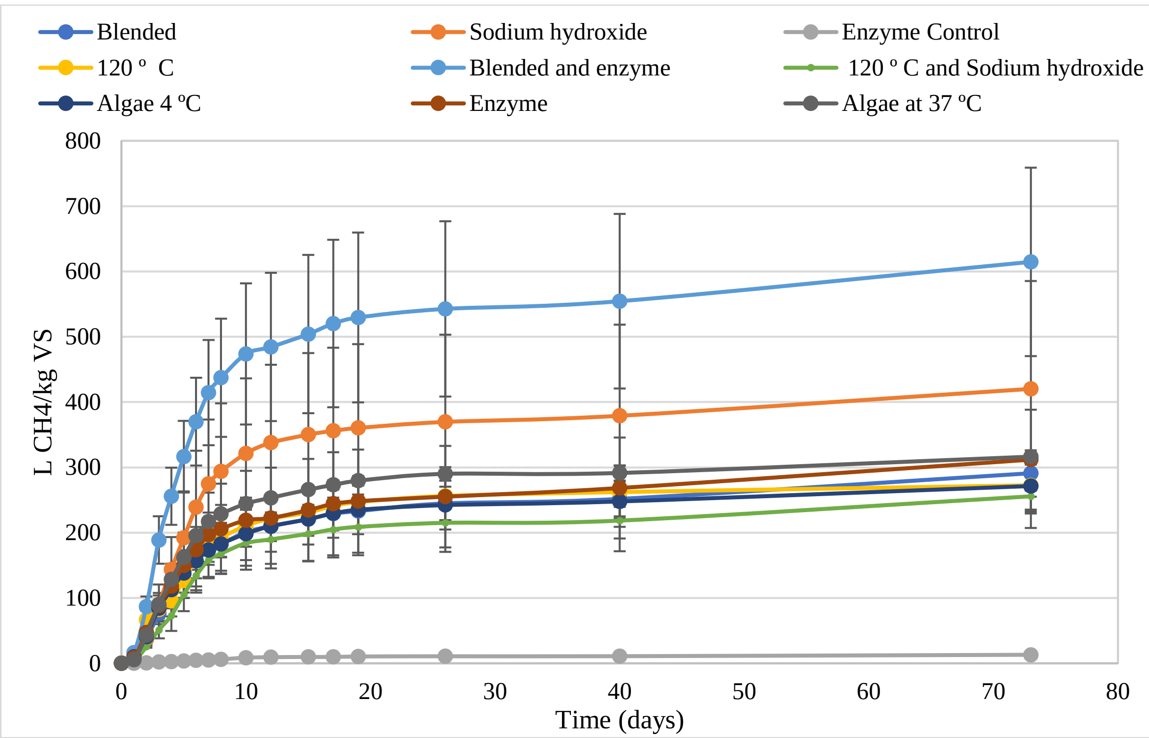

Figure B2-5: Cumulative CH_4 production from algal pretreatment study.

<u>Prior to the batch experiment, a preliminary experiment was conducted with the enzyme mixtures to determine if 1% or 0.5% enzymes should be used in the batch testing.</u> In this preliminary experiment, the same mixture of five enzymes (cellulose, protease, alpha amylase, lipase, and pectinase) were mixed at 1% and 0.5% with and without algae feedstock. The prepared enzymes were mixed with algae for 24 hours at 50ºC. The enzyme mixture that released the highest amount of soluble chemical oxygen demand (sCOD), the 1% enzyme mixture, was the enzyme concentration used in the subsequent BMP test.

The results of this preliminary study showed that addition of 1% enzyme increased sCOD by 17.8% (Figure B2-6, Table B2-3). Decreased sCOD was observed for the other treatments (addition of 0.5% enzyme, the enzyme-only treatment, and algae without enzyme addition). Addition of 1% enzyme could thus be beneficial for the digestion of algae, potentially increasing CH_4 production by similar amount, and was used in the digestion experiment.

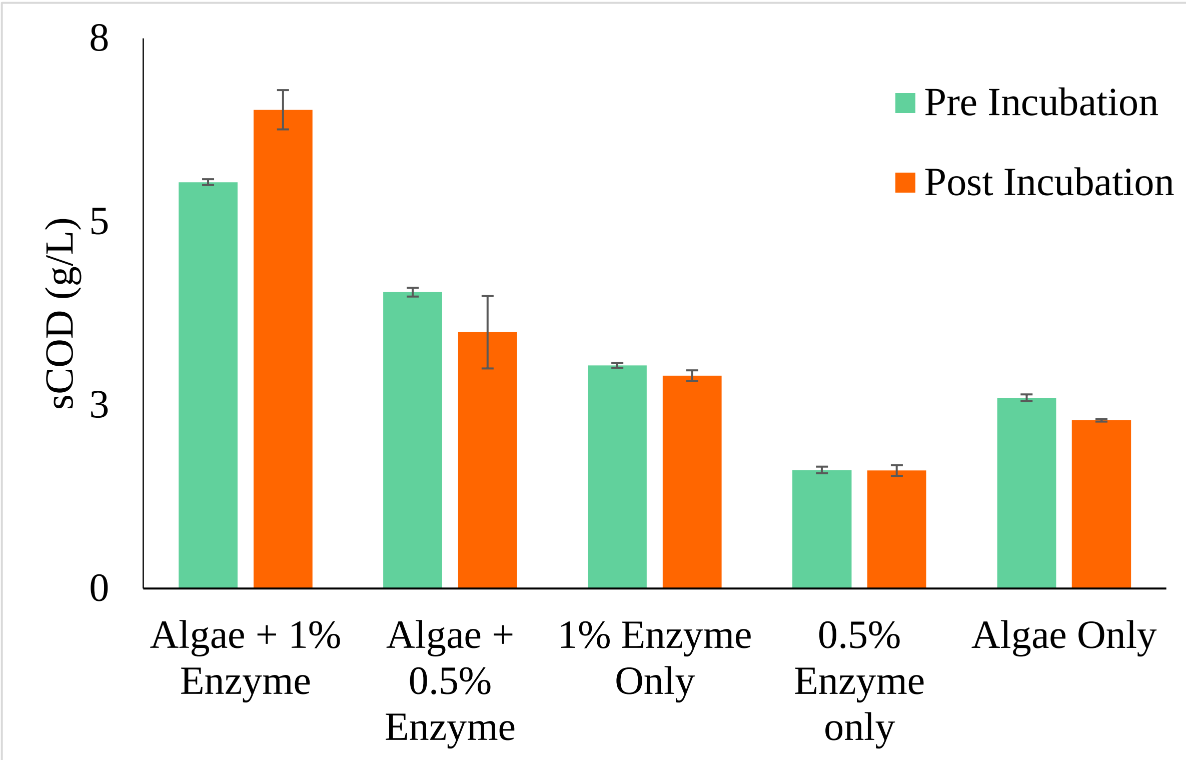

Figure B2-6: Changes in soluble chemical oxygen demand (sCOD) when enzymes are added to algae and incubated for 24 hours.

Table B2-3: Percent changes in soluble chemical oxygen demand (sCOD) when enzymes are added to algae and incubated for 24 hours.

Treatment	**% Change in sCOD**
Algae and 1% Enzyme	17.8
Algae and 0.5% Enzyme	-13.5
1% Enzyme Only	-4.7
0.5% Enzyme only	-0.5
Algae Only	-11.8

Professional Presentations:
The project was also presented at the annual American Ecological Engineering Society Conference held in Athens, Georgia on May 23-25, 2017:

1.) Oral presentation: Witarsa, F., Lansing, S., Kangas, P., May, P., Darby, E. Creating Bioenergy from Algal Flow Way Using Anaerobic Digestion.

2.) Poster presentation: Maile-Moskowitz, A., Witarsa, F., Lansing, S., Kangas, P., May, P. Pre-treatment of Algae from an Algal Flow Way for Anaerobic Digestion.

Appendix C
Standard Operating Procedures and Information Sheets

GreenPort of Baltimore

Biofuel Demonstration

AT THE DUNDALK MARINE TERMINAL

Quick Facts

- Three small digesters at the Dundalk Marine Terminal will produce biogas from algae.
- The biogas will enhance an existing pilot project that uses controlled algal growth to reduce nutrient pollution in the Patapsco River.
- The biogas will feed a fuel cell that generates electricity for the system's water pump.
- The biogas project begins in July 2017 and is expected to continue through late fall or early winter.
- The project is part of the MPA's Green Port initiatives, which encourage sound environmental practices and innovative approaches to improving air and water quality.

The Maryland Department of Transportation Maryland Port Administration (MDOT MPA) has teamed up with scientists and technical experts to notch up the environmental benefits of a pilot project that is removing nutrients from surface water in the Patapsco River. Excess nutrients can degrade water quality in a number of ways.

The algal flow-way project, which began operations in 2013, pumps water out of the Patapsco River at the Dundalk Marine Terminal. The water flows down a runway, 200 feet long and 6 feet wide, that consists of a plastic sheeting material covered in a screen. Nutrients are consumed as the algae grows on the screen, thereby removing the nutrients from the water. Once a week, the algae is harvested from the runway. Cleaner, oxygenated water is returned to the river.

The system is being expanded to demonstrate the ability to produce electricity through a series of steps, starting with the algae. The algae will be fed through a series of three digesters — small, greenhouse-like structures — in which micro-organisms breakdown the algae and produce biogas. The biogas will supplement natural gas as a feedstock to a fuel cell that produces electricity. The electricity will be used to run one of the pumps in the system.

To date, demonstrating the use of biogas in a fuel cell has been limited or non-existent in an industrial or marine environment. This project addresses the feasibility of coupling an algal digester, biogas collection and storage system, and fuel cell for continuous operations and the ability to run a fuel cell relatively maintenance-free using biogas feedstock in a marine environment.

Partners in the biofuel demonstration project include the U.S. Department of Transportation Maritime Administration (MARAD); MDOT MPA; University of Maryland; Anchor QEA, LLC; Biohabitats, Inc.; and Maryland Environmental Service. Major funding for the project is provided by MARAD.

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July 2017

Port of Baltimore Digester Decommission Suggestions

1. Flare and meter all biogas in the external biogas bags and the digesters.
2. Empty three main digester bags using pump system after recirculation, if possible – collect three samples per digester when emptying to evaluate digester contents (one acidified sample per digester and two un-acidified samples).
3. Run water through the system and recirculate to clean any algal residue resting at the bottom.
4. Leave some water in the digester but below the digester outlet pipes, so the pipes are empty of water
5. Secure the greenhouses and digesters using racket straps and cinder blocks.
6. Detach and take the biogas bags to the hanger for storage.

Inoculum Loading Procedure:

<u>Tuesday, August 15th</u>
Using our lab truck and the Green Silverado collect the following from BARC:

- Two 1m^3 cube tanks – place one in the bed of each truck and strap down against the cab (Gary has plenty of racket straps, and we have many in the lab as well).
  - Replace the valve on the bottom of one of the tanks (Walter has the necessary parts)
- Sump pump with 1 ½ inch tubing
- Relay pump

Upon return to UMD, please have Gary Siebel help you secure the tanks against the cab with more racket straps. Do not remove the straps when filling or emptying the tanks (basically, leave the tanks securely in place until returning to UMD on Wed afternoon).

Please send Bryce at Port Authority the security forms for Amro, Casey and Maggie and the tag information for the two trucks, including indicating who will be traveling in which truck.
Truck: license # and state of issue; make, model, color & name on the truck.
Driver: License # and state of issue & name

Bryce, we would like to empty the bags of most of the water before we add the inoculum to keep from diluting the inoculum. The bags seems to hold their form well when liquid is added and do not seem to fold upon themselves. On Tuesday, can you please disconnect the bottom of outlet pipe (we have done that before to drain the previous water), which is the lowest point of the digester. It may not drain all the water, but should drain most. Afterwards, you can insert a tube through the outlet pipe (after draining most of the water) to drain the rest of the water through a siphon system. If this could be done before we arrive, it would make our time go faster. Also, can you vacuum pump all of the air out of the biogas bags, as we do not want to mix the air and the biogas that is produced. If this could also be done on Tuesday, we would appreciate it.

Additionally, if any changes need to be made to properly attach the heating blankets, this can be done after the water is drained before we add the inoculum, as the digesters will be too heavy to move once the inoculum is loaded.

<u>Wednesday, August 16th</u>
Supplies needed:

- Long extension cord
- Extra fernco fittings and 1 ½ inch tubing for connections (should be in our lab or the Mezzanine storage area, or the Shop storage area – ask Gary for assistance). We may not need these items, but we will bring them just in case.
- A 2 x 4 piece of lumber, rope and tie cables, zip ties, and scissors, sledge hammer
- Two clean 5 gallon buckets (to collect inoculum for Jenna)
- Gloves, paper towels, sample labeling tap, Sharpies
- Three 1 L Sample Bottles
- Landtec and YSI

Using our lab truck and the Green Silverado drive to Kilby Farm (795 Firetower Rd, Colora, MD):

Inoculum loading procedure:

1. Using the sledge hammer, add a 2x4 lumber next to inoculum effluent pit (if needed, there may be an existing structure we can attach the sump pump to).
2. Securely tie the effluent pump to the 2x4 or existing structure, so you can keep the pump submerged 3-4 inches below the surface but the pump is not resting at the bottom of the effluent pit.
3. Pull the truck as close as needed to the effluent pit, and secure the tub from the sump pump into the top of the first tank. Make sure someone is always standing with this tube to make sure that it stays securely within the tank and to monitor the level of the inoculum in the tank
4. Plug in the pump using the extension cord. If there is not a nearby electricity source, you may have to go to the biogas scrubbing shelter, so make sure that you have enough extension cord length to reach this far.
5. Fill each tank with inoculum to about 90-95% full. Then close and secure the tops of the tanks.
6. Collect two buckets of inoculum for Jenna
7. Take YSI readings of the inoculum
8. Take biogas readings of the biogas for us to know the CH_4 and H_2S content and share this information with Abhinav. Abhinav can give you instructions on where he takes the reading.
9. Drive to the Port Authority
10. Use the relay pump to pump from the bottom valve of the tanks into the first digester. You might need to turn the pump on for a few minutes and then let it rest for a few minutes to give the digesters time to move the liquid and air from the first digester to the next digester. Unload both tanks of inoculum.

Once the inoculum is loaded, you are done. Make sure that the biogas bags are properly attached. I believe that the Port Authority ordered a biogas meter. If that meter has not arrived, you can leave the Landtec with Bryce and show him how to take a reading. The biogas meter is $10k, so it should not be left out in the sun or left unattended. It needs to be in a locked space when not being utilized or directly supervised.

As soon as biogas is produced (within 4-12 hours), a reading should be taken with the Landtec twice a day (Mon-Friday) for the first few weeks. It will likely take one to two weeks before the biogas bags are full and need to be flared. Please let us know how full the bags are on a daily basis, so we can schedule a time to come show everyone how to flare safely, but we need to wait until there is enough biogas collected for flaring before we can give a proper demonstration.

Assuming the biogas production has commenced, I would suggest adding the first batch of algae on Friday, August 18th. I am still unclear how the decanting process works, so I do not feel comfortable creating the digester loading procedure. If someone can type this part of the process up, we can add the digester loading piece, so we have a working digester operating guide.

MARYLAND ENVIRONMENTAL SERVICE

SAFETYWORKS

Job Hazard Analysis

Task: Iron Sponge Operation and Decommissioning			**Facility: Fuel Cell Demo Project – Dundalk Marine Terminal**	
Prepared by: Elaine Darby (Anchor QEA), Bryce Selby, Andrew Blair		Date: 10/08/2017	Reviewed by:	Date:
Approved by:		Date:	Date JHA was revised:	Revision by:
Equipment Operated: Biogas Conditioning Skid			Physical Demands: Operations – none; Decommissioning – opening sponge bed flanges and handling iron sponge with Fe2S3	

Recommended Personal Protective Equipment (Check Box and List Type):

☐ Head/	☒ Hand/ work gloves/ nitrile gloves	☒ Foot/ Steel toe boots	☐ Hearing/	☒ Eye/ Safety glasses
☐ Face/ face shield	☐ Torso/	☐ Leg/	☐ Electrical/	☐ Respiratory/

Environmental Conditions:	Open weather conditions.
Special Equipment:	Sodium carbonate solution during operations; Appropriately sized wrench to open flange when decommissioning.
Special Precautions:	Spent iron sponge is pyrophoric if not kept moist with while exposed to air. Procedures have been provided by Connolley-GPM (vendor) for decommissioning (see attached pdf)
Specialized Training:	Review the Biogas Conditioning Skid Sequence of Operations and Connolley-GPM procedures
Testing/Monitoring Equipment:	

Sequence of Events	Potential Accidents/Hazards	Preventive Measure
Operations	Slip and fall during water addition to iron sponge bed, if needed	Water from the iron sponge bed accumulates in the drip trap at the bottom of the iron sponge. The discharge water should 8 or higher. A water solution of sodium carbonate is to be added at the inlet port to bring up the pH. A ladder and second person on hand securing the ladder should be used to access the inlet port. (Also note that the bottom temperature should be less than 120 degrees F as above this temperature, the iron sponge is not as effective for removing sulfides; this is also an indicator that the iron bed is spent and needs to be replaced.
Decommissioning – removal and disposal of the iron sponge	Exothermic reaction of air and iron sponge – causing a flammable condition	Sponge needs to be kept moist when exposed to air. After the biogas conditioning unit is shut down and taken off line, the iron sponge vessel should be flooded from the bottom with water. The top of the unit valve should be open to allow venting of any trapped biogas. Once the system is full of water, open the top

		cover and remove the spent iron sponge using small shovels or ranks. The final material may need to be floated out by adding water to the system. The removed material needs to spread out in a container (such as the waste trough on site) into a layer 5-5 inches deep. Add water to the container so the material is thoroughly soaked and sitting in water. Keep the material moist for a period of 10 days. The material is then ready for disposal. For this project, we will not reuse the iron sponge.
Decommissioning – storage of unspent iron sponge in the vessel	Exothermic reaction of air and iron sponge – causing a flammable condition	If you would like to store the material in the vessel for future use, first, flood the vessel, then, bubble air up through the bed for a couple days ('til the water temperature curve flattens out). Then drain the bed. When you are ready to bring the bed back on line, soak the bed with a soda ash solution for 24 hours before starting it back up.

TAI/Atrex/MES Discussion on Start Up and Operations

September 18, 2017

ANCHOR QEA

Start-up and Operations Discussion

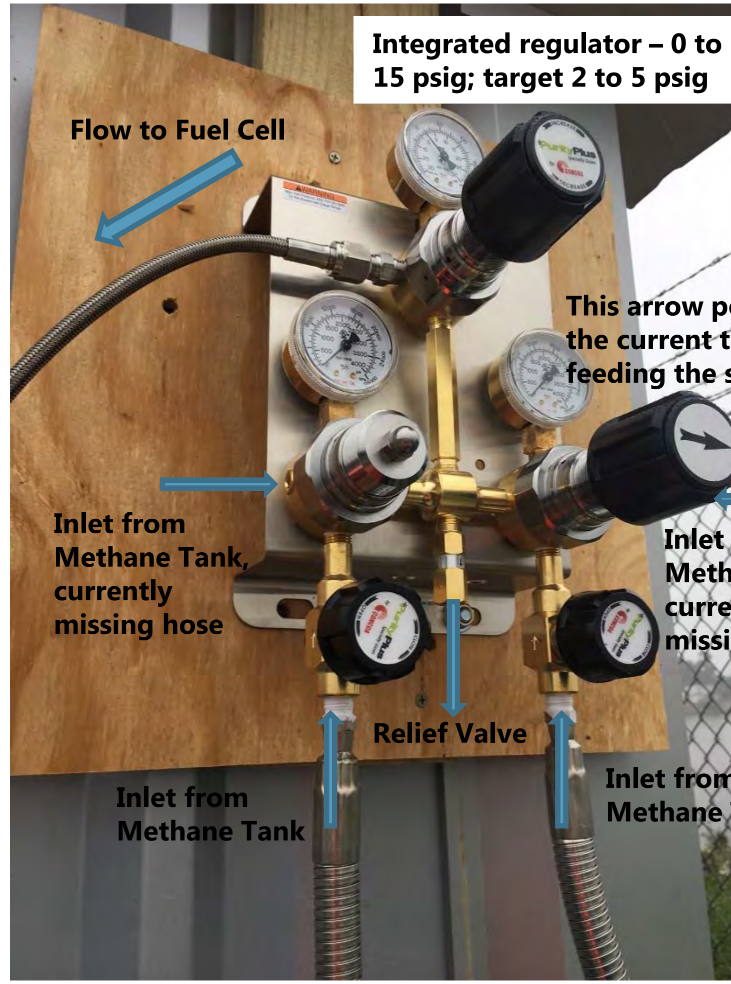
- Automatic Switchover System – Manifold
  - Set up and operations discussion
- Biogas Conditioning Skid
  - Connections
    - Biogas
    - Methane
  - Diaphragm pump
    - Replacement
    - Testing and operations
  - Desiccant Dryer #2 installation
    - In backwards?
  - Biogas/Methane fuel mix control

Start-up and Operations Discussion

- Fuel Cell
  - Connections
  - Start-up
    - Electrical output
      - Extension cord to ½ hp water pump to be located at headworks
  - Operations

Manifold Set Up and Operations

- Two manifolds
  - Recommend just running **one** manifold with four tanks
  - Requires changing two tanks out at a time
    - Each tank should last approximately 3 days; change out 2 tanks per week
  - To run both manifolds would require manual switching between systems and could lead to fuel cell shut-down



Manifold Start-up and Operations

- General Handling
  - Before disconnecting nearly empty cylinders, always rotate the priority valve (one with big black arrow pointing to left or right), so the arrow on the know is pointing to the in-use (full) side of the switchover
  - Always close all manifold station and cylinder valves on the nearly empty side of the switchover before disconnecting the hoses
    - Always stand to the side and slowly open the cylinder connection nut on the hose where it's connected to the cylinder
  - Always open cylinder valves slowly when high-pressure gases are being used (our cylinders are high pressure @ 2000 psig)
  - Always leak-test any manifold and distribution piping before use
  - Close all cylinder valves before disconnecting cylinders from the manifold

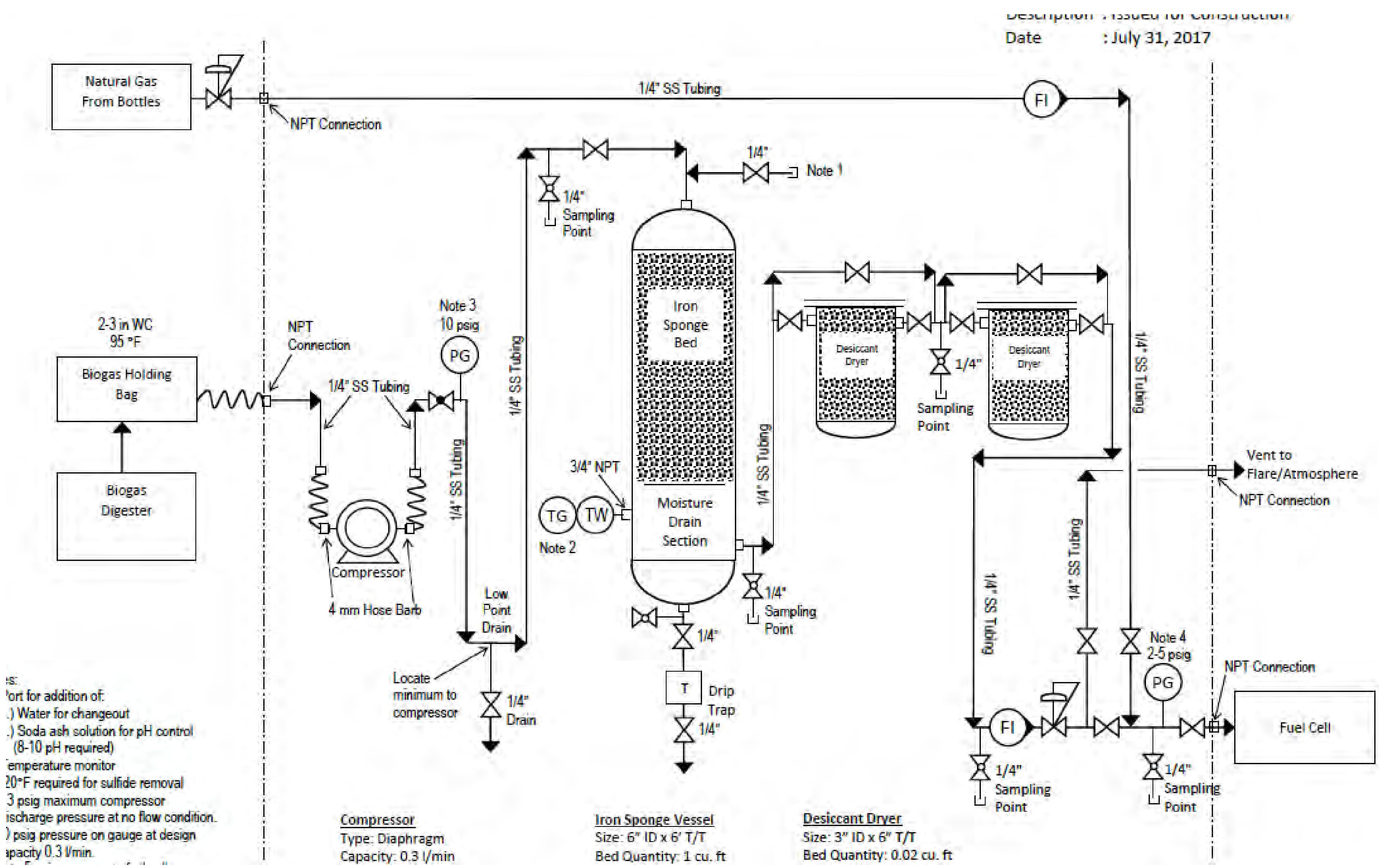
Manifold Start-up and Operations

- Be sure that all fittings are secure and leak tight. PTFE tape should be used on pipe threads (no oil or grease)
- Connect to cylinders
  - Remove cylinder cap
  - Be sure the cylinder valve is tightly closed (clockwise)
  - Secure cylinder connections
- Turn the line regulator knob counterclockwise until the now stops turning
- When pressurizing for the first time – do not stand in front of the manifold. Slowly open the cylinder valve. Observe the high pressure gauge for a rise in pressure up to full cylinder pressure.
- Inspect all connections for leaks and fix any leaks. Never attempt to fix a leak under pressure. If leaks are detected, depressurize the system and retighting the connection.
- Slowly turn the line regulator know clockwise – this will increase the pressure of the line. Adjust to the desired working pressure and again check for leaks.

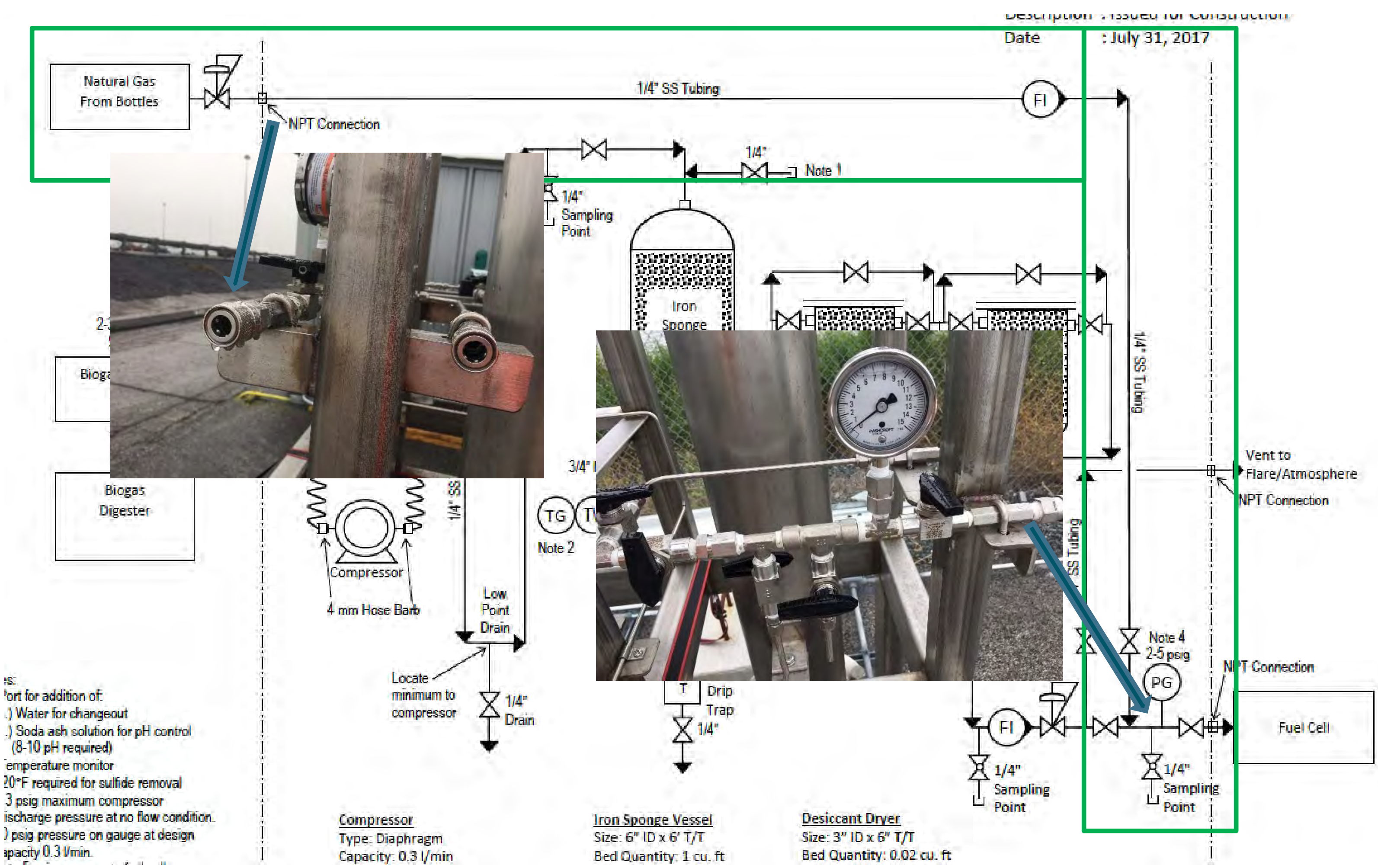
Manifold Operations – See pages 10 – 11 in Concoa Manual

- The arrow on the priority valve always points to the primary side; the bank opposite the primary side is considered the reserve side.
- Starting with the arrow pointing to the right side, gas will flow from the right side cylinders. When the pressure drops to the pressure setting of the reserve side regulator (70 psig), flow will begin from the reserve site; the inlet pressure on the primary side will stabilize. This is a changeover.
- At this point, the gas pressure on the reserve side will drop. This indicates that its time to change the cylinders. Before removing the nearly depleted primary cylinders, the priority valve should be rotated 180 degrees. This makes the reserve cylinder the primary source. Remove the depleted cylinders and replace with two full cylinders. Before removing the cylinders be sure to close the cylinder valves.

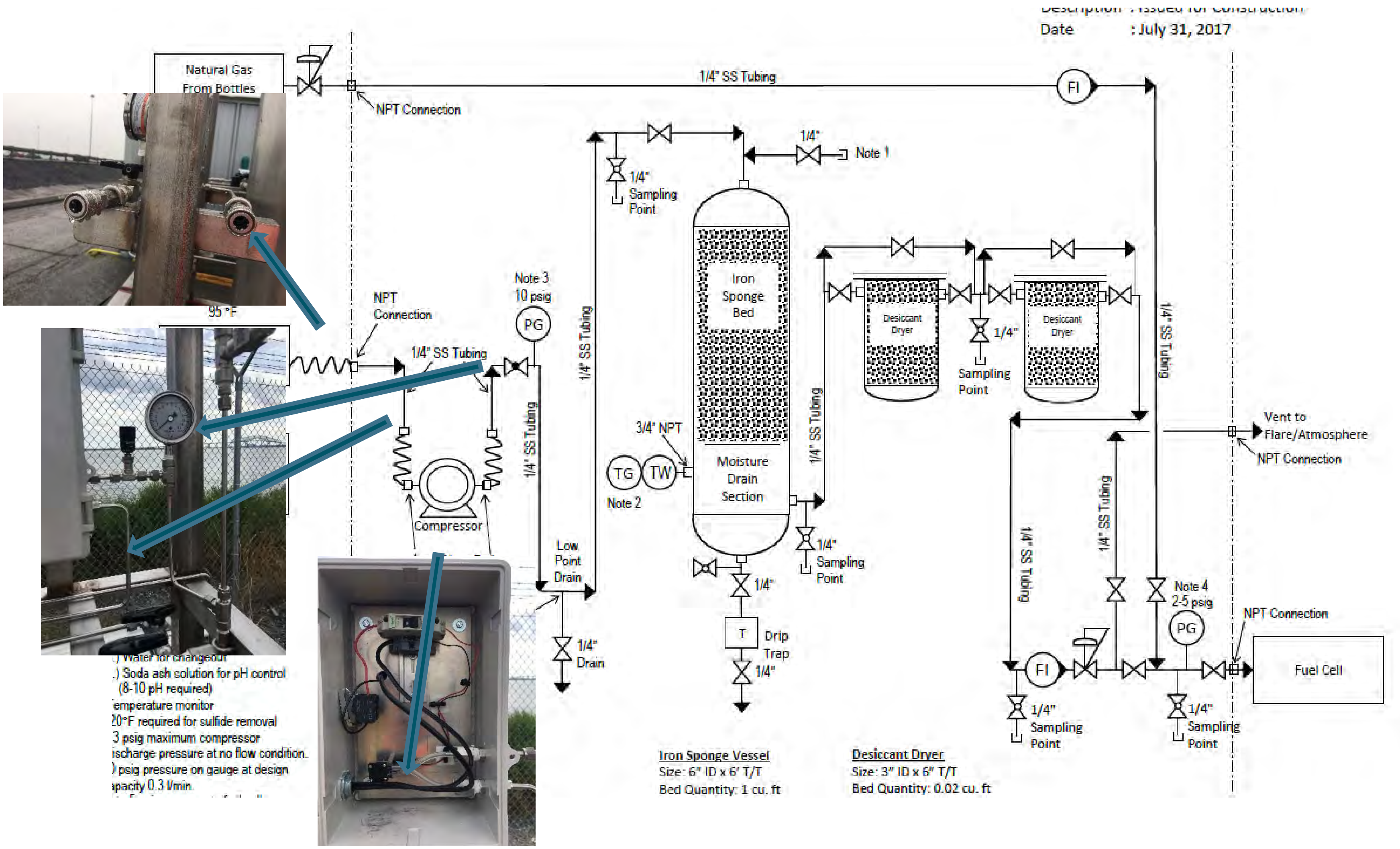
Gas Conditioning Unit – Reduce H2S and H2O



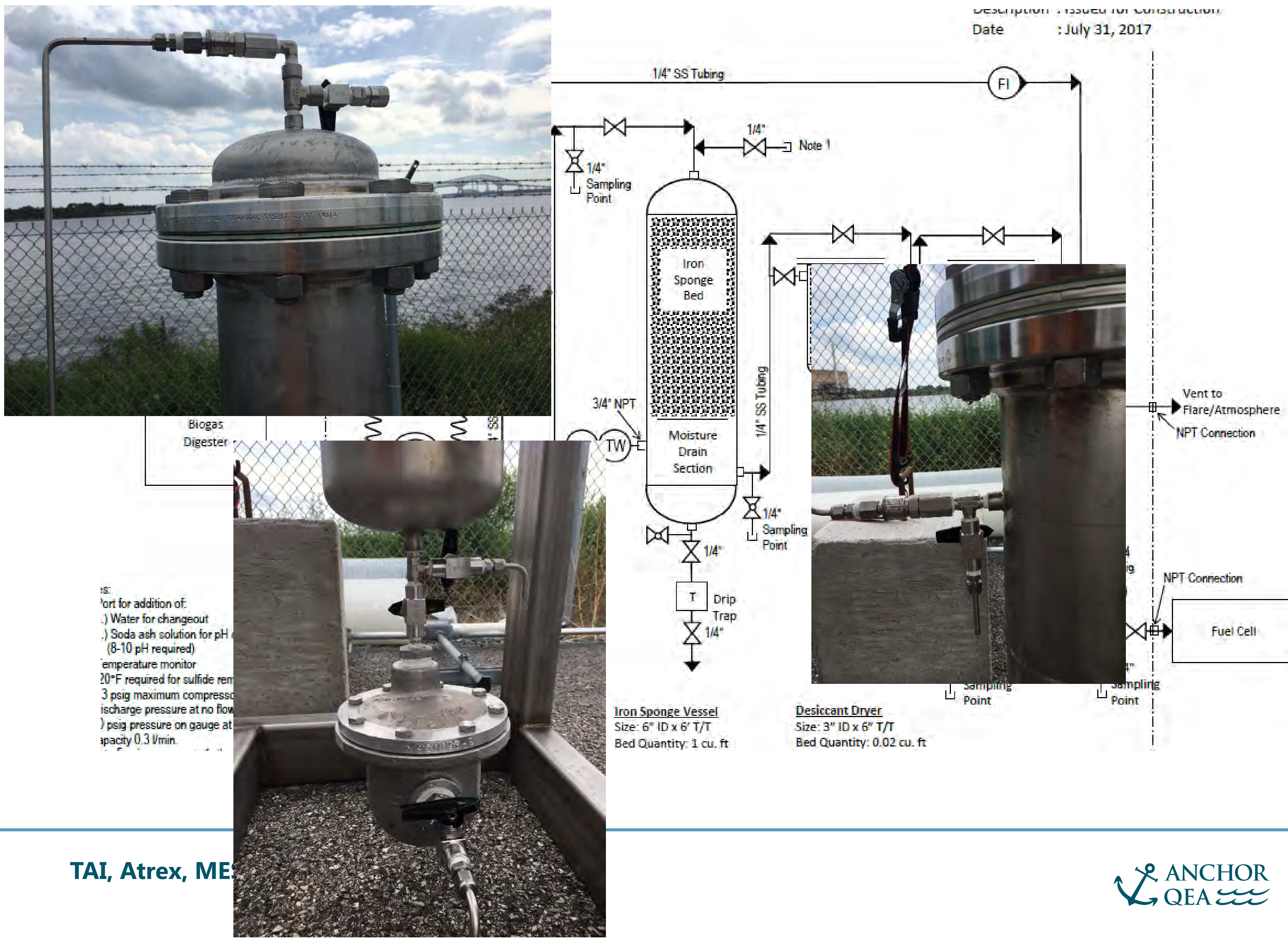
Gas Conditioning Unit – Methane Connections



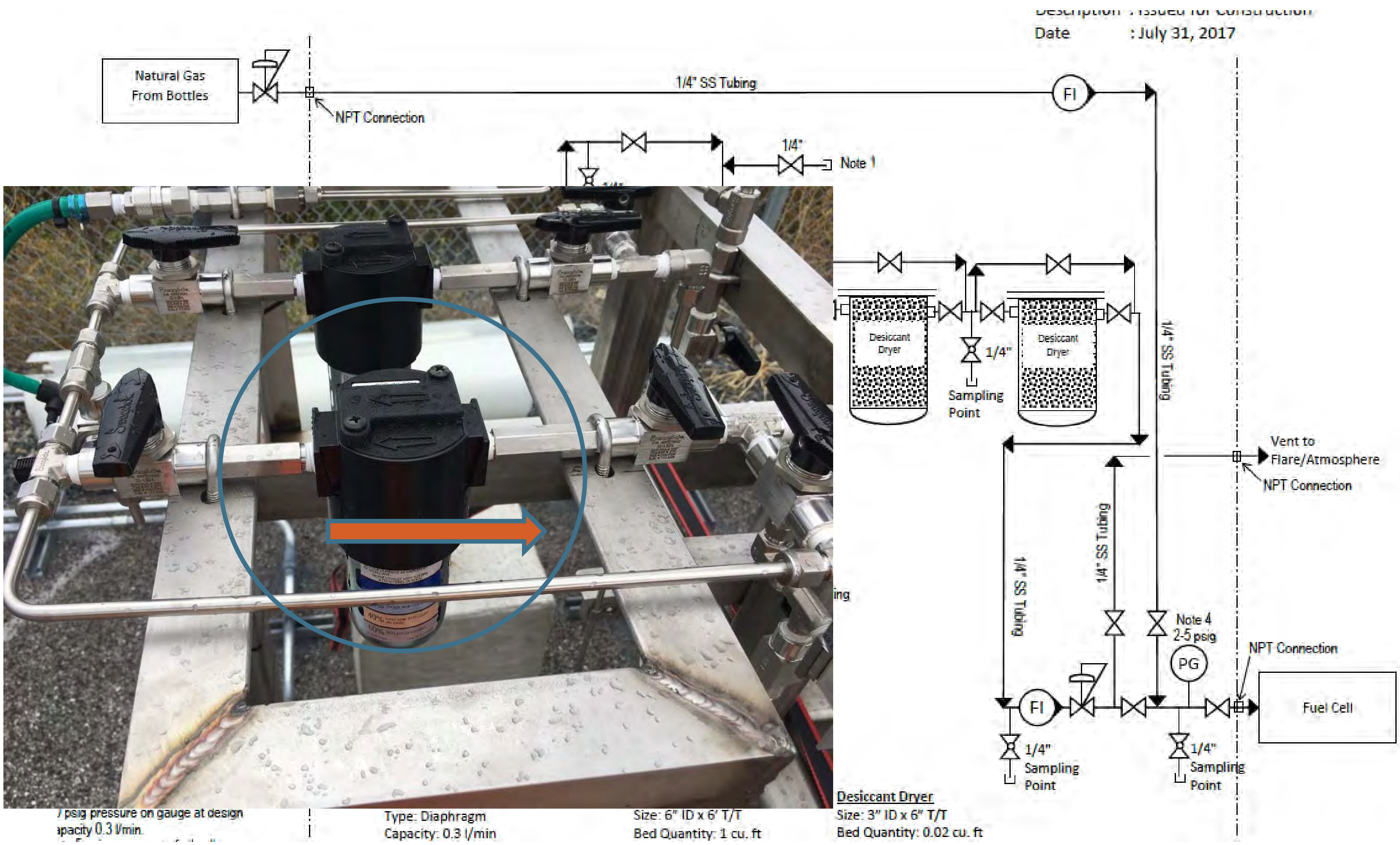
Gas Conditioning Unit – Diaphragm Pump



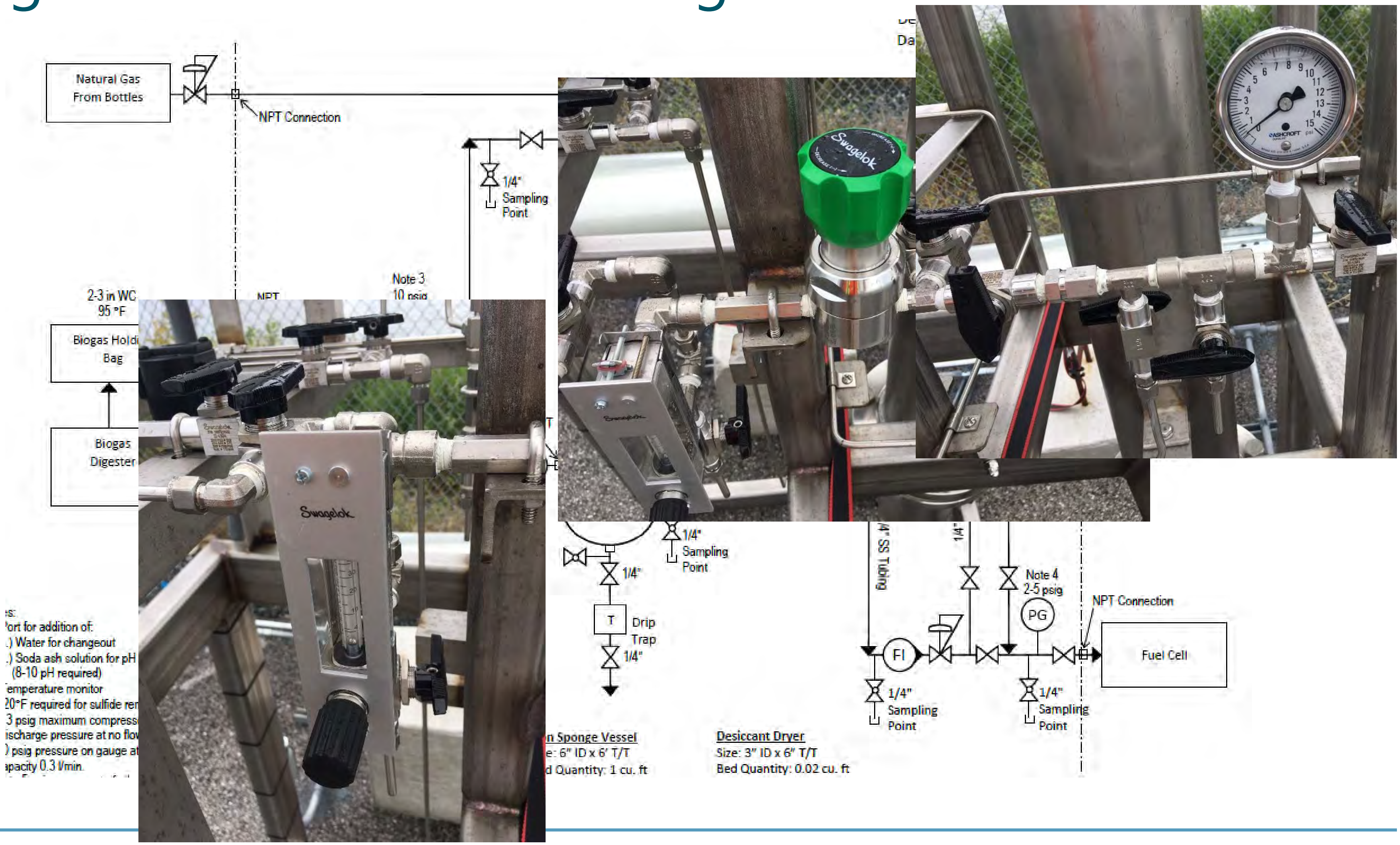
Gas Conditioning Unit – Iron Sponge



Gas Conditioning Unit – Desiccant Dryers



Gas Conditioning Unit – Flow Meter,Pressure Regulator and Pressure Gauge

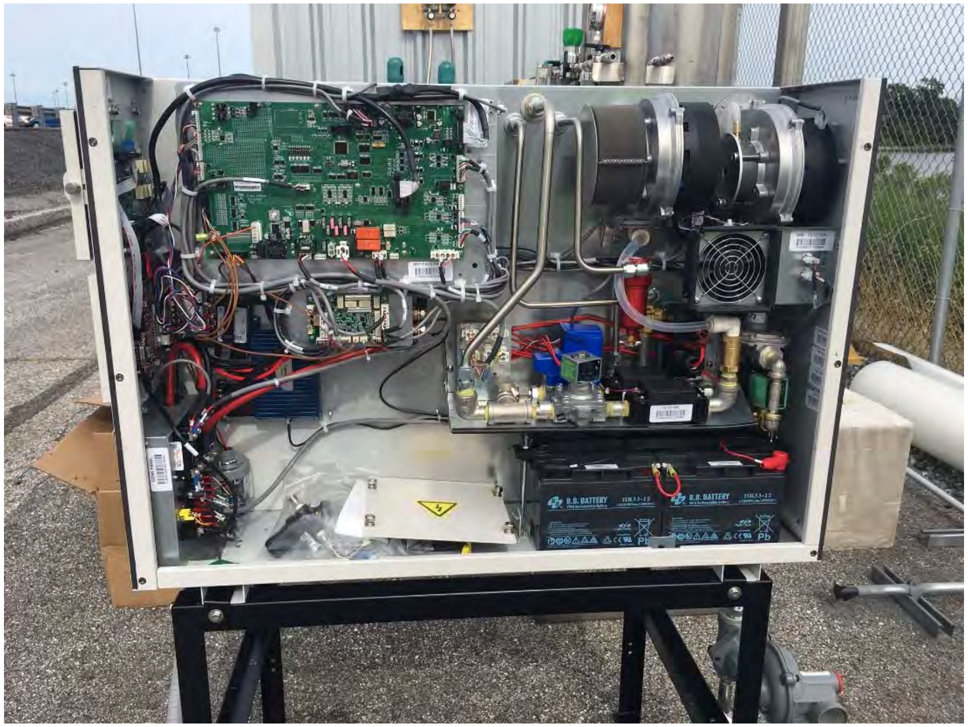


Fuel Cell

FLOW
Parker
MAXIMUM RATINGS
HN2S-4CA
1/2 NPT COALESCING HSG
W/ AUTODRAIN
Assembled In USA
PASSED QC CHECK
NAME MD
DATE 7-25-17

DC VOLTAGE OUTPUT: 5 TO 60 VDC, ADJUSTABLE
OPERATIONAL ELEVATION: 0 – 8000 FEET (2438 METERS)
FUEL SUPPLY PRESSURE: 2 TO 5 PSIG (13.8 TO 34.5 kPa)
FUEL INPUT AT RATED POWER: 7350 BTU/HR (2160 WATTS)
OPERATING TEMPERATURE: -40° F TO 122° F (-40° C TO 50° C)
FOR OUTDOOR AND NON-RESIDENTIAL INDOOR USE
SERVICE BY TRAINED AND AUTHORIZED PERSONNEL ONLY
Read equipment manufacturer's manual before using this product

Fuel Cell



MARYLAND ENVIRONMENTAL SERVICE

SAFETYWORKS

Job Hazard Analysis

Task: Concoa 526 Switchover System Installation and Operations	**Facility: Dundalk Marine Terminal (DMT)/Biogas Fuel Cell Demonstration Project**
Prepared by: Bryce Selby, Andrew Blair, and Elaine Darby (Anchor QEA) Date: 10/9/2017	Reviewed by: Date:
Approved by: Date:	Date JHA was revised: Revision by:
Equipment Operated: High pressure cylinders, regulator manifold, and gas hoses	Physical Demands: Handling 5 ft cylinders, connecting and disconnecting hoses

Recommended Personal Protective Equipment (Check Box and List Type):

☐ Head/	☒ Hand/ work gloves/ nitrile gloves	☒ Foot/ Steel toe boots	☐ Hearing/	☒ Eye/ Safety glasses
☐ Face/ face shield	☐ Torso/	☐ Leg/	☐ Electrical/	☐ Respiratory/

Environmental Conditions:	Open weather conditions
Special Equipment:	Large wrench (don't over tighten connections -have on hand to remove cylinder caps and untighten connections)
Special Precautions:	No smoking in the area.
Specialized Training:	Review attached Concoa 526 Series Automatic Switchover System Installation and Operation Instructions
Testing/Monitoring Equipment:	Liquid soap to apply to hose connections to check for leaks

Sequence of Events	Potential Accidents/Hazards	Preventive Measure
Secure and store tanks in brackets	Pinching between tanks, support brackets; dropping a tank and having it hit the ground or other equipment; sliding the tank on a foot	Use two people to support and move the tanks into the brackets. Regularly check the brackets that they are secure on the support structure. Store cylinders with valve caps screwed on.
Secure high pressure hoses from the manifold to the cylinders	Pinching while attaching; high pressure gas leakage	All valves should be closed upon initial connections. This manifold has 4 hoses for feed from 4 cylinders. See pages 9-10 for connecting to a cylinder
Pressurizing the system	Leakage of high pressure gas	Turn the regulator knob counterclockwise unit it stops (close the regulator valve). Do not stand directly in front of the switchover system. Slowly open the valves on the cylinders. The inlet gauges should read 2000+psig on new cylinders. Test the connections between the manifold and the cylinders for leaks with liquid soap. Stop, close cylinder valves before tightening leaking connections. Check that downstream valves in the methane/natural gas line is closed. Slowly turn the regulator knob counterclockwise, stop when top gauge is at 5 psig.

Operating the system	Leakage of high pressure gas; pinching between cylinders; dropping cylinders	The arrow on the priority valve (black valve with arrow) always points to the primary side; the bank (2 tanks in a bank for our system) opposite the primary side is considered the reserve side. Starting with the arrow pointing to the right side, gas will flow from the right side cylinders. As gas in the primary side is depleted, the gas pressure will drop on the gauge of the primary regulator. When the pressure drops to the pressure setting of the reserve side regulatory, flow will begin from the reserve cylinders; inlet pressure on the primary side will stabilize (this is a changeover). It is time to change the cylinders on the primary side. First – rotate the priority valve 180 degrees so it points to the side now supplying the gas. Close the valves at the cylinders on the empty side. Carefully remove the high pressure hose from the empty cylinders at the cylinders. Secure cylinder valve caps. Replace the depleted cylinders with full cylinders. Secure high pressure hoses. Carefully open the cylinder valves and check for leaks.
Handling full and empty cylinders	Leakage of high pressure gas; pinching between cylinders; dropping cylinders	Each bank of cylinders (2 cylinders) may require changing every 5 to 6 days. Off-site storage of full and empty cylinders will be needed. MES will identify secure location and keep full and empty cylinders clearly segregated and marked. All stored cylinders need to be secured with a chain to keep them falling in the event of someone or something bumping the cylinders. Stored cylinders must always have valve caps securely screwed on.

Installation, Operation and Maintenance Manual for Atrex Energy ARP™ Series Remote Power Systems

Model numbers ARP500NU, ARP500PU, ARP1000NU, ARP1000PU, ARP1500NU, ARP1500PU

The Atrex Energy ARP Generator is a quiet, clean and reliable DC power generator based on fuel cell technology to serve remote, off grid applications. This manual describes the major components of the system and how to install, operate, troubleshoot and maintain the generator.

IMPORTANT SAFETY INSTRUCTIONS

__Save These Instructions.__ This manual contains important instructions that should be followed during installation, use and maintenance of the ARP Generator. Read all the instructions before operating the equipment. Save this manual for future reference.

WARNING:
FIRE OR EXPLOSION HAZARD
Failure to follow safety warnings exactly could result in serious injury, death or property damage.

- Do not store or use gasoline or other flammable vapours and liquids in the vicinity of this or any other appliance.
- Installation and service must be performed by a qualified installer, service agency or the gas supplier.

19 Walpole Park S Walpole, MA 02081 (800) 332-0277 www.atrexenergy.com

Table of Contents

1.0 General Hazards

- Atrex Energy recommends that onsite installation and initial operation is undertaken with the assistance of factory certified personnel.
- Only factory trained service personnel are to perform repairs. Annual maintenance may be performed by personnel whom have undergone the appropriate training.
- Do not modify the generator in any way (contact the manufacturer).
- To prevent injury to personnel or equipment damage, use proper lifting equipment (fork lift, pallet jack, hoist, etc.) to move this equipment during installation. Once installed and connected to gas supply, do not attempt to move the equipment.
- The area surrounding the generator must be kept clear and free of combustible materials, gasoline and other flammable vapours and liquids (refer to Installation section).
- Do not obstruct the air inlet or exhaust vents in the cabinet or the air openings to the area which the generator is installed (refer to Installation section). A blocked vent may lead to reduced power output, generator damage, overheating and generator failure.
- • Do not use this generator if any part has been under water. A flood-damaged fuel cell is potentially dangerous. Attempts to use the fuel cell can result in fire or explosion. A qualified service agency should be contacted to inspect the fuel cell and to replace all gas controls, control system parts, electrical parts that have been wet.
- Ensure all enclosure covers are installed during normal operation of the generator.
- If troubleshooting of the system requires removal of the enclosure covers during operation, exercise care when doing work inside the fuel cell compartment. The surface temperature of the fuel cell module can reach temperatures exceeding 60 °C (140°F).
- Know how to shut the generator off quickly in case of emergency (refer to the Shutdown section).
- Indoor units must have proper room inlet air and exhaust ducting to the outside (refer to Installation section). The ARP generator is intended for non-residential indoor use.
- Excessive exposure of the generator to contaminated air may result in safety and performance related problems.
- The generator is not to be used by persons (including children) with reduced physical, sensory or mental capabilities, or lack of experience and knowledge, unless they have been given supervision or instruction.
- See additional Hazards on the following pages.

1.1 Electrical Hazards

- HIGH VOLTAGE is used in the operation of this equipment. DEATH ON CONTACT may result if personnel fail to observe appropriate safety precautions.
- The generator must be connected to an approved earth ground.
- Ensure all enclosure covers are installed during operation.
- When accessing or working within the electronics compartment, ensure you are standing on an insulated, dry surface to reduce shock hazard.
- Remove jewelry when working within the generator. Metal jewelry posses a shock hazard.

1.2 Battery Hazards

- The batteries used by this generator contain lead and pose a hazard to the environment and human health if NOT disposed of properly. Proper disposal of the batteries is required. Please refer to local codes for proper disposal requirements or return the unit to a factory authorized Service Center for battery replacement or disposal.
- Lead-acid batteries are used in this equipment. Do not use any battery that shows signs of damage such as: bulging, swelling, disfigurement, brown liquid in plastic wrap, or inflated plastic wrap and leakage.
- Personnel familiar with the danger of batteries should perform battery replacement. Keep unauthorized personnel away from the batteries. Do NOT smoke near batteries. Sparks, flames or other sources of ignition may cause a battery explosion.
- Use gloves and wear protective eye equipment whenever working with batteries.
- When replacing the batteries, ensure the connectors located below the power electronics chassis do NOT come in contact with any metals, liquids, etc. A risk of electrical shock and high short circuit current may exist.
- A battery can present a risk of electrical shock and high short circuit current.
- When replacing batteries, wristwatches and jewelry such as rings should be removed. Use tools with insulated handles.

1.3 Fire and Heated/ Hot Surface Hazards

- The ARP Generator contains internal components that operate at HIGH TEMPERATURES and contain areas of combustion.
- Ensure generator is installed, operated and maintained in accordance with the manufacturer's instructions.
- The fuel cell compartment operates at elevated temperatures. Some components and surfaces within the fuel cell compartment may at times exceed 60 °C (140°F). Introducing combustible material into the fuel cell compartment is not recommended.
- Keep a fire extinguisher near the generator at all times. Ensure fire extinguisher is suitable for use with electrical systems (ABC rating, NFPA). Ensure fire extinguisher is kept charged and that the appropriate staff are familiar with its use.

1.4 Explosion Hazards

- Sparks, flames or other sources of ignition may cause a GAS EXPLOSION. Follow safe gas handling procedures, including restricting smoking or other sources of ignition around this unit.
- Ensure fuel system is installed, operated and maintained in accordance with the instructions included in this manual.
- Gas pressure to the unit must not exceed the nameplate rating. If the supply system is such that gas pressure exceeding the nameplate rating is possible due to upstream component malfunction, a suitable pressure relief valve – limiting the maximum pressure – should be installed upstream of the unit.
- Ensure system installation is undertaken according to applicable codes.
- Fuel system leak testing should be conducted in accordance with the maintenance schedule.

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2.0 Standards Index

The ARP Generator has not been certified by a recognized testing laboratory. However, the standards below may also be referred to for safe installation of the generator.

UL 1950, 3rd Edition, March 1, 1998	Safety of Information Technology Equipment
IEEE/ANSI C62.41-1991, Category B3	IEEE Guide for Surge Voltages in Low Voltage AC Power Circuits
FCC 47 CFR Ch 1 (10-1-96), Part 15	Subpart B, paragraph 15.107 specifies conducted limits. Paragraph 15.109 specifies radiated limits. Additional paragraphs specify manual and equipment markings.
NFPA 54	Fuel Gas Code
NFPA 70	National Electric Code
NFPA 255	Standard Method of Testing of Surface Burning Characteristics of Building Materials
NFPA 853	Standard for the Installation of Stationary Fuel Cell Power Systems
EN60950	Safety of Information Technology Equipment
EN61326	Electromagnetic Compatibility Standard
CAN/CSA C22.1-12	Canadian Electrical Code
ANSI/CSA FC1-2014	Fuel cell technologies — Part 3-100:
	Stationary fuel cell power systems — Safety
CAN/CSA-22.2 No. 62282-3-100:15	Fuel cell technologies — Part 3-100:
	Stationary fuel cell power systems — Safety

3.0 Introduction

3.1 Overview

The ARP Generator is a high efficiency, natural gas or propane fueled generator based on Solid Oxide Fuel Cell (SOFC) technology developed by Atrex Energy. The ARP Generator is an excellent option for the supply of DC power for off grid applications.

A fuel cell generator is an electrochemical device that converts fuel directly into electricity in the presence of heat. The system is equipped with a specially developed Local User Interface (LUI) and a Control System capable of providing fully automatic operation of the fuel cell generator. It monitors key Gas Utility Module, Fuel Cell Module and Power Electronics variables allowing for unattended operation of the system. See Figure 1.

Figure 1 System Overview

3.2 System Components

The ARP Generator consists of the following major system components shown Figure 2, 3 and 4.

3.2.1 The Local User Interface provides for operator control and monitoring of the generator through an LED display and multi-function buttons.

3.2.2 The Electrical Connection Panel contains the circuit breakers, remote monitoring connections and power output of the unit.

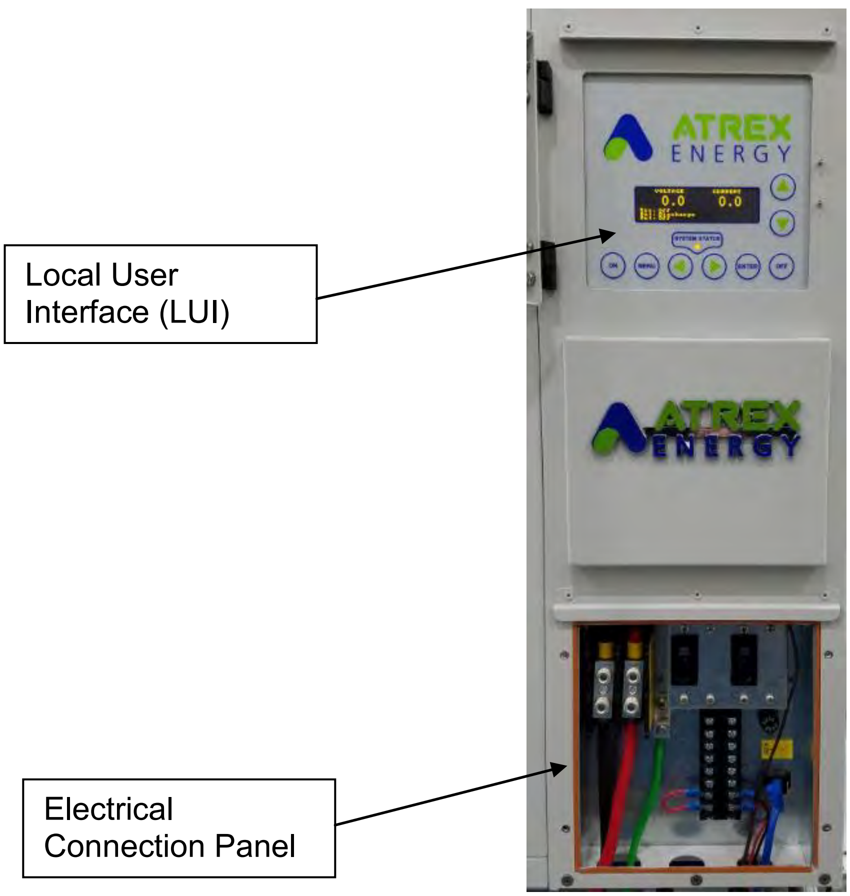

Figure 2 System Components

3.2.3 The Electronics contains the controller, power converter, safety circuit, battery charger and batteries.

3.2.4 The Gas Utility Module (GUM) supplies air and fuel to the Fuel Cell Module and includes flow meters, blowers, valves and air filters.

3.2.5 The Start-up Batteries are used to supply power to the system during startup and shut down and prolonged standby mode for local and remote operation.

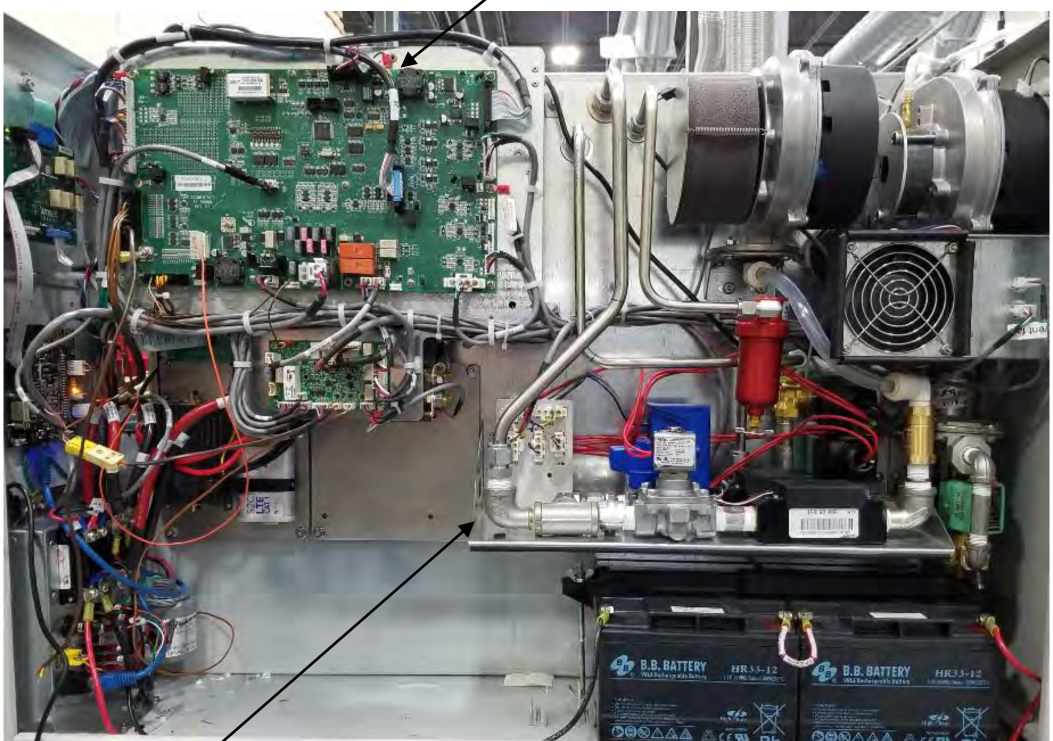

Figure 3 System components

3.2.6 The Desulfurizers remove sulfur from the fuel and are mounted on top of the Fuel Cell Module.

3.2.7 The Fuel Cell Module (FCM) consists of the bundle, heat exchanger and the burner igniter housed in a thermally insulated enclosure.

3.2.8 The Replaceable Bundle contains the cells that produce the electricity.

3.2.9 The Igniter is used to heat up the bundle to start the chemical reaction that produces the electricity.

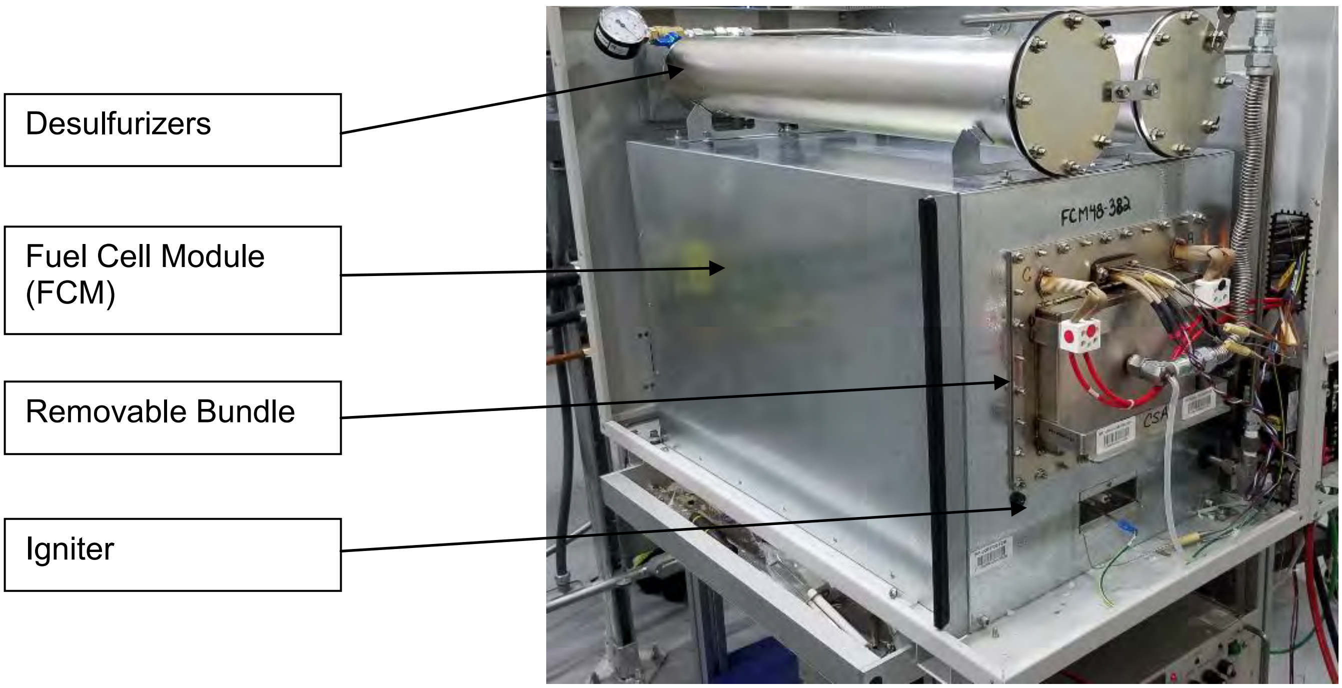

Figure 4 - Fuel Cell Compartment

4.0 Installation

⚠ **NOTICE:** Read all installation instructions before installing the generator.

4.1 Shipping

The ARP Generator is shipped on a custom shipping pallet which includes vibration isolation. The generator is sensitive to severe vibration and sudden impact. The generator should always be transported on its shipping pallet. Exercise caution while handling the shipping pallet. The shipping pallet can be moved using either a forklift truck or pallet mover. The Replaceable Bundle is shipped in protective packaging and must always be transported while in its packaging.

⚠ **NOTICE:** Do not remove the generator from the shipping pallet until the generator is installed in a fixed location.

⚠ **NOTICE:** Do not remove the replaceable bundle from its packaging or install the replaceable bundle into the generator until the generator is installed in a fixed location.

4.2 Inspection

Carefully inspect the pallet and its contents for signs of damage. Shipping damages are not covered under warranty. If there is obvious packaging damage upon receipt, customers should contact Atrex Energy at FieldService@AtrexEnergy.com or (800)-332-0277 and Atrex Energy may advise the customer to make a claim with the carrier.

4.3 Unpacking

Tools Required for Unpacking:

Metal strap cutters

The generator should be installed as per instructions below. The lifting weight of the generator is 300-350 lbs (135-160 kg), depending on the power level. The generator should be lifted with a suitable lifting device such as a fork truck or with 4 personnel. If personnel are utilized to lift this device, proper lifting training and personal protective equipment should be used.

⚠ **WARNING:** Do not lift the generator by the plastic handles on the enclosure covers. Serious injury or damage to the equipment may result.

4.4 Bundle Installation

The replaceable bundle box should be stored in a safe and dry location until the generator is installed in a fixed location. The replaceable bundle will then be unpacked and installed into the generator by factory trained service personnel. Reference bundle installation manual 91-0181.

4.5 Dimensions

Figure 5 below give the overall size of the generator enclosure, the key dimensions and the location of fuel and electrical connections, the air inlet and exhaust. All dimensions are in inches.

	A	B	C	D	E	F	G	H	I	J	K	L	M
ARP500	13.7	7.5	8.4	25.7	24.6	39.2	35.1	3.3	24.6	21.5	6.4	6.9	22.1
ARP1000/1500	19.3	13.2	8.4	25.7	24.6	39.2	35.1	3.3	24.6	27.1	9.9	6.9	27.8

Note: Dimension F changes to 42.2 when using the ARP500/1500 Exhaust Adapter.

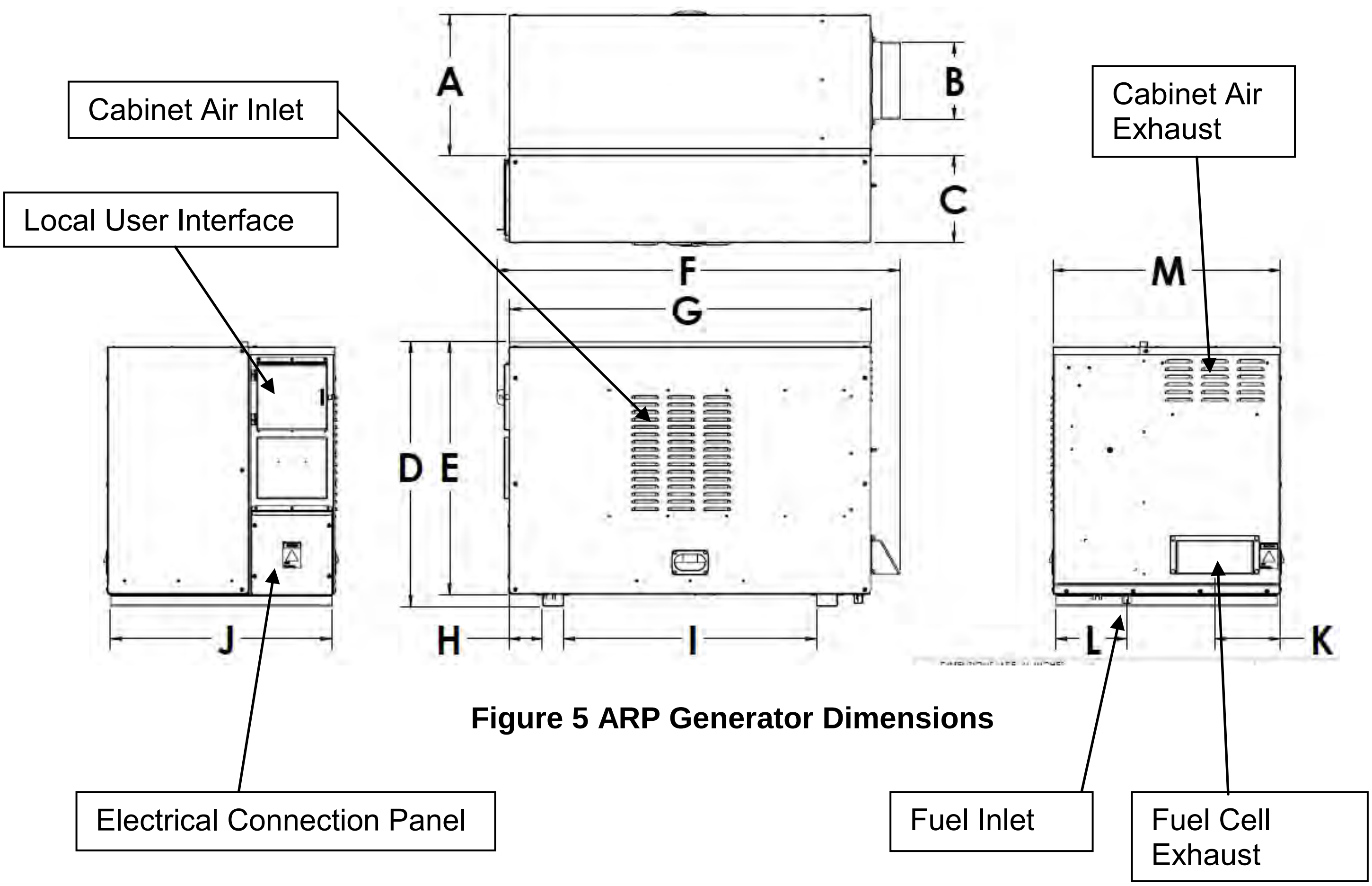

Figure 5 ARP Generator Dimensions

4.6 Site Requirements

<u>Mounting</u>

The ARP Generator is designed for indoor (non-residential) and outdoor use. The ARP Generator should also be raised off the ground to protect from damage and allow for proper gas connection and conditioning. For outdoor installations, insure that the generator is installed above the base flood elevation and that the exhaust is located above the highest possible snow line. The recommended clearances are shown in Figure 6.

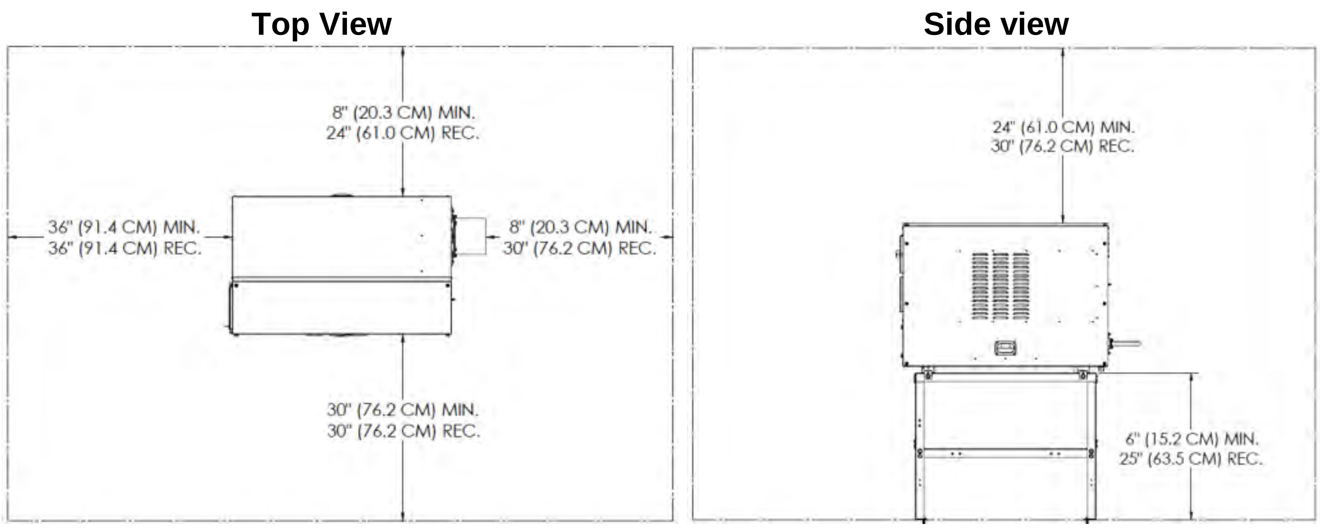

Figure 6: Minimum and Recommended clearances

The ARP Generator is designed for mounting on a field stand. An optional field stand may be purchased for the generator, part numbers ARP500-FS for 500W generators and ARP1500-FS for 1000/1500W generators. The drawing gives the field stand details and is provided with the field stand.

The field stand should be mounted to a suitable base. A 30” x 36” x 4” concrete slab is recommended with attachment of the field stand via (4) 3/8” sleeve anchors or other suitable fasteners. The generator enclosure should be carefully placed on the field stand and secured using the mounting hardware provided.

If a customer supplied field stand is to be utilized, Atrex Energy will provide further attachment instructions. Contact Atrex Energy if some other form of mounting is desired such as direct mount to an equipment pad.

Elevation Compensation

The burner fuel flow on the ARP Generator is controlled by an orifice in the burner fuel line and an internal pressure regulator that ensures pressure at the inlet side of the orifice remains constant. The burner fuel flow is not actively controlled except for opening and closing a solenoid valve.

The correct size orifice is to be used for each generator type for given elevations at 2,000 foot increments up to 8,000 feet, the maximum rated elevation of the ARP Generator. The table below gives the orifice size to be utilized at each elevation range for the different size generators and fuel types.

	ARP500 Natural Gas		ARP500 Propane		ARP1000/1500 Natural Gas		ARP1000/1500 Propane	
Elevation (ft)	Part Number	Orifice (in)	Part Number	Orifice (in)	Part Number	Orifice (in)	Part Number	Orifice (in)
0-2000	ARP500N-EL2	0.052	ARP500P-EL2	0.040	ARP1500N-EL2	0.073	ARP1500P-EL2	0.052
2001-4000	ARP500N-EL4	0.049	ARP500P-EL4	0.038	ARP1500N-EL4	0.070	ARP1500P-EL4	0.049
4001-6000	ARP500N-EL6	0.049	ARP500P-EL6	0.037	ARP1500N-EL6	0.067	ARP1500P-EL6	0.049
6001-8000	ARP500N-EL8	0.047	ARP500P-EL8	0.035	ARP1500N-EL8	0.063	ARP1500P-EL8	0.047

4.7 Indoor Use

The ARP Generator is intended for non-residential indoor use. When installing in a protective shelter of any kind, where extra protection from the environment is desired, the generator must be set up for indoor use with the exhaust system components specified below.

An Atrex Energy exhaust transition is required to provide a transition from the fuel cell module rectangular flange to a 4” diameter exhaust tube for connection to third party exhaust system components. For the ARP 500 generator, this transition is available as an exhaust adapter P/N ARP500-EXH, and for the ARP1000/1500 exhaust adapter P/N ARP1500-EXH.

The exhaust system is to consist of a maximum of 10’ of 4” diameter straight duct and a maximum of (3) 90 degree 4” diameter elbows. The exhaust system must be rated for positive pressure and a maximum exhaust temperature of 250^{o} C (480 ^{o} F) The vent termination should have a minimum open area equal to the 4” diameter pipe or equivalent and protect against blockages such as tree limbs or animals nesting.

The table below specifies the required exhaust system components. Atrex Energy provides these exhaust system components as accessory items. Please contact Atrex Energy or your local distributor for details and pricing on the exhaust system components.

Atrex Energy Part Number	Manufacturer's part number and description
ARP500-EXH	Atrex Energy ARP500 exhaust adapter, 4" duct
ARP1500-EXH	Atrex Energy ARP1000/1500 exhaust adapter, 4" duct
ARP-EX1	DURAVENT FasNSeal FSTB4 OR EQUIVALENT
ARP-EX2	DURAVENT FasNSeal W2-3604 OR EQUIVALENT
ARP-EX3	DURAVENT FasNSeal W2-WT4 OR EQUIVALENT
ARP-EX4	DURAVENT FasNSeal W2-9004 OR EQUIVALENT
ARP-EX5	DURAVENT FasNSeal W2-AA4 OR EQUIVALENT

Figure 7 shows a typical equipment shelter exhaust system configuration. The equipment shelter must have sufficient intake louver capacity to supply a minimum of 300L/min of air to the ARP Generator.

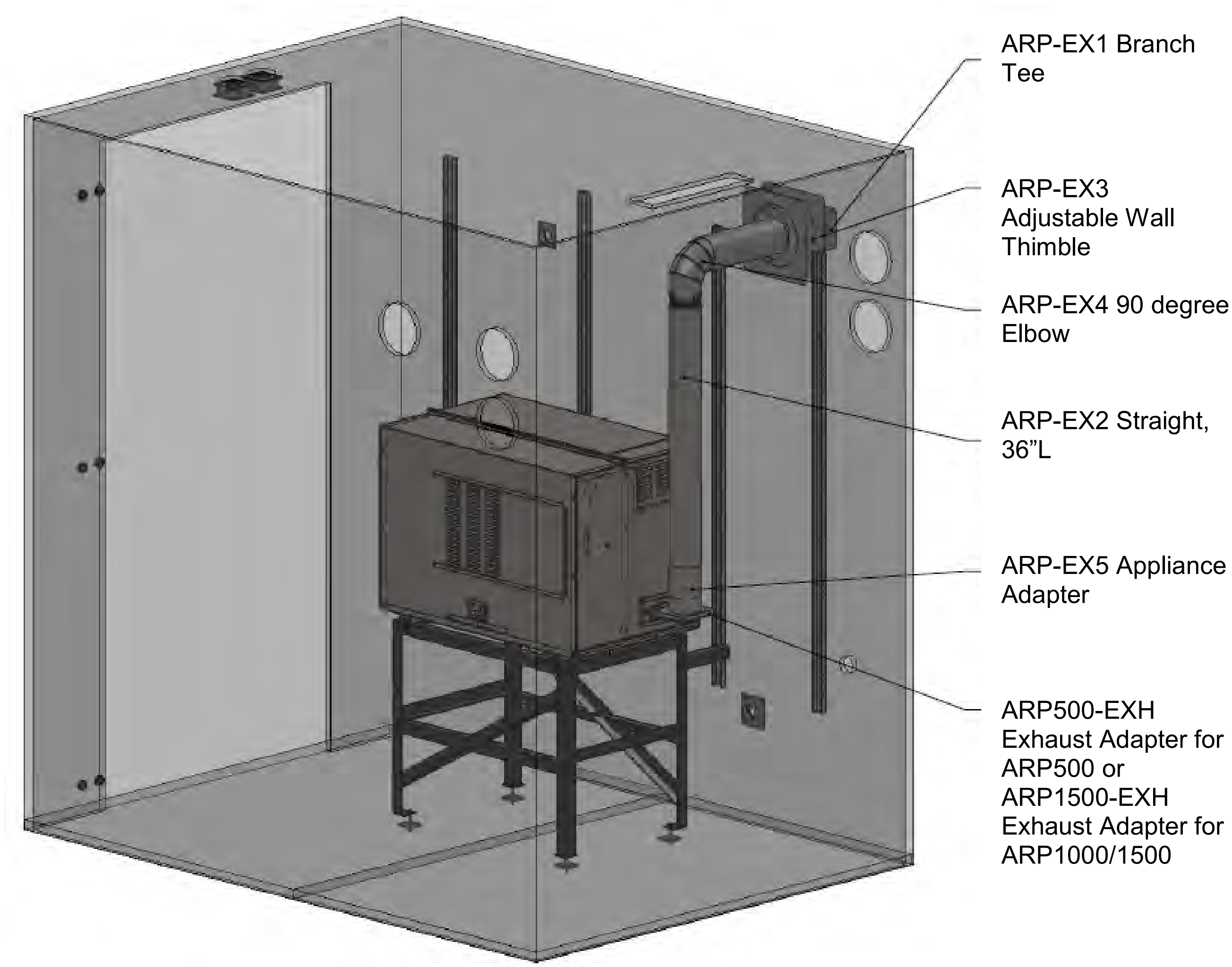

Figure 7: Indoor Use Ventilation

Because the ARP Generator removes nearly all sulfur compounds from the incoming fuel gas rendering the gas undetectable by the sense of smell, a fuel gas detector should be located within the equipment shelter to warn of possible fuel leaks. This detector can be interlocked with the Estop circuit to automatically shutdown the system in the event of gas detection in the shelter. As with all fossil fuel appliances, a carbon monoxide detector should also be included in the space.

4.8 Gas Connection

⚠ **WARNING:** The following information pertaining to gaseous fuel systems is provided to assist gaseous fuel technicians in planning installations. In no way should this information be interpreted to conflict with applicable fuel gas codes. Consult applicable local codes.

Fuel Type

The ARP Generator is available in natural gas and propane models. The customer is responsible for ensuring that the correct fuel gas is supplied to the generator. A system label will specify the fuel type.

The customer is responsible for ensuring that the gas sulfur content meets the specifications of the product. If gas with higher than specified sulfur contents is to be utilized, the fuel gas desulfurizer will need to be replaced more often. Atrex Energy should be consulted to determine the replacement schedule for the fuel gas desulfurizer.

Fuel Requirements

The ARP Generator is supplied with an upstream Fuel Pressure and Regulator Kit, part numbers ARP-HWN for natural gas and ARP-HWP for propane generators. Each contains a fuel pressure regulator, coalescing filter and manual shut off valve. The allowable inlet pressure into the Fuel Pressure and Regulator Kit is 5-125 PSIG.

A 0-15 PSIG pressure gage is supplied with the Fuel Pressure and Regulator Kit to adjust the fuel pressure into the generator. The generator inlet gas pressure should be adjusted to 2 to 5 PSIG. Gas pressure should be set not less than 2 PSIG and not greater than 5 PSIG to ensure optimum operation.

For indoor generators, the pressure regulator should be installed outside the shelter or have the regulator vent plumbed to the outdoors.

Fuel Connection

The gas supply piping should be sized to deliver 30,000 Btu/hr. With the gas conditioning kit, the inlet size is ½” FNPT for natural gas and 3/8” swage for propane generators.

WARNING: After the gas connection has been established the gas lines internal to the generator need to be leak checked with a combustible gas detector to check that no shipping damaged occurred.

4.9 Electrical Connection

With the Cellular Network connection, the system can be monitored and diagnosed remotely when within the range of a cell signal. Attach the antennae cable to the cell modem connection at the back of the unit as show in Figure 8. Mount the antennae to the top of the enclosure and secure the cable. The antennae must be installed at least 8 inches from any person.

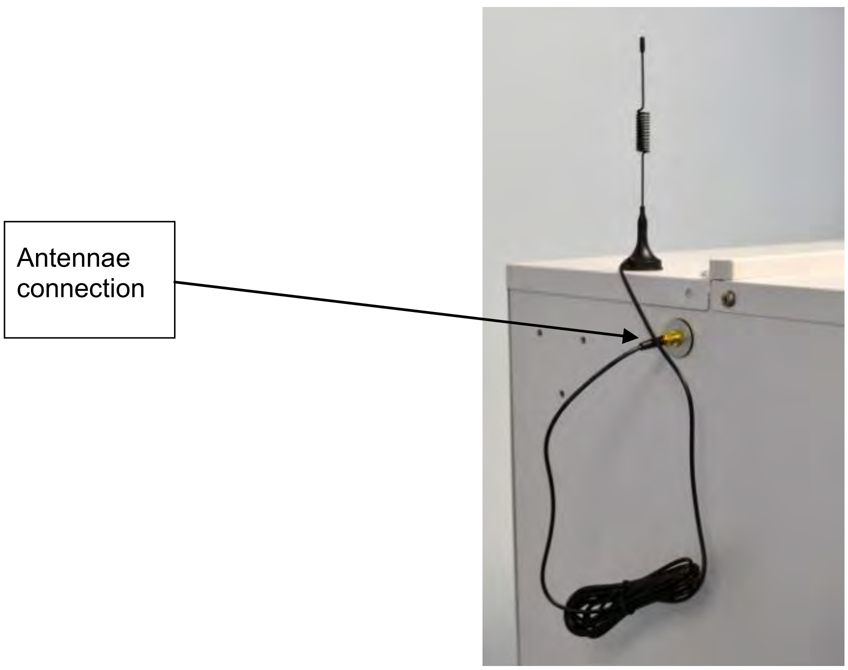

Figure 8: Antennae connection

WARNING: The following information pertaining to electrical systems should in no way be interpreted to conflict with applicable electrical codes. Work should only be undertaken by a qualified electrician.

WARNING: The ARP Generator is a Direct Current (DC) Device; only DC loads should be connected to the generator.

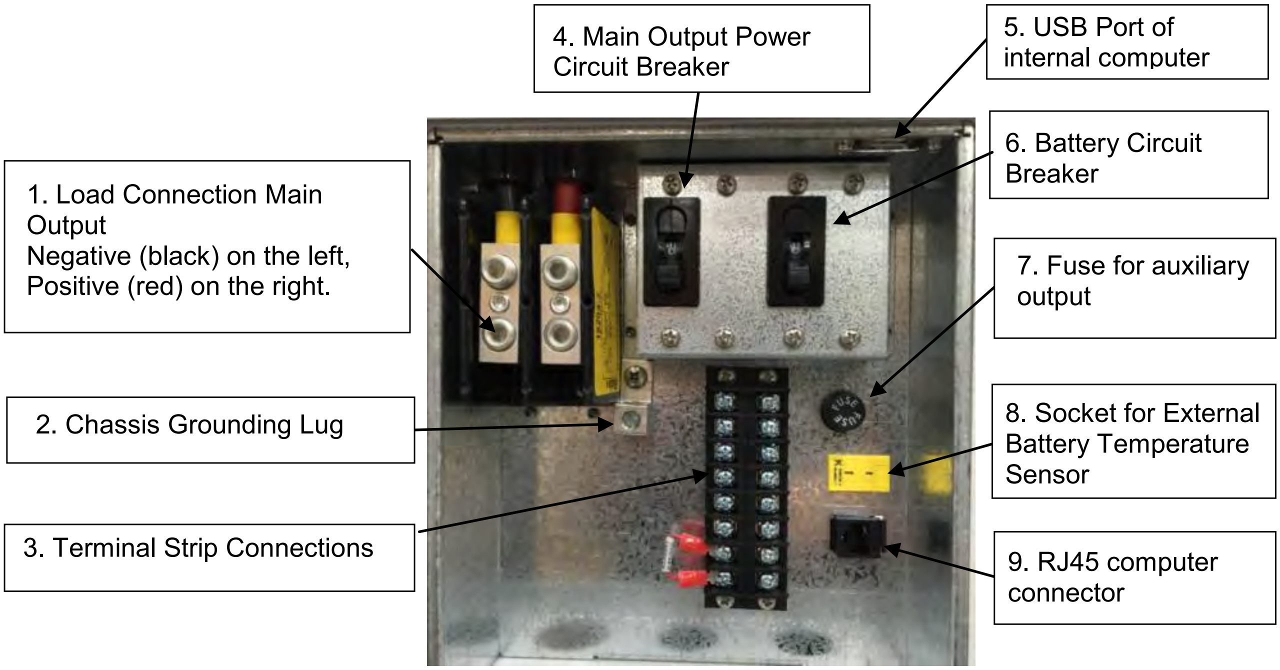

Figure 9: Connection Panel Layout

1. Load Connection to the main output terminal is designed to accept up to a 2 AWG bare wire leads for connection of the user load. Negative (black) is on the left and Positive (red) is on the right. Wires should be stripped 1" from the end, housed in a suitable conduit and strain relieved. Recommended torque is 5.6 N-m or 50 in-lb.
2. Chassis Ground is adjacent to the main output terminal block on the right hand side. Recommended torque is 5.6 N-m or 50 in-lb.
3. The Terminal Strip Connections are used for auxiliary power and data connections. Recommended torque is 1.2 N-m or 10.6 in-lb.
4. The Main Output Power Circuit Breaker disconnects the fuel cell from the load.
5. The USB Port is connected to the USB port of the internal computer and can be used to download data.
6. The Battery Circuit Breaker is connected to the internal batteries. DO NOT turn off the battery circuit breaker unless the system has completely shut down otherwise damage to the bundle or generator may result.
7. The Fuse for the Auxiliary Output supplies power to the auxiliary output at terminal strip pins 3 and 4.
8. A Socket for the External Battery Temperature Sensor is provided for generators that are to be used for external battery charging. A thermocouple socket is provided to allow for sensing of the external battery bank temperature. A 30 ft thermocouple cable is provided and should be placed near the external batteries. Only a "K" type thermocouple should be used. The generator control system will utilize this temperature reading to determine the temperature compensated float voltage. If a thermocouple is not installed when operating in "Battery

Charge" mode, the float voltage will be based on the ambient temperature measured by the ARP controller.

9. The RJ45 computer connector ties into the internal computer for access to the data.

4.10 Terminal Strip Connections

Rly NC	8
Rly NO	7
Rly Com	6
RCI Sig	5
- V24	4
+ V24	3
E-Stop	2
E-Stop	1

16	- V AUX out
15	+ V AUX out
14	RMU Volt
13	RMU Current
12	RMU Comm
11	SCADA Gnd
10	SCADA RX
9	SCADA TX

Figure 10: Terminal Strip Connections

Positions	Function
1 and 2	Emergency Stop (E-Stop) is available to allow the user to install an external emergency stop switch. The emergency stop circuit is a two wire 24VDC, 2A circuit in which interruption of the circuit will stop the output of power and shutdown the generator in a controlled manner. The generator is shipped with a jumper installed on the emergency stop circuit on the terminal strip in the connection panel.
3 and 4	24VDC Power (+V24, -V24) limited to 50W is available as an option. It can be used as an auxiliary output or with the current interrupt option.
5, 12, 13 and 14	Remote Current Interrupt (RCI) and Remote Monitoring Unit (RMU) are available as an option. See the RCI/ RMU instructions for more information.
6, 7 and 8	The Status Relay (Rly) connections are located on the terminal strip. The relay changes state from the normal position to indicate that the system is outputting power.
9, 10 and 11	(SCADA) The ARP series power generator operates as a Remote Terminal Unit (RTU) in a SCADA network. See optional SCADA instructions for more information.
15 and 16	VDC Auxiliary Power (+V AUX, -V AUX) is an additional auxiliary output available as an option.

At the base of the connection panel are (2) ¾" and (1) 1" standard knock out size openings to route power, signal and communication wires and conduits. Install plugs if not used. Conduit fittings used to connect load and auxiliary wires to the unit must include anti-chafing features or a plastic insert. Proper strain relief must be provided.

5.0 Electrical Configuration

All ARP Generators share a common electrical platform with slight variations to achieve the desired operating characteristics**.** gives a schematic of the electrical configuration. An isolation barrier is necessary within the electronics because the signal conditioning circuits of the controller need to be negative-grounded whereas the load output might be positive-grounded (e.g. in certain applications such as telecommunication battery banks). Generators are supplied pre-configured to either constant current, constant voltage or battery charge operating mode.

In general, a generator is brought up to temperature utilizing battery power.   Once operating temperature is reached, the battery charger is enabled to re-charge the internal batteries. Once the batteries are charged, then the output power is enabled to provide power to the load.

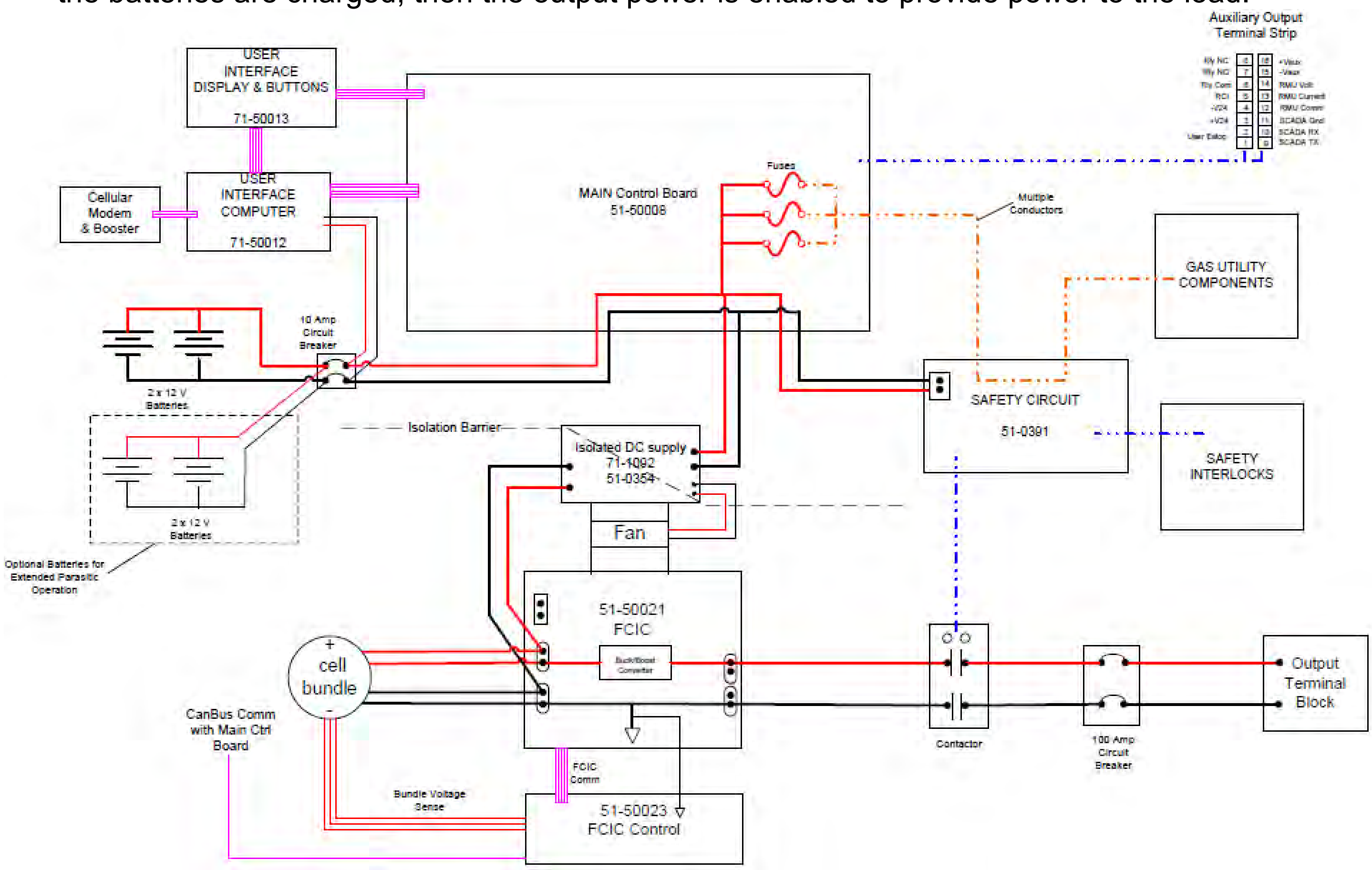

Figure 11: Electrical Schematic

6.0 Operation

System Overview

A fuel cell generator is an electrochemical device that converts fuel directly into electricity in the presence of heat. Because there are few moving parts, airborne noise emissions by the fuel cell are very low, about 52 dB at 1 meter. The system is equipped with a specially developed control system capable of providing fully automatic operation of the fuel cell generator. It monitors key Gas Utility Module, Fuel Cell Module and Electronics variables allowing for unattended operation of the system. The system status, key operating parameters and system faults can be accessed through the Local User Interface (LUI) and data from the system can be downloaded through an Ethernet connection.

6.1 Desulfurizer Bleed Procedure

6.1.1 Verify that the fuel pressure into the generator is between 2 and 5 psi and the fuel pressure into the high pressure regulator and coalescing filter is 5 to 125 psi.

6.1.2 Take the covers off the generator and remove the power cable from the control board. This will prevent the generator from powering up while opening the main safety solenoid. Do this by removing the V130 cable from the GUM electrical interface. Next remove the power cable 82-50048 from the 51-50008 control board and plug it into the V130 cable connection at the GUM electrical interface as seen in Figure 12.

Figure 12: Power cable connection

6.1.3 Close the battery circuit breaker on the right hand side of the connection panel by moving it to the up position. This will open the master safety solenoid.

6.1.4 Remove the plug and open the manual bleed valve near the desulfurizer, see Figure 13.

6.1.5 Before the first startup, bleed the lines for 15 minutes for propane generators and 5 minutes for natural gas generators.

> ⚠ **DANGER:** The odorants used to detect the presence of gas have been removed at this point in the system.

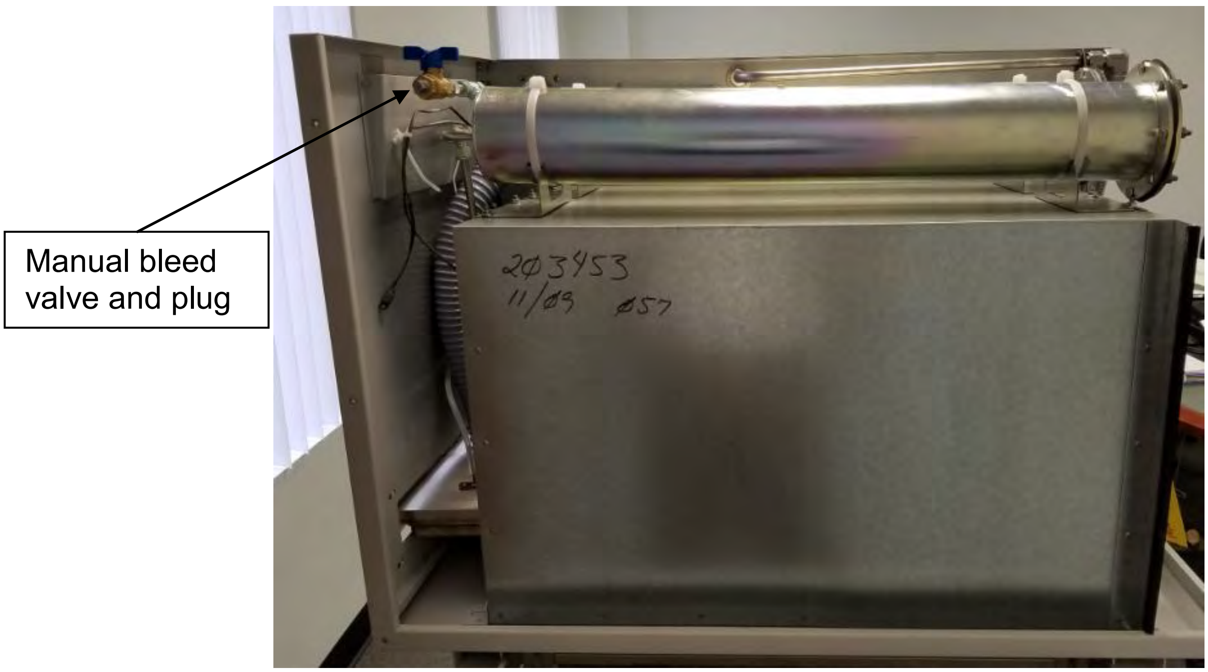

Figure 13: Manual Bleed Valve

6.1.6 Close the manual bleed valve and reinstall the plug.

6.1.7 Open the battery circuit breaker on the right hand side of the Connection Panel by moving it to the down position. Disconnect the 82-50048 power cable from the V130 cable connection at the GUM and reinstall it onto the J18 connector on the 51-50008 control board. Reinstall the V130 cable connection at the GUM electrical interface.

7.0 Precheck List

7.1 Verify that the air intake and the exhaust port are open and free of obstructions. Remove any debris.

7.2 Connect the load (e.g. ground bed or external battery) before starting the system.

7.3 Close the two circuit breakers on the Connection Panel by moving them to the up position. This will energize the control system and connect the load.

7.4 Replace the cover on the Connection Panel only.

7.5 Connect the positive and negative cables to the terminals of the internal batteries.

7.6 Reinstall both halves of the enclosure cover. Replace the Fuel Cell Module (larger) cover first.

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8.0 Local User Interface

The operation of the system is controlled through the Local User Interface Panel (LUI) shown in Figure 14.

Figure 14: Local User Interface (LUI) Panel

8.1 The ON button powers up the LUI and the User Interface computer (UIC).

8.2 The MENU button will go back one screen and return to the HOME MENU.

8.3 The ARROW buttons scroll thru the menu screens of the LUI- up, down, left and right.

8.4 The SYTEM STATUS light will indicate the status of the system according to the following table.

LED	Meaning
Steady Yellow	System Off/Shutdown
Blinking Yellow	Fault
Blinking Green	System Startup
Steady Green	Output Enabled
Off	Main DSP Off

8.5 The ENTER button will navigate to the next lower level of the menu or accept the entered value.

8.6 The OFF button will send the system into the Shutdown mode.

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9.0 Menu Structure

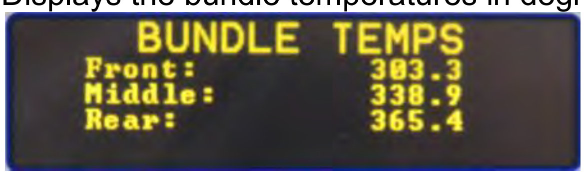
9.1 HOME MENU

Displays the generator output voltage and current. It also lists the states for the System, Battery and Output according to the following table.

Sys (System)	Off, Start, Run, Shutdown, Off
Bat (Internal Battery)	Discharge, Charging, Charged
Out (Output)	Enabled, Off

9.2 BUNDLE TEMPERATURES

Displays the bundle temperatures in degrees C at the front, middle and rear of the bundle.

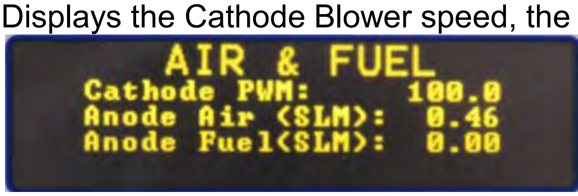


9.3 ENCLOSURE TEMPERATURES

Displays the temperatures inside the enclosure. These are used for troubleshooting.

9.4 AIR & FUEL

Displays the Cathode Blower speed, the Anode Air flow and the Anode Fuel flow rates.



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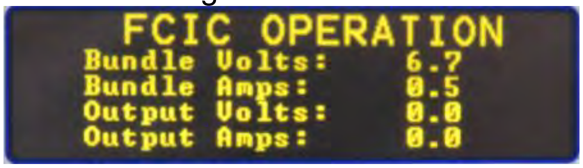
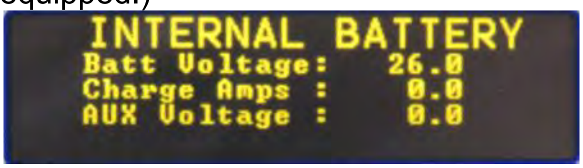
9.5 FCIC OPERATION

Displays the bundle output and the system power output. These are used for troubleshooting.



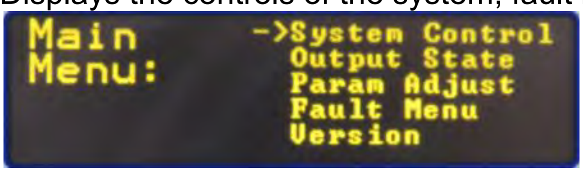
9.6 INTERNAL BATTERY

Displays the Internal battery voltage, charging current and auxiliary voltage output (if equipped.)



9.7 MAIN MENU

Displays the controls of the system, fault information and firmware versions.



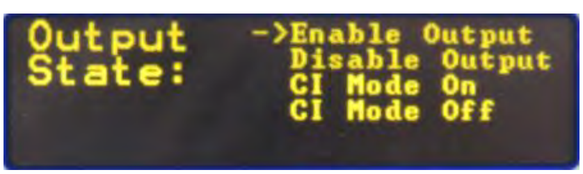
9.8 MAIN MENU>SYSTEM CONTROL

9.8.1 RUN starts the system.

9.8.2 SHUTDOWN starts the shutdown process.

9.8.3 INTERNAL BATTERY DISCONNECT is used for long term shutdown of the unit and disconnects the internal batteries. The system will not be able to be restarted remotely.

9.9 MAIN MENU>OUTPUT STATE



9.9.1 ENABLE OUTPUT will automatically enable the output once the system is turned on, up to temperature and the internal batteries are fully charged.

9.9.2 DISABLE OUTPUT will disable the output and put the system in the Battery Charge state.

9.9.3 CI MODE ON will put the system into manual Current Interrupt Mode.

9.9.4 CI MODE OFF will take the system out of manual Current Interrupt Mode.

9.10 MAIN MENU>PARAMETER ADJUSTMENT

9.10.1 LOAD SETPOINT is used only in systems configured for Current Control Mode. It is not used in systems using the Battery Charge Mode.

(a) Press MENU to Cancel or ENTER to Edit

(b) To modify the parameter use the up and down arrows to change and ENTER to accept the new value.

Note: The system will gradually reach the new set point and the actual values will be displayed on the HOME MENU until the set point is reached.

9.10.2 MAXIMUM POWER is used to limit the Maximum Power output of the system. It cannot exceed the rated Power Output of the system.

(a) Press MENU to Cancel or ENTER to Edit

(b) To modify the parameter use the up and down arrows to change and ENTER to accept the new value.

9.10.3 RB CURRENT MAXIMUM is used to limit the current output of the bundle.

(a) Press MENU to Cancel or ENTER to Edit

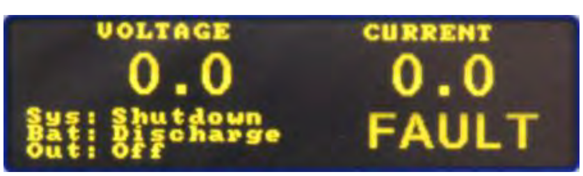
(b) To modify the parameter use the up and down arrows to change and ENTER to accept the new value.

9.10.4 FUEL UTILIZATION MAXIMUM displays the fuel flow limits and should only be adjusted by direction of Atrex Energy.

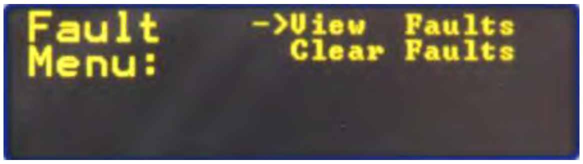
(a) Press MENU to Cancel or ENTER to Edit

(b) To modify the parameter use the up and down arrows to change and ENTER to accept the new value.

9.11 FAULT will be displayed on the bottom right of the HOME MENU when a fault is present.



MAIN MENU>FAULT MENU



9.11.1 VIEW FAULTS

(a) Explanation of Fault

9.11.2 CLEAR FAULTS

(a) CONFIRM CLEAR

9.12 MAIN MENU>VERSION

9.12.1 Unit model number, fuel type and output configuration

9.12.2 ARP Firmware Version

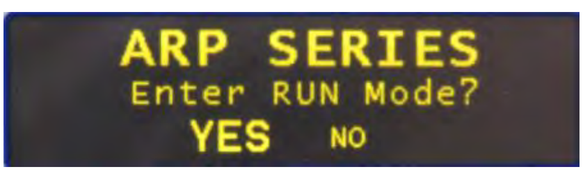
9.12.3 UIC Firmware Version

9.12.4 LUI Firmware Version

9.13 SLEEP MODE - The LUI display will turn off after 10 minutes. Press any button to reenergize the display. The HOME MENU will be displayed.

10.0 Startup

10.1 To start the generator, push the ON button on the LUI panel. The system will open the START menu and will prompt if the user wants to enter RUN mode.



10.2 The SYSTEM STATUS LED indicator light will be solid yellow (System OFF).

10.3 To start up the system from the START menu and enter RUN mode, press ENTER.

10.4 To navigate to the HOME MENU, RIGHT ARROW until NO is highlighted and press ENTER.

10.5 The menu will go to the HOME MENU.

10.6 If the system is not put into RUN mode within 5 minutes and the internal battery voltage is <25.0VDC, then the UIC will upload the data from the startup attempt and disconnect power from the LUI and the UIC. Press the ON button again to restart the system.

10.7 If there are any faults detected, FAULT will be displayed on the HOME screen and the SYSTEM STATUS light will be blinking yellow. Navigate to the MAIN MENU > FAULT INFO > VIEW FAULTS to see any faults. Refer to the troubleshooting guide. Once the fault has been rectified, clear the faults by going to the MAIN MENU > FAULT INFO > CLEAR FAULTS menu.

10.8 For Battery Charging control systems, the output voltage is set at the factory to either 12, 24 or 48VDC.

10.9 For Constant Current control systems, the current is set by navigating to the MAIN MENU>PARAM ADJUST>LOAD SETPOINT>CURRENT VALUE> MODIFY PARAMETER menu. Use the up and down arrows to change the value of the CURRENT and press ENTER to accept the new value.

> **NOTICE:** The system will gradually reach the new set point and the actual values will be displayed on the HOME MENU until the set point is reached.

10.10 To start the system from other than the START menu, navigate to MAIN MENU> SYSTEM CONTROL>RUN.

10.11 The system will go through the following sequence during start-up:

10.12 The SYSTEM STATUS indicator light will be blinking green.

10.13 The system will run its ventilation and cathode fans for 60 seconds to flush the machine.

10.14 The fuel safety valves will open and the start up burner will light using a spark igniter.

10.15 If the initial ignition fails, the system will try again. After five unsuccessful trials it will shut down and give the corresponding Fault message.

10.16 When the front of the stack reaches a temperature sufficient to combust the unused fuel, the system starts to supply fuel to the cells. This should occur after 15 to 30 minutes.

10.17 When the front of the stack reaches operating temperature, the system shuts off the start-up burner and continues to heat up on the fuel to the cells only.

10.18 When the minimum stack temperature reaches a temperature sufficient to sustain the fuel cell reaction, the system starts to draw power from the stack to charge the internal batteries. This should occur after about 50 to 70 minutes.

10.19 When the internal battery is charged, the power output to the load is enabled and the SYSTEM STATUS light will be steady green. The output level will ramp up to the set output voltage or current. It will take about 5 to 10 minutes until the output will settle at the desired level. If no load is connected at this time, the system will disable the output and de-energize the output terminals after 1 minute. Confirm that the Load Circuit Breaker is turned on and the load is connected. Navigate to the MAIN MENU>SYSTEM CONTROL> RUN menu to restart the system.

11.0 Shut Down

11.1 To put the system in Shutdown Mode, press the OFF button on the LUI panel and hold for 3 seconds. The SYSTEM STATUS indicator light will be steady yellow. The LUI display will return to the HOME MENU and display the following states:

Sys: Shutdown

Bat: Discharging

Out: Disabled

11.2 The cathode blower and ventilation fan will continue to operate until the stack temperature is < 400°C. Once the blower and fan have turned off, the SYSTEM STATUS indicator light will turn off.

11.3 If the system is to be restarted or there is a need to remotely communicate with the system, keep the INTERNAL BATTERY connected.

⚠ **NOTICE:** Do not disconnect the internal batteries until the system has fully shut down and the SYSTEM STATUS indicator light has turned off or damage to the bundle may occur.

11.4 If the generator is to be completely shut down, navigate to MAIN MENU>SYSTEM CONTROL>INTERNAL BATT and disconnect the internal batteries. This will remove power from the control system. The LUI will power off. If the INTERNAL BATTERY is not disconnected and the battery voltage falls below 23.5VDC, the controller will automatically disconnect the internal batteries using the latching relay.

12.0 Troubleshooting

⚠ **WARNING:** Only factory trained service personnel should remove the main enclosure covers. Disconnect the remote system diagnostics if needed when working inside the generator.

⚠ **NOTICE:** If the small enclosure cover is removed the large enclosure cover must also be removed in order to avoid over-heating.

12.1 To disconnect the remote system diagnostics while working inside the generator, disconnect the power cable 82-50064 from the J11 connector on the UIC board, 51-50011 as shown in Figure 15.

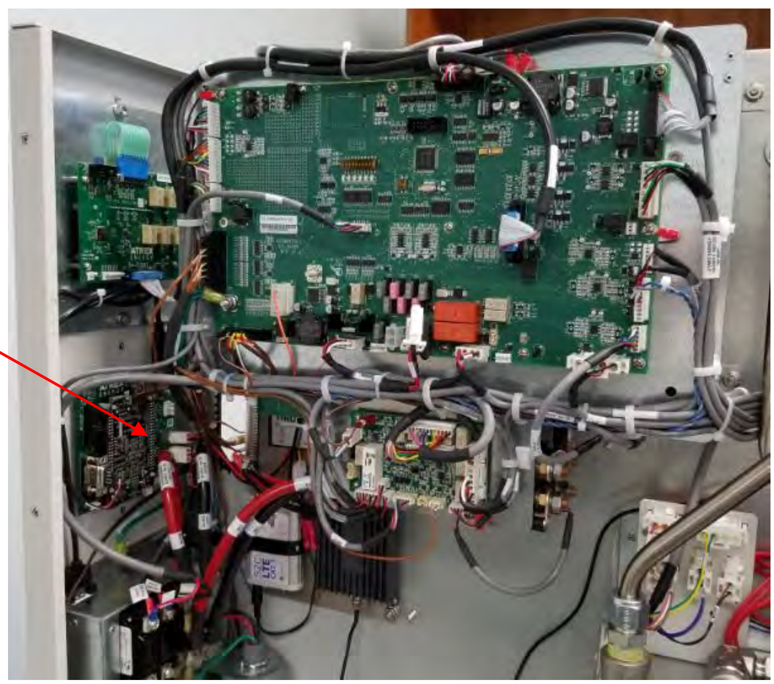


Figure 15: J11 connector on UIC board

12.2 If there are any faults detected, FAULT will be displayed on the HOME screen of the LUI and the SYSTEM STATUS light will be blinking yellow. Navigate to the MAIN MENU > FAULT INFO > VIEW FAULTS to see any faults. Refer to the troubleshooting guide below. Once the fault has been rectified, clear the faults by going to the MAIN MENU > FAULT INFO > CLEAR FAULTS menu.

12.3 E-Stop Fault

24VDC E-Stop signal does not reach the control board from the terminal strip position C8-2. The ARP Generator is equipped with a hardwired analog safety circuit which contains discrete temperature and pressure switches to interrupt power to the main fuel valves in the event of out of bounds temperature or pressure conditions.

When the system is powered up, if the three temperature switches, the ventilation flow switch, the over pressure switch and e-stop switch (if supplied) are all in their normal operation state, a timer circuit will be activated. This timer circuit ensures that the ventilation fan has been on for a pre-determined amount of time to adequately purge the enclosure of any flammable gas build up prior to allowing the main controller to enter the start state. It also ensures that dc power cannot reach any of the fuel valves and the ignition module (independent of the main controller status) until the ventilation time is complete.

If any of the interlock devices enter into an abnormal state, e.g. a temperature switch opens due to high enclosure temperature, then the power to the fuel valves is interrupted, closing the valves. An E-stop fault signal is also sent to the main controller, putting the system into a shutdown condition.

12.4 Min Off Gas Temp

Fuel Cell offgas combustion zone too cold.

12.5 Stack Temp

Fuel Cell bundle too hot.

12.6 Battery Voltage

Battery voltage is below 23.0VDC.

If the voltage is below 23.0VDC, recharge each battery by removing them from the system and charging them with a suitable battery charger.

12.7 Fuel Outage

The fuel pressure is not detected by the fuel pressure switch

The pressure switch indicates that fuel is available to the generator. The pressure switch is located near the fuel inlet on the inside of the enclosure.

12.7.1 Verify that there is fuel pressure at the inlet.

12.7.2 Verify that 24VDC are supplied to the red wire.

12.7.3 If the switch sees the pressure and is closed then 24 V will show on the yellow wire.

12.7.4 If the 24VDC are not present, measure for continuity across the switch.

12.7.5 The factory set point is 0.75 psi. Verify that the pressure is greater than the set point.

12.8 Fuel Ratio

Air to fuel ratio out of range. Contact Atrex Energy.

12.9 Cathode Air

Air blower (C301, cathode, blower on the right) gives no tach signal. Check its operation and wires for damage.

12.10 Anode Air

Anode air flow meter (F101, in front) gives no flow signal. Check its operation and wires for damage.

12.11 Ignition Count

The startup burner did not light successfully after 5 attempts.

12.11.1 Bleed the fuel line by following section 6.1 above.

12.11.2 The ignition sequence begins with a 60 sec air purge (prime igniter) and a 30 sec ignition interval (establish flame) in which the control board sends 24VDC via J23 (red and black wire) to the (Benni) ignition module. The ignition module generates a high voltage spark and sends 24VDC back on the brown wire to J23. The control board forwards that signal to the burner valve V251 (3-pin connector on the right side of the GUM). The ignition module will keep the valve open for 7 seconds while it waits to measure flame ionization current. Measure the voltage at the V251 connector and confirm that 24VDC are present for 7 seconds.

12.11.3 Verify the cathode air blower (C301, right blower with large diameter hose) is free of obstructions and that exhaust air can exit the generator.

12.11.4 Remove the igniter from the system to verify spark:

Unplug the DC connector to the burner module before servicing the burner assembly.

Remove the high voltage cable from the spark igniter.

Remove and collect the white fluffy insulation from the igniter well.

Remove the 2 nuts from threaded rods, remove the spacer tubes and remove the igniter. Observe whether the Mica gasket is reusable.

Clean the spark igniter end and cable connector from any soot build-up. Verify that the spark gap is 3/32” and that the electrodes are bent 15 degrees down from the centerline.

Reinstall making sure the mica gasket and insulation are in place.

12.12 **Stack Voltage**

Fuel cell bundle voltage too low. The bundle may need to be replaced.

12.13 **Cabinet Hot Temp**

Temperature inside the fuel cell enclosure is too high. Check the location of the temperature sensors.

12.14 **Reactor Max Temp**

This fault indicates that the reactor temperature in the front of the removable fuel cell bundle exceeded its maximum limit. There is too much oxygen relative to hydrocarbon in the fuel/air mix.

The fuel flow meter (F131) or the air flow meter (F101) are misreading, possibly by contamination with dust or liquids.

The propane gas is too lean.

12.15 **Fuse**

Blown fuse.

Measure output voltage or continuity across of all the fuses (F101 through F109). They are located on the main circuit control board inside the generator. Repair and replace as needed.

12.16 **The output power cycles on and off**

The low fuel cell bundle voltage may have triggered a load disconnect, which is cleared after one hour.

Lower the output requirement.

The fuel cell bundle may be damaged and needs to be replaced.

12.17 **The output power does not reach the desired level**

The power setting has exceeded the power rating for the fuel cell bundle.

The fuel cell bundle has reached its maximum output level and may need to be replaced.

13.0 Wire list

Connector	J24		
label	Not used		
connected device	51-50008		
pin count	3		
type	0.100		
Cable APN			
	Signal	Connects to	Color
Pin 1	RLY4_COM		
Pin 2	RLY4_NO		
Pin 3	RLY4_NC		
Pin 4			

Connector	J20	J309	
label	Assy, Cbl,Burner controller		
connected device	51-50008	51-0391	
pin count	3	4	
type	0.156	0.156	
Cable APN	82-50026		
	Signal	Connects to	Color
Pin 1	26V_ESTOP	J309-1	red
Pin 2	A_GND	J309-2	blk
Pin 3	BIN_24V_8	J309-3	wht
Pin 4		not used	

Connector	J1		
label	Assy, Cbl, vent fan		
connected device	51-50008	VF701	
pin count	4	4	
type	M&L	Mini-Fit	
Cable APN	82-50041		
	Signal	Connects to	Color
Pin 1	+24V_F7	VF701-1	blk
Pin 2	A_GND	VF701-2	red
Pin 3	TACHIN_3	VF701-3	grn
Pin 4	PWM_24V_3	VF701-4	wht

Connector	J3	C8	
label	Assy, Cbl,connection panel signals		
connected device	51-50008	Conn Panel	
pin count	8		
type	0.100	FastOn	
Cable APN	82-50021		
	Signal	Connects to	Color
Pin 1			
Pin 2	SS Estop	J305	brn
Pin 3	AUX_PWR	C8-3	red
Pin 4	Analog_ground	C8-4	blk
Pin 5	RLY3_COM	C8-6	org
Pin 6	RLY3_NO	C8-7	grn
Pin 7	RLY3_NC	C8-8	wht
Pin 8			
Pin 9			
Pin 10			

Connector	J16		
label	Assy, Cbl, blowers		
connected device	51-50008	C101 / C301	
pin count	8		
type	0.156		
Cable APN	82-50015		
	Signal	Connects to	Color
Pin 1	+24V_F5	C301-1	red
Pin 2	A_GND	C301-5	blk
Pin 3	PWM_24V_2	C301-4	grn
Pin 4	TACHIN_2	C301-2	wht
Pin 5	+24V_F4	C101-1	red
Pin 6	A_GND	C101-5	blk
Pin 7	PWM_24V_1	C101-4	grn
Pin 8	TACHIN_1	C101-2	wht
Pin 9			
Pin 10			

Connector	J9		
label	Assy, Cbl, Fuel Press Sw		
connected device	51-50008	PSA 131/TSA701/TSA702	
pin count	10		
type	0.100		
Cable APN	82-50042		
	Signal	Connects to	Color
Pin 1			
Pin 2			
Pin 3			
Pin 4			
Pin 5	PR_SW_IN	PSA131_24v	red
Pin 6	BIN_24V_2	PSA131_24v_rtn	blk
Pin 7	AIN_8+	not used	n/a
Pin 8	AIN_8-	not used	n/a
Pin 9	CONT_POS	CONT_POS	red
Pin 10	CONT_NEG	CONT_NEG	blk

Connector	J6	J13	
label	Assy, Cbl,comm power		
connected device	51-50008	51-50011 UIC	
pin count	6	3	
type	0.156	0.156	
Cable APN	82-50038		
	Signal	Connects to	Color
Pin 1	+26V_SAT	Not used	
Pin 2	A_GND	Not used	
Pin 3	+20V_COMPUTER	Not used	
Pin 4	A_GND	Not used	
Pin 5	DSP_Pwr On	UIC J13-3	grn
Pin 6	A_GND	Not used	
Pin 7			
Pin 8			
Pin 9			

Connector	J14	J309	
label	Assy, Cbl,Chrg signal		
connected device	51-50008	51-0354	
pin count	6	0.100	
type	0.100		
Cable APN	82-50022		
	Signal	Connects to	Color
Pin 1	24V_ESTOP	J309-8	blk
Pin 2	A_GND	J309-7	red
Pin 3	AOUT_3	J309-1	org
Pin 4	BOUT_24V_6	J309-3	grn
Pin 5	AIN_6+	J309-6	blu
Pin 6	AIN_6-	J309-5	wht
Pin 7			
Pin 8			
Pin 9			

Connector	J21		F131/F101
label	Assy, Cbl,flowmeter signals		
connected device	51-50008	F101 / F131	
pin count	9		
type	0.100		
Cable APN	82-50016		
	Signal	Connects to	Color
Pin 1			
Pin 2	FM_GRND		
Pin 3	AIN_2+	F131_anode_fuel (1)	blu
Pin 4	FM_GND	F131_9V_rtn (3)	grn
Pin 5	9V_FM2	F131_9V (4)	brn
Pin 6	FM_GRND		
Pin 7	AIN_1+	F101_a air (1) / VOUT	wht
Pin 8	FM_GRND	F101_9V_rtn (3)/ GND	blk
Pin 9	9V_FM1	F101_9V (4)/ VCC	red

Wire list cont.

Connector	J7	J10	
label	ASSY, SERIAL CABLE		
connected device	51-50008	51-50011 UIC	
pin count	10	DB9	
type	mod4		
Cable APN	82-50017		
	Signal	**Connects to**	**Color**
Pin 1	SCI TXA	DB9-2	wht
Pin 2	GND_COMM		
Pin 3	SCI RXA	DB9-3	red
Pin 4	GND_COMM		
Pin 5	SCI TXB		
Pin 6	GND_COMM		
Pin 7	SCI RXB		
Pin 8	GND_COMM	DB9-5	blk
Pin 9	CAN_HI		
Pin 10	CAN _LO		
Pin 11	Shield to ChsGnd		
Pin 12			
Pin 13			
Pin 14			

Connector	J19	J307	
label	Assy, Cbl,GUM valves		
connected device	51-50008	51-0391	
pin count	12	13	
type	0.100	0.100	
Cable APN	82-50028		
	Signal	Connects to	Color
Pin 1	BOUT_24V_1	J307-12	org
Pin 2	Analog Ground	J307-11	pnk
Pin 3	BOUT_24V_4	J307-10	wht
Pin 4	Analog Ground	J307-9	gry
Pin 5	BOUT_24V_3	J307-8	vio
Pin 6	Analog Ground	J307-7	blu
Pin 7	BIN_24V_8	J307-6	yel
Pin 8	Analog Ground	J307-5	org
Pin 9	24V_ESTOP_1	J307-4	red
Pin 10	A_GND	J307-3	red
Pin 11	AOUT_1	J307-2	brn
Pin 12	AOUT_rtrn	J307-1	blk
Pin 13			
Pin 14			

Connector	J11		
label	Assy, Cbl, System Thermocouples		
connected device	51-50008	System TC	
pin count	14		
type	mod4		
Cable APN	82-50025		
	Signal	**Connects to**	**Color**
Pin 1	THK_1_POS	external temperature	yel
Pin 2	THK_1_NEG	external temperature	red
Pin 3	THK_2_POS	electronics enclosure	yel
Pin 4	THK_2_NEG	electronics enclosure	red
Pin 5	THK_3_POS	external battery	yel
Pin 6	THK_3_NEG	external battery	red
Pin 7	THK_4_POS	fuel cell enclosure	yel
Pin 8	THK_4_NEG	fuel cell enclosure	red
Pin 9	THK_5_POS		yel
Pin 10	THK_5_NEG		red
Pin 11	THK_6_POS	burner outlet	yel
Pin 12	THK_6_NEG	burner outlet	red
Pin 13	THK_7_POS		yel
Pin 14	THK_7_NEG		red

Connector	J5	J5	
label	Assy, Cbl, Local User Interface		
connected device	51-50008	51-50012	
pin count	16	16	
type	mod4	mod4	
Cable APN	82-50018		
	Signal	**Connects to**	**Color**
Pin 1	+24V_F3	J5-1	ribbon
Pin 2	BIN_24V_3	J5-2	ribbon
Pin 3	BIN_24V_5	J5-3	ribbon
Pin 4	BIN_24V_6	J5-4	ribbon
Pin 5	BIN_24V_7	J5-5	ribbon
Pin 6	LTCH_RLY_DISCON	J5-6	ribbon
Pin 7	LTCH_RLY_CONN	J5-7 On Button	ribbon
Pin 8	A_GND	J5-8	ribbon
Pin 9	PR_LED_POS	J5-9 not used	ribbon
Pin 10	PR_LED_NEG	J5-10 not used	ribbon
Pin 11	vacant	J5-11 not used	ribbon
Pin 12	+5VD	J5-12	ribbon
Pin 13	DGND	J5-13	ribbon
Pin 14	CS_EXP02	J5-14	ribbon
Pin 15	SPICLKA	J5-15	ribbon
Pin 16	SPISIMOA	J5-16	ribbon
Pin 17			
Pin 18			
Pin 19			
Pin 20			

Connector	J26		
label	Assy, Cbl, Stack TC		
connected device	51-50008	Bundle Thermocouples	
pin count	18		
type	mod 4		
Cable APN	82-0878		
	Signal	**Connects to**	**Color**
Pin 1	THK_8_POS		yel
Pin 2	THK_8_NEG		red
Pin 3	THK_9_POS		yel
Pin 4	THK_9_NEG		red
Pin 5	THK_10_POS	Stack Front	yel
Pin 6	THK_10_NEG	Stack Front	red
Pin 7	THK_11_POS		yel
Pin 8	THK_11_NEG		red
Pin 9	THK_12_POS	Stack middle	yel
Pin 10	THK_12_NEG	Stack middle	red
Pin 11	THK_13_POS		yel
Pin 12	THK_13_NEG		red
Pin 13	THK_14_POS	Stack rear	yel
Pin 14	THK_14_NEG	Stack rear	red
Pin 15	THK_15_POS		yel
Pin 16	THK_15_NEG		red
Pin 17	THK_16_POS	reformer outlet	yel
Pin 18	THK_16_NEG	reformer outlet	red
Pin 19			
Pin 20			

Connector	J12	J612	
label	Assy, Cbl, FCIC control signal		
connected device	51-50008	51-0314	
pin count	20	20	
type	mod4	mod4	
Cable APN	82-50020		
	Signal	**Connects to**	**Color**
Pin 1	24V_ESTOP	+24V	ribbon
Pin 2	24V_ESTOP	+24V	ribbon
Pin 3	A_GND	24V_RTN	ribbon
Pin 4	A_GND	24V_RTN	ribbon
Pin 5	vacant	vacant	ribbon
Pin 6	vacant	vacant	ribbon
Pin 7	+5VA	+5V_ISO	ribbon
Pin 8	A_GND	ISO_RTN	ribbon
Pin 9	AIN_7-	I_SHUNT1+	ribbon
Pin 10	AIN_7+	I_SHUNT1-	ribbon
Pin 11	A_GND	ISO_RTN	ribbon
Pin 12	AIN_4+	I_SHUNT2+	ribbon
Pin 13	AIN_4-	I_SHUNT2-	ribbon
Pin 14	A_GND	ISO_RTN	ribbon
Pin 15	vacant	vacant	ribbon
Pin 16	vacant	vacant	ribbon
Pin 17	RLY1_COM	ENABLE_IN	ribbon
Pin 18	RLY1_NO	DGND	ribbon
Pin 19	CAN_HIGH	CAN_HI	ribbon
Pin 20	CAN_LOW	CAN_LO	ribbon

Wire list cont.

Connector	J15	J303	
label	Assy, Cbl, Safety Circuit 24V		
connected device	51-50008	51-0391	
pin count	2	2	
type	0.156	0.156	
Cable APN	82-50018		
	Signal	**Connects to**	**Color**
Pin 1	+24V_Vicor	J303-1	ribbon
Pin 2	A_Gnd	J303-2	ribbon
Pin 3			

Connector	J18		
label	Assy, Cbl, Circuit Bkr Load to Controller		
connected device	51-50008	10 Amp Circuit Bkr	
pin count	2		
type	M&L		
Cable APN	82-50048		
	Signal	**Connects to**	**Color**
Pin 1	Power_In	CtBkr Pos	red
Pin 2	A_Gnd	CtBkr Neg	blk

Connector	J30	J301	
label	Assy, Cbl, Battery Charger		
connected device	51-50008	51-0354	
pin count	2	2	
type	0.156	0.156	
Cable APN	82-50047		
	Signal	**Connects to**	**Color**
Pin 1	+29V Vicor	J301-1	red
Pin 2	A_Gnd	J301-2	blk

Connector	J101		
label	Assy, Cbl, Thermocouple, Offgas Temp		
connected device	51-0391	RB Thermocouple	
pin count	2		
type	PAP		
Cable APN	82-50052		
	Signal	Connects to	Color
Pin 1	THK_POS	RB TC	yel
Pin 2	THK_NEG	RB TC	red
Pin 3			
Pin 4			

Connector	J103		
label	Assy, Cbl, Thermocouple, Stack Temp		
connected device	51-0391	RB Thermocouple	
pin count	3		
type	PAP		
Cable APN	82-50051		
	Signal	Connects to	Color
Pin 1	THK_POS	RB TC	yel
Pin 2			
Pin 3	THK_NEG	RB TC	red
Pin 4			

Connector	J306		
label	Assy, Cbl, Exh Temp Switch		
connected device	51-0391	FCM Temp Switch	
pin count	2		
type	0.100		
Cable APN	82-50034		
	Signal	Connects to	Color
Pin 1	J306-1	TSA_EXH_24v	red
Pin 2	J306-2	TSA_EXH_signal	blk

Connector	J304		
label	Assy, Cbl, Safety Devices		
connected device	51-0391	PSA 131/TSA701/TSA702	
pin count	10		
type	0.100		
Cable APN	82-50042		
	Signal	Connects to	Color
Pin 1	J304-1	TSA702	blk
Pin 2	J304-2	TSA702 Return	red
Pin 3	J304-3	TSA701	blk
Pin 4	J304-4	TSA701 Return	red
Pin 5	J304-5	C8-1	blk
Pin 6	J304-6	C8-2	red
Pin 7	J304-7	FSA701	blk
Pin 8	J304-8	FSA701 Return	red
Pin 9	J304-9	PSA301	blk
Pin 10	J304-10	PSA301 Return	red
Pin 11			
Pin 12			

Connector	J307		
label	Assy, Cbl,GUM valves		
connected device	51-0391	GUM Valves	
pin count	12		
type	0.100		
Cable APN	82-50014		
	Signal	Connects to	Color
Pin 1	BOUT_24V_1	V130_24v / 12v*	blk
Pin 2	Analog Ground	V130_24v_rtn	brn
Pin 3	BOUT_24V_4	V101_24v / 12v*	red
Pin 4	Analog Ground	V101_24v_rtn	org
Pin 5	BOUT_24V_3	V131_24v / 12v*	yel
Pin 6	Analog Ground	V131_24v_rtn	grn
Pin 7	BIN_24V_8	V251_24v	blu
Pin 8	Analog Ground	V251_24v_rtn	pur
Pin 9	24V_ESTOP_1	C131_24v	gry
Pin 10	A_GND	C131_V-	wht
Pin 11	AOUT_1	C131_anode_fuel_	pnk
Pin 12	AOUT_rtrn	C131_anode_fuel_	yel

Connector	J102	J27	
label	Assy, Cbl, Safety Circuit Status		
connected device	51-0391	51-50008	
pin count	6	6	
type	PAP	PAP	
Cable APN	82-50033		
	Signal	Connects to	Color
Pin 1	TEMP_OK+	J27-6	wht
Pin 2	TEMP_OK-	J27-5	blu
Pin 3	TC_OPEN_HI+	J27-4	grn
Pin 4	TC_OPEN_HI-	J27-3	red
Pin 5	VOLTAGE_OK+	J27-2	brn
Pin 6	VOLTAGE_OK-	J27-1	blk

Connector	J310		
label	Assy, Cbl,Burner controller		
connected device	51-0391	C702 Ignition Module	
pin count	3		9
type	0.156		
Cable APN	82-50069		
	Signal	Connects to	Color
Pin 1	IGNMOD_OUT	C702-2	red
Pin 2	A_GND	C702-5	blk
Pin 3	BIN_24V_8	C702-6	wht
Pin 4		C702-4-2 (jpr)	blk
		C702-9 (to igntr)	grn

Connector	J302		
label			
connected device	51-0391	FCIC/Safety Contactor	
pin count	4		
type	0.100		
Cable APN	82-50030		
	Signal	Connects to	Color
Pin 1	VSENSE+	FCIC OUT+	blk
Pin 2	VSENSE-	FCIC OUT-	red
Pin 3	GND	SAFETY CONTACTOF	blk
Pin 4	FCIC COIL	SAFETY CONTACTOF	red

Connector	J301		
label	Assy, Cbl, Exh Temp Switch		
connected device	51-0391	PSA302 Exh Press Switch	
pin count	3		
type	0.100		
Cable APN	82-50032		
	Signal	Connects to	Color
Pin 1	24V_TD	PSA302 NC	red
Pin 2	No Connection		
Pin 3	24V Return	PSA302 Comm	blk

14.0 Preventive Maintenance

Maintenance is to be performed by factory trained service personnel. Refer to the individual replacement procedure that is included with each maintenance part.

Maintenance tasks	Part no.	ARP500	ARP1000	ARP1500
Air inlet filter, cathode blower, 4.4" diameter x 2.3" H, replace	RP-AF	Annually or as needed	Annually or as needed	Annually or as needed
Air inlet filter, enclosure cover, 12"x 24" x1", replace	RP-AF	Annually or as needed	Annually or as needed	Annually or as needed
Internal Coalescing filter cartridge, clean or replace	RP-CFI	Annually or as needed	Annually or as needed	Annually or as needed
External Coalescing filter cartridge, clean or replace	RP-CFHW	Annually or as needed	Annually or as needed	Annually or as needed
Desulfurizer assy, replace	RPN-DS or RPP-DS	As needed	As needed	As needed
Fuel system leak check	NA	Annually	Annually	Annually
Inspect intake and exhaust openings to be sure it is free and clear of obstructions	NA	Annually	Annually	Annually
Inspect the physical support of the fuel cell to be sure it is sound without sagging cracks, gaps, etc,	NA	Annually	Annually	Annually
Inspect the fuel cell to be sure there are no obvious signs of deterioration	NA	Annually	Annually	Annually

15.0 Warranty

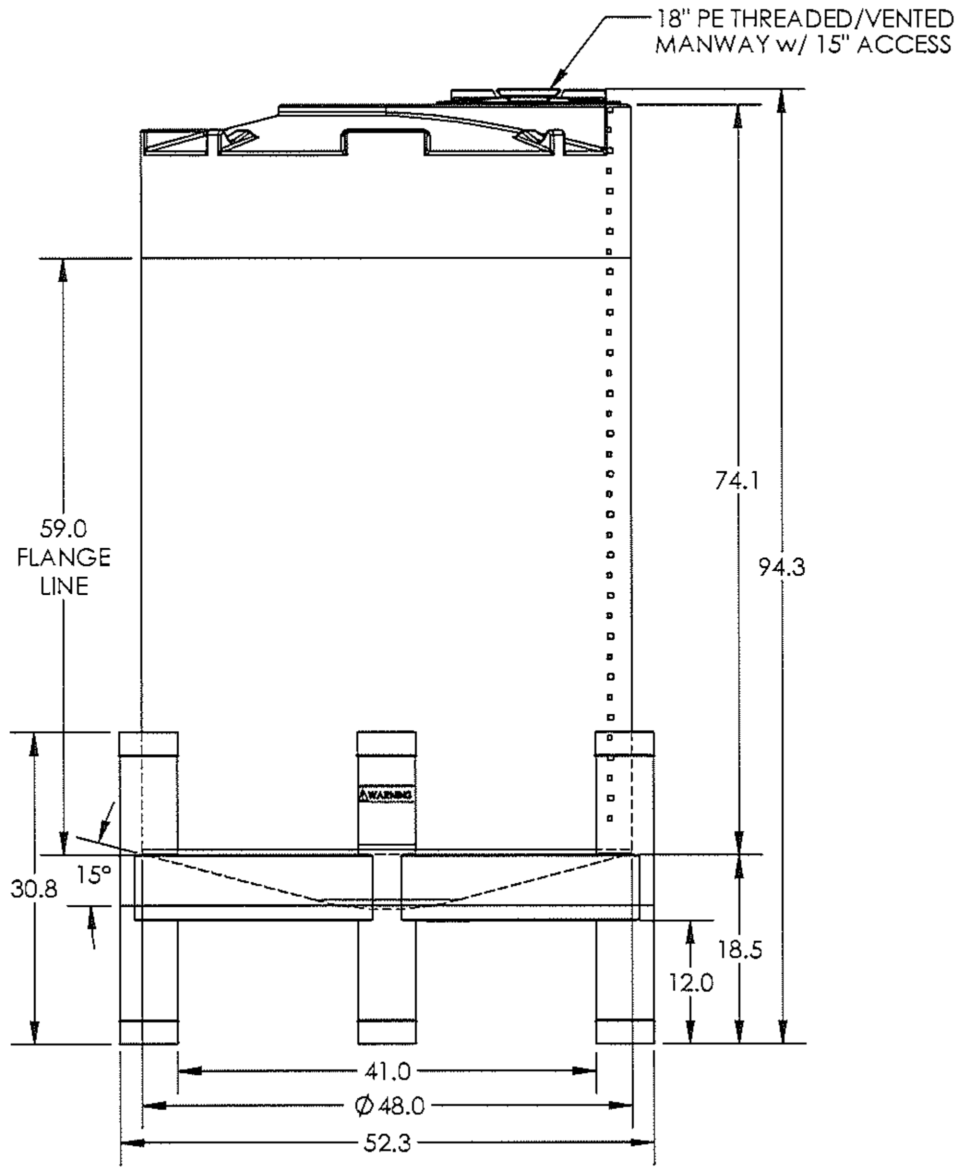
Standard Warranty: See Atrex Energy Standard Warranty for details at http://www.atrexenergy.com/services-resources/warranties.

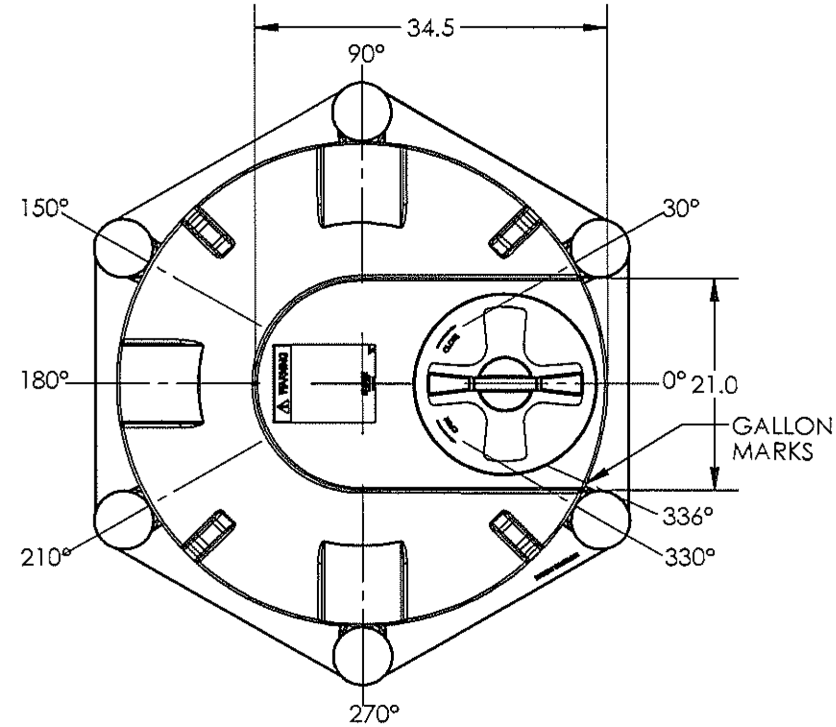
16.0 Product Specifications

	ARP500	ARP1000	ARP1500
Electricity Efficiency	~25%	~30%	~35%
DC Output Power Max	500W	1000W	1500W
DC Output Voltage	5-60VDC	5-60VDC	5-60VDC
DC Output Current Max [1]	100A	100A	100A
Operating Modes	Current Control (CC) , Voltage Control (VC), Battery Charge (Bx, x=12, 24 or 48VDC)		
Start-up Time to Max Output Power	<60 minutes		
ARP Series P/N x = Fuel (P=Propane, N=Natural Gas)	ARP500xU	ARP1000xU	ARP1500xU
Fuel Cell Inlet Supply Pressure	2 psig - 5 psig (13.8kPa - 34.5kPa)		
Fuel Supply Pressure with High Pressure Regulator Kit (RP-HWN/RP-HWP)	5 psig - 125 psig (35.5kPa - 861.8kPa)		
Max Sulfur Content	<60ppmw (42mg/m^3)		
Max Water Content	<5000ppmv for standard system, non-condensing at operating temperature and pressure		
Fuel Consumption-Propane (HD5)	2.4G/day 9L/day	3.6G/day 13.5L/day	5.2G/day 19.6L/day
Fuel Consumption-Natural Gas	185ft^3/day 5.3m^3/day	298ft^3/day 8.4m^3/day	398ft^3/day 11.3m^3/day
Operating Temperature	-40°C to +50°C (-40°F to +122°F)		
Storage Temperature	-40°C to +55°C (-40°F to +131°F)		
Humidity	5% to 95% (non-condensing)		
Operating & Storage Altitude	0 to 8,000 feet (2,438 meters)		
Unit Dimensions (H x W x D)	26"x22"x39" (66cm x 56cm x 99cm)	26"x28"x39" (65cm x 71cm x 99cm)	
Unit Weight	293lbs (133kg)	351lbs (160kg)	358lbs (163kg)
Shipping Dimensions (H x W x D)	45" x 46" x 38" (114cm x 117cm x 97cm)	48" x 46" x 38" (121cm x 117cm x 96cm)	
Shipping Weight	359lbs (163kg)	419lbs (190kg)	426lbs (194kg)
Noise Levels (at 1m)	52dBA		
Fuel Connection to ARP-HWP (Propane)	1/2" FNPT		
Fuel Connection to ARP-HWN (Natural Gas)	1/2" FNPT		
Data Interface	MODBUS RTU via Terminal Strip (requires ARP-RSC8 option)		
Local Computer Interface	RJ45		
Electrical Interface	Terminal Block 2/0 - 8 AWG		
Enclosure IP Category	IP23		
Enclosure Construction	Powder coated galvanized steel		
Warranty	12 Months after installation or 13 months after date of shipment		

[1] - Current will also be limited by maximum output power of unit

Appendix D
Equipment Specifications





NOTE:
TANK MUST BE SOLD WITH A STAND
***1760000N - 12" STAND**
***1760001N - 18" STAND**
APPLICATIONS FOR THIS TANK CANNOT EXCEED 1.7 SPECIFIC GRAVITY

TANK ONLY DRAWING

***ALL EXTERNAL PIPING MUST BE INDEPENDENTLY SUPPORTED.**
***ONLY BASE FITTINGS TO BE LEFT INSTALLED AT TIME OF SHIPMENT PER SII PROCEDURE.**
***Consult Snyder's Guidelines for Use and Installation prior to delivery.**
Available on-line at http://www.snyderindustriestanks.com/Technical
ALL DIMENSIONS ARE IN INCHES, NOMINAL, & SUBJECT TO CHANGE WITHOUT NOTICE.
ALL DIMENSIONS ON ROTATIONAL MOLDED PARTS ARE SUBJECT TO A ± 3% TOLERANCE.

DO NOT SCALE	DRAWN BY	SII SNYDER INDUSTRIES, INC.	TITLE: ASM 550G TOTAL DRAIN TANK W/ 12" STAND	REVISION A
STATUS: Released	IGG			SHEET 1 OF 1
© SNYDER INDUSTRIES INC., 2015				
ALL DIMENSIONS, DESIGNS, AND INFORMATION ON THIS PRINT MUST BE CONSIDERED PROPRIETARY TO SNYDER INDUSTRIES, INC. AND MAY NOT BE USED, COPIED, OR DISTRIBUTED WITHOUT WRITTEN PERMISSION OF AN OFFICER (OR HIS AGENT) OF THE FIRM.		(402) 467-5221 www.snydernet.com	PART NO. 1800100N & 1760000N	ENG. ID. A005018

PROFORMA INVOICE

NO.: PUXIN-1713

SHENZHEN PUXIN TECHNOLOGY CO. LTD
1-2ND FLOOR, BLDG 4, MASHA XUDA HIGH TECH. INDUSTRY PARK, 49 JIAOYU NORTH RD, GAOQIAO DISTRICT, PINGDI STREET, LONGGANG, SHENZHEN, GUANGDONG PROVINCE P. R. CHINA
TEL: +86-755-28938251 FAX:+86-755-28938252

2700 Broening Highway
Baltimore Maryland 21222
TEL: 240-841-1354

DATE: April 28th. 2017

THE SELLER AGREES TO SELL AND THE BUYER AGREES TO BUY THE FOLLOWING GOODS ON TERMS SET

ITEM	DESCRIPTION	UNIT PRICE(USD)	Q'TY/PCS	AMOUNT(USD)
FOR PUXIN FAMILY SIZE 1.2M3 PORTABEL BIOGAS DIGESTER				
1	Portable Assembly Membrane Digester 1.2CBM	450.00	1	450.00
	Biogas pump 220V AC 20W		1	
	Biogas desulfurizer PX-1L		1	
	Biogas dehydrator PX-PX-0.6L		1	
FOR PUXIN FAMILY SIZE 3.4M3 PORTABEL BIOGAS DIGESTER				
2	Portable Assembly Membrane Digester 3.4CBM	850.00	2	1,700.00
	Biogas pump 220V AC 20W		2	
	Biogas desulfurizer PX-1L		2	
	Biogas dehydrator PX-PX-0.6L		2	
3	Biogas stove with double burner	21.00	1	21.00
4	Biogas Fitting	14.00	3	42.00
5	Biogas Rice Cooker2.5L	19.00	1	19.00
6	Circulate pump (125W Single phase)including pipe and flange	92.00	3	276.00
7	Shredder 20L(only needed for food waste shredding)	350.00	1	350.00
8	Sewage pump with shredder (1.1KW Single phase)	102.00	1	102.00
9	PX-CQD-HY02 2M3 biogas storage bag	64.00	3	189.00
10	Electric Heater(heat for digester)	60.00	6	360.00
11	1.5KW biogas generator	456.00	1	456.00
TOTAL OF ABOVE USD				US$3,965.00
2% DISCOUNT FOR ABOVE CARGO				US$79
TOTAL IN USD				US$3,886
SHIPMENT FROM SHENZHEN TO BATIMORE, USA				US$557.00
TOTAL IN USD				US$4,443

NOTE: AT PRESENT 1USD= 6.87 RMB(THE ACTUAL EXCHANGE RATE SHOULD VALID BASE ON PAYMENT DATE)
SAY U.S. DOLLARS FOUR THOUSAND FOUR HUNDRED AND FORTY THREE ONLY
SHIPMENT: BY SEA(28 days)
PRICE TERM: CNF BATIMORE, USA
DELIVERY : FROM SHENZHEN TO BATIMORE, USA
LEAD TIME: WITHIN 15 DAYS
PAYMENT TERM : 100% TT IN ADVANCE
COUNTRY OF ORIGIN: PEOPLE' S REPUBLIC OF CHINA

ACCOUNT NO.: 0120177710874
Bank: BANK OF CHINA（HONG KONG）LTD
Bank address: 1 GARDEN ROAD, HONG KONG
SWIFT CODE: BKCHHKHH

ON BEHALF OF THE SELLER **ON BEHALF OF THE BUYER**

Biogas Conditioning Skid
Sequence of Operations

The Biogas Conditioning Skid is an integral component of the Biofuel Demonstration Project, and provides the following functions for feeding a mixture of biogas and natural gas to a fuel cell:

1.) Compresses the biogas generated from the algae digesters to the pressure required to flow through the conditioning skid and feed the fuel cell at the required 2 to 5 psig supply pressure.
2.) Removes H2S (hydrogen sulfide) from the biogas to the acceptable level for feed to the fuel cell (less than 60 ppm H2S).
3.) Removes moisture from the saturated biogas to the acceptable level for feed to the fuel cell (less than 500 ppm water).
4.) Provides biogas and natural gas flow measurements and metering valves for controlling the biogas content in the feed to the fuel cell (5% to 25% biogas target).

Biogas Compressor

The Biogas Compressor is a micro diaphragm gas pump that will increase the pressure of the biogas from the digester and holding bags to the pressure needed to flow through the conditioning equipment and supply the fuel cell at the required 2 to 5 psig. The biogas bags operate at a slight positive pressure (2 to 3 inches water column) and are connected to the conditioning skid through a hose (1/4 inch connection). The compressor has a maximum discharge pressure of 13 psig at no flow conditions, and an operating pressure of 8 psig at the maximum operating capacity of 0.5 l/min. The operating capacity of the compressor will be controlled by adjusting a metering valve on the discharge of the compressor, and monitoring the biogas rotameter installed downstream of the desiccant dryers. At the maximum operating capacity, the metering valve will reduce the pressure to 7 psig as monitored by a pressure gauge installed on the outlet of the valve. The metering valve thumb handle will be turned to adjust the pressure at the compressor and throttle the flow. Fine adjustments of flow can also be made using the needle valve that is a component of the rotameter. Downstream of the biogas rotameter is a pressure reducing regulator. The knob handle of this regulator will be adjusted to set the delivery pressure to the fuel cell as measured by the pressure gauge installed on the outlet of the skid (1/4 inch connection).

Iron Sponge Bed

The Iron Sponge Bed is the first step in the biogas conditioning process. The biogas from the compressor and metering valve comes into the bed in a down flow configuration. A low point drain and sample point is provided in this inlet line to check for water and to check the H2S content of the biogas before conditioning. The vertical iron sponge vessel is made of 6 inch ID 150# flanged SS pipe. The top 5 feet long section holds the iron sponge above a SS perforated support plate with SS mesh. A one foot long bottom section below the support plate provides disengagement space for water separation.

The iron sponge contains iron oxide (Fe2O3) deposited on wood shavings. The iron oxide reacts with the hydrogen sulfide (H2S) in the biogas to produce iron sulfide (Fe2S3) and water. The process is a chemical adsorption of H2S. The reaction product iron sulfide stays as a solid in the bed and the water generated exits with the gas at the bottom of the bed. The biogas entering the bed is saturated with water vapor and this is necessary in order for the adsorption process to proceed efficiently. The gas exiting the bed goes into a moisture drain section where water particles will disengage from the gas. Water accumulates in a 2 quart capacity drip trap that will automatically drain the water via a float mechanism connected to a needle valve. To ensure that there is a continuous hydration on the bed, water discharge from the drip trap should be monitored. In addition, the discharge water coming from the trap should be checked periodically for pH. The pH of the drip water should be 8 or higher for optimum desulfurization. When drip water pH becomes acidic (less than 7), a water solution of sodium carbonate can be added at the inlet port on top of the vessel to bring the pH up.

The bed contains about 1 cubic foot of iron sponge which can last more than 100 days based on the biogas H2S loading. The volume of the bed is high relative to the H2S loading of 1000 ppm (max) because the design was based on the contact time or residence time required for the gas. A sample point is provided on the gas line exiting the vessel for checking the H2S level of the biogas. Increasing H2S level at gas outlet is an indication that the bed is approaching end of run state. When this occurs, the bed may be regenerated or emptied and replaced with fresh iron sponge. Also, a temperature gauge is installed in the bottom section of the bed to verify that the temperature is less than 120 degrees F. Above this temperature, the iron sponge is not as effective for removing sulfides.

There are safety considerations during regeneration and discharging of the iron sponge. The iron sponge vendor or corresponding vendor manual should be consulted for these operations. Specifically, the spent iron sponge is pyrophoric if not kept moist while exposed to air, which reverses the sulfur-iron reaction and is exothermic. The vendor recommends that spent material be kept moist as it reacts exothermically with air for a period of ten (10) days as per D.O.T mandated procedure. The moisture limits heating of the material which otherwise could cause a slow smoldering of the iron sponge wood carrier.

Desiccant Dryer

The final step in the biogas conditioning process is the desiccant dryer. There are two dryers installed in series with the second dryer installed as a guard bed that also allows the first dryer to be recharged or replaced without taking the conditioning unit offline. There is a sampling point on the outlet of both dryers where the biogas can be tested for moisture level. When moisture levels are on the high side out of the first dryer (greater than 200 ppm water), the dryer will be monitored more frequently for breakthrough. When moisture breaks through the first dryer (greater than 500 ppm water) the dryer will be bypassed to recharge with fresh desiccant or replaced (low cost item, <$100). Each dryer has about 0.02 cubic foot of silica gel which is estimated to last around 23 days per dryer at maximum operating capacity. A bypass is installed around the second dryer as well, in case this dryer needs to be recharged or replaced. This is an unlikely event if the first dryer is recharged or replaced in a timely manner.

Biogas/Natural Gas Fuel Mixture Control

The biogas conditioning skid has a biogas rotameter (4.0 to 40 normal L/hr range) and a natural gas rotameter (25 to 250 normal L/hr range) to monitor flowrates and to allow control of the fuel cell feed biogas content. Each rotameter has an integral needle valve for adjusting the flow through the flow metering device. In addition, valves are provided to allow the biogas flow to be vented or flared through a ¼ inch connection at the skid outlet upstream of the natural gas mix point. This will allow the fuel cell to be operated on 100% natural gas, while the biogas is being conditioned and vented/flared in an idle or test mode. When the biogas is verified to be conditioned for feed to the fuel cell, the vent valve will be closed and the outlet valve upstream of the natural gas mix point will be opened.

PROCUREMENT LIST

PROJECT TITLE: BIOGAS CONDITIONING SKID

CLIENT: ANCHOR QEA — REVISION: C

PROJECT LOCATION: BALTIMORE, MD — DESCRIPTION: RE-ISSUED FOR PROCUREMENT

TAI PROJECT NUMBER: 17-0757 — DATE: 8/4/17

Tag Designation	P&ID	Size/Range	Description	Quantity	Manufacturer	Model	Vendor	Vendor Contact	Vendor Phone Number	Quote Reference Number	Price	Lead Time (Weeks)	Purchase Order Number	Notes
1		0.5 L/MIN, 8 PSIG	Micro Diaphragm Gas Pump	2	KNF	NMP 015 B	KNF Neuberger Inc.	Roberto Franchetti	609-890-8600	077532/075706	$312	3-4 weeks		
2		3"X6" 1/4" NPT	Silica Gel Desiccant Dryer	2		# 558R603	Gamut				$113.26	2 days		www.gamut.com
3		50-65% WT FE_2O_3 ON WOOD SHAVINGS	Iron Sponge	1 Bag (2 cu.ft.)	Connelly-GPM		Connelly-GPM	Galen Dixon	773-247-7231	17063001	$55	3 days		1 cu. ft. per changeout
4		2.5" STEM, 0-200 °F, 1/2" MNPT	Temperature Gauge, SS, Glass	1	Swagelok	T48A-025-FS-05-G-8-SS	Dibert Valve & Fitting	Mark Harris	301-606-6524	99495953	$307.02	7 weeks		Alternate model for shorter lead time: Ashcroft 50EI60E025 0/250F Procure from: www.grainger.com
5		0-10 PSI OUTPUT, 1/4" NPT	Pressure Reducing Regulator, SS	1	Swagelok	KPR1CFA411A20000	Dibert Valve & Fitting	Mark Harris	301-606-6524	99495953	$287.47	3 weeks		
6		1/4" SWAGELOK, 0.004 Cv	Metering Valve, SS	1	Swagelok	SS-SS4-VH	Dibert Valve & Fitting	Mark Harris	301-606-6524					Corrected model #. Specified model # (SS-SS1-VH) in quote 99495953 was incorrect.
7		4.0-40 NL/H	Biogas Variable Area Flowmeter, SS/Glass	1	Swagelok	VAF-G1-04M-1-0-W	Dibert Valve & Fitting	Mark Harris	301-606-6524	99495953	$683.20	4 weeks		
8		**25-250 NL/H**	Nat. Gas Variable Area Flowmeter, SS/Glass	1	Swagelok	**VAF-G1-07M-1-0-W**	Dibert Valve & Fitting	Mark Harris	301-606-6524					**Revised model # from original quote for a higher range.**
9		0-15 PSIG, 1/4" SWAGELOK	Pressure Gauge, SS	2	Swagelok	PGI-63B-PG15-LAQ3-N	Dibert Valve & Fitting	Mark Harris	301-606-6524	99495953	$218.78	7 weeks		Alternate model for shorter lead time: Ashcroft 251009SWL02L15# Procure from: www.grainger.com
10		2 QUART, 1" NPT, COND. TRAP	Drip Trap, Al/SS	1	Varec Biogas	245 Series	Bowen, Calhoun & Associates Inc.	Bob Calhoun	410-321-8930	-	$982	1-2 weeks		
11		1/4" FNPT	Ball Valve, Swagelok 40G Series, SS	19	Swagelok	SS-43GF4-SH	Dibert Valve & Fitting	Mark Harris	301-606-6524					
12		1/4" MNPT	Ball Valve, Swagelok 40G Series, SS	2	Swagelok	SS-43GM4-SH	Dibert Valve & Fitting	Mark Harris	301-606-6524					
13		1/4" FNPT x 1/4" TUBE	Elbow, 90 deg., Swagelok, SS	4	Swagelok	SS-400-8-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
14		1/4" MNPT x 1/4" TUBE	Elbow, 90 deg., Swagelok, SS	2	Swagelok	SS-400-2-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
15		1/4" MNPT x 1/4" MNPT	Elbow, 90 deg., Swagelok, SS	2	Swagelok	SS-4-ME	Dibert Valve & Fitting	Mark Harris	301-606-6524					
16		1/4" FNPT x 1/4" FNPT x 1/4" MNPT	Tee, Swagelok, SS	2	Swagelok	SS-4-BT	Dibert Valve & Fitting	Mark Harris	301-606-6524					
17		1/4" FNPT x 1/4" TUBE x 1/4" TUBE	Tee, Swagelok, SS	2	Swagelok	SS-400-3-4TFT	Dibert Valve & Fitting	Mark Harris	301-606-6524					
18		1/4" FNPT x 1/4" MNPT x 1/4" FNPT	Tee, Swagelok, SS	1	Swagelok	SS-4-ST	Dibert Valve & Fitting	Mark Harris	301-606-6524					
19		1/4" MNPT x 1/4" MNPT x 1/4" MNPT	Tee, Swagelok, SS	8	Swagelok	SS-4-MT	Dibert Valve & Fitting	Mark Harris	301-606-6524					
20		1/4" TUBE x 1/4" TUBE x 1/4" MNPT	Tee, Swagelok, SS	3	Swagelok	SS-400-3-4TTM	Dibert Valve & Fitting	Mark Harris	301-606-6524					
21		1/4" MNPT x 1/4" TUBE	Coupling, Swagelok, SS	11	Swagelok	SS-400-1-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
22		1/4" FMPT x 1/4" TUBE	Coupling, Swagelok, SS	4	Swagelok	SS-400-7-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
23		1/4" FNPT x 1/4" FNPT	Coupling, Swagelok, SS	1	Swagelok	SS-4-HCG	Dibert Valve & Fitting	Mark Harris	301-606-6524					
24		1/4" MNPT x 1/4" TUBE	Coupling, Bulkhead, Swagelok, SS	2	Swagelok	SS-400-11-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
25		1/4" FNPT x 1/8" HOSE BARB	Adapter, Hose Barb, Swagelok, SS	2	Swagelok	SS-2-HC-7-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
26		1/4" TUBE	Quick Connect, Stem, Swagelok, SS	2	Swagelok	SS-QF4-S-400	Dibert Valve & Fitting	Mark Harris	301-606-6524					
27		1/4" FNPT	Quick Connect, Body, Swagelok, SS	7	Swagelok	SS-QF4-B-4PF	Dibert Valve & Fitting	Mark Harris	301-606-6524					
28		1" MNPT x 1/4" FNPT	Bushing, Reducing, Swagelok, SS	2	Swagelok	SS-16-RB-4	Dibert Valve & Fitting	Mark Harris	301-606-6524					
29		1/4" x1" Lg.	Nipple, Sch 40, Swagelok, SS	2	Swagelok	SS-4-CN	Dibert Valve & Fitting	Mark Harris	301-606-6524					
30		1/4" x 2-1/2" Lg.	Nipple, Sch 40, Swagelok, SS	2	Swagelok	SS-4-HLN-2.50	Dibert Valve & Fitting	Mark Harris	301-606-6524					
31		1/4" x 3" Lg.	Nipple, Sch 40, Swagelok, SS	8	Swagelok	SS-4-HLN-3.00	Dibert Valve & Fitting	Mark Harris	301-606-6524					
32		1/4"	Tube, Swagelok, SS	19'-0"	Swagelok	-	Dibert Valve & Fitting	Mark Harris	301-606-6524					
33		-	Manual Starter	1	Square D	2510FW1 55433	United Electric Timonium	Chuck Love	443-275-6366	S103836895	$341.10			
34		-	Thermal Unit	1	Square D	A. 78 58514	United Electric Timonium	Chuck Love	443-275-6366	S103836895	$25.02			
35		1/4"	U-Bolts	10			Grainger							www.grainger.com
36		1/4"	Tubing Clamps	4	Dixie Line Clamps	401	Grainger							www.grainger.com
37		-	Enclosure (NEMA Box)	1	Bud Industries Inc.	NBB-22243	Bud Industries Inc.							www.budind.com
38		3/4" NPT, 2.5" STEM, 1/2" NPSM	Thermowell, SS	1	Grainger Approved	24C461	Grainger							www.grainger.com
39		5/32" ID, 9/32" OD 1/16" THK	Tygon Brand PVC Tubing	1 Box(50')	Tygon	AAC00010	General Laboratory Supply							www.gogenlab.com

QUOTE

Maryland Environmental Service
7201 Corporate Center Drive
Hanover, MD 2107

Date
11 July 2017

Quote Number
Q001296/1

Job Number

Diamond Systems LLC
PO Box 348
Mims, Florida 32754
www.DiamondSci.com
info@DiamondSci.com
Phone: 001-321-223-7500
Fax: 001-321-747-0316

MRU

Costs	Quantity	Rate	Amount
Optima 7 Biogas Analyzer O2 (0 ... 25 %) (long-life electrochemical cell) CH4 (0... 100 %) (infrared dual gas bench) CO2 (0 ... 100 %) (infrared dual gas bench) H2S (0 ... 2,000 ppm) (electrochemical cell) Biogas pressure (0 ... +/- 300 mbar) (Biogas / duct pressure) Optimized, backlit condensate separator with re-usable PTFE (star) filter for protection against dust and soiling IRDA interface for high speed infrared thermal printer Mini-USB interface for cable data transfer to PC SD card reader incl. activating software Internal data storage for up to 16000 measurements, with color data records visualization on display Battery and mains operation - high energy Li-Ion battery, with 8 - 10 hours mains free operation Wall-plug, universal grid power supply 90-240Vac / 50-60Hz for battery charging over the USB port Biogas sampling line Ø3x2mm Viton with 5m length and stainless steel instrument gas inlet port	1.00	4,011.00	4,011.00
ABS Storage Case with large Compartment 629631	1.00	242.00	242.00
Gas Flow Velocity Using Pitot Tubes 65730	1.00	335.00	335.00
Biogas sampling hose 5 meter with quick connector 65130	1.00	85.00	85.00
Type K thermocoupler coiled cable 6" insertion 85003	1.00	60.00	60.00
Calibration Gas Kit 2 58L tanks with tubing, regulators and case USCalKit	1.00	800.00	800.00

Subtotal	5,533.00
Florida Sales Tax	0.00
Total	**5,533.00**

Valid To: 8 August 2017

Pressure Differential Switchovers

526 SERIES

Switchover

The 526 Series Switchover is an automatic switchover system designed to supply a continuous supply of high purity, non-corrosive gas. The system comes with either flexible hoses for use with two cylinders or manifold connectors for use with the Maniflex Modular Manifold System. Due to pressure differential considerations, an integral line regulator is available to maintain constant downstream pressure.

526 4111 shown with attached flexible hoses. Available with optional remote alarm.

Typical Applications
Ultra high purity gases
Gas chromatograph carrier and support gases
AA grade acetylene
Cell culture incubator CO_2 and N_2
Pure and mixed process gases
Central gas supply system for laboratory, research or process plants

Features

400 Series Brass Barstock Regulators
CAPSULE® seat

Metal-to-Metal Diaphragm Seal
No possibility of gas contamination

User-Friendly
One knob switches cylinder priority

Check Valves in Hose Inlet Glands
Prevents contamination and back flow

Compatible with Maniflex Manifolds
Multiple cylinders per side

Optional Line Regulator
Stable line pressure during change over

Optional Remote Alarm
Easy integration with Advantium system
CE marked 220 volt alarm

Optional Purge Valves
Allows purging after cylinder change over

Optional Outlet Valve
Allows isolation of pipeline

Materials

Bodies
Brass barstock

Diaphragms
316L stainless steel

Seats
PTFE
PCTFE with 4500 PSIG (310 BAR) inlet

Filters
10 micron sintered bronze

Internal Seals
PTFE

Specifications

Maximum Inlet Pressure
3000 PSIG (210 BAR)
4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2" (53mm) diameter brass

Outlet Connection
1/4” MPT (without line regulator)
1/4” FPT (with line regulator)

Helium Leak Integrity
1 x 10^{-8} scc/sec

Cv
0.1

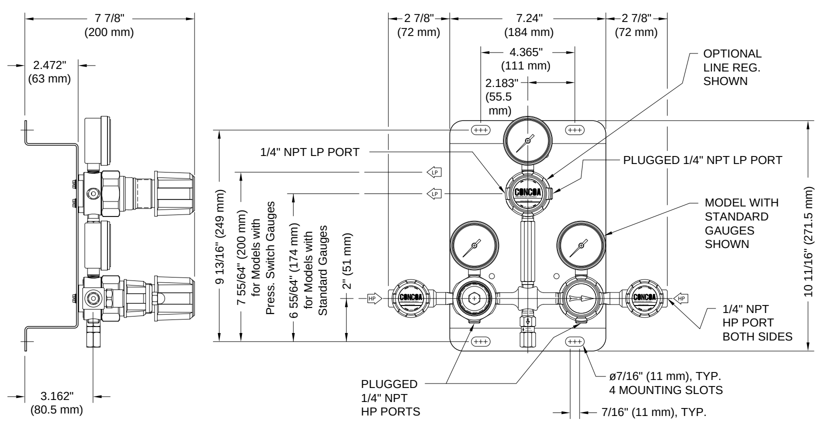
Weight
8.25 lbs. (3.71 kg)

CRN OH 5806.5

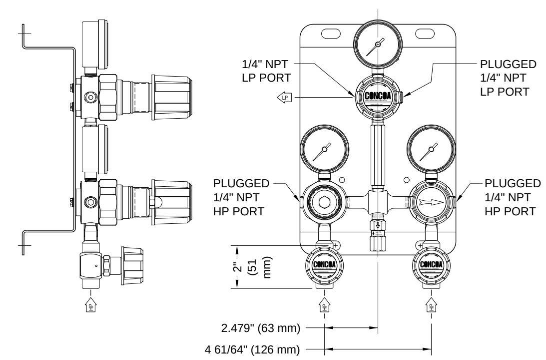
Pressure Differential Switchovers

Installation Information

Diaphragm Valves on Side Ports



Diaphragm Valves on Bottom Ports



Ordering Information

526	A	B	C	D	-CON	Optional
Series 526	Switching Pressure (Priority R/L)	Inlet Connection	Line Regulator	Assembly	Hose	
	1: 125/105 PSIG* (8.4/7.1 BAR)	**0:** 1/4" FPT ports	**0:** None	**1:** 0-4000 PSIG/0-28,000 kPa gauges no alarm capability*	Please specify inlet connection (if applicable) CGA DIN 477 BS 341 and others available	**A:** Outlet valve
	2: 70/50 PSIG* (4.8/3.5 BAR)	**1:** 36" (900mm) stainless steel flexible hoses	**1:** 0-15 PSIG (0-1 BAR)	**2:** 0-275 BAR/0-4000 PSIG gauges no alarm capability*		**B:** Outlet valve and purge valve
	3: 100/75 PSIG (6.8/5.1 BAR)	**2:** Manifold connectors*	**2:** 0-50 PSIG (0-3.5 BAR)	**4:** 0-275 BAR/0-4000 PSIG with pressure switches and remote alarm (110/220 VAC)†*		**V:** Purge valves
	4: 200/170 PSIG (13.5/11.5 BAR)	**3:** 24" (600mm) stainless steel flexible hoses	**3:** 0-100 PSIG (0-7 BAR)	**5:** 0-40 BAR/0-600 PSIG gauges no alarm capability		
	5: 500/470 PSIG (33.8/31.8 BAR)	**4:** Diaphragm valves with 1/4" FPT port	**4:** 0-250 PSIG (0-17 BAR)	**7:** 0-40 BAR/0-600 PSIG with pressure switches and remote alarm (110/220 VAC)†		
	7: 150/130 PSIG (10.1/8.8 BAR)	**5:** Diaphragm valves with 36" (900mm) hoses	**5:** 0-400 PSIG (0-27 BAR)	**8:** 0-275 BAR/0-4000 PSIG* with pressure switches and without remote alarm†		
	8: 300/270 PSIG (20.3/22.3 BAR)	**6:** Diaphragm valves with manifold connectors*	**7:** 0-150 PSIG (0-10 BAR)	**9:** 0-40 BAR/0-600 PSIG with pressure switches and without remote alarm		
	**Not available with 4500 PSIG (310 BAR) inlet* *Note: switching pressure must be higher than line regulator pressure selected in column C.*	**7:** Diaphragm valves with 24" (600mm) hoses	**A:** 0-15 PSIG (0-1 BAR) redline for acetylene	**0-6000 PSIG/405 BAR gauges with 4500 PSIG (310 BAR) maximum inlet option* *†Intrinsic safety barriers are required for flammable gas service or for use in hazardous environments.*		
		8: 36" (900mm) stainless steel flexible hoses and 4500 PSIG (310 BAR) maximum inlet pressure				
		9: 1/4" FPT ports and 4500 PSIG (310 BAR) maximum inlet pressure				
		A: 36" (900mm) stainless steel flexible hoses with flashback arrestor for acetylene				
		B: 36" (900mm) stainless steel flexible hoses with flashback arrestor for acetylene and with diaphragm valve				
		C: Compact manifold connector*				
		D: Diaphragm valves with compact manifold connectors*				
		**See pages 54-55 for manifold ordering information*				

SPECIALTY GASES, EQUIPMENT
AND CHEMICALS

August 23, 2017

Maryland Environmental Service
Bryce Selby
259 Najoles RD
Millersville, MD 21108

Subject: Quote for (2) individual Concoa 526 Series Switchover units for flammable gas.

Lowest switching pressure: 70 / 50 psig
Hose length: 36 inches with diaphragm valves
Line Regulator: 0 – 15 psig delivery
Assembly: 0 – 4000 psig Gauges
CGA 350 for Methane Service
Relief valve with unit / set pressure of 20 psig

Dear Mr. Selby,

Thank you very much for taking the time to talk with me recently and the courtesies that were extended to me. Per our conversation, Spec Air Specialty Gases is pleased to quote on Maryland Environmental Service's specialty gas equipment requirements. The quote is as follows:

Part Number / CONCOA 526 SERIES SWITCHOVER	Price	Total Price
526 2511-350 Quantity Required: (2)	$1,585.00 / UNIT	$3,170.00
Open-style, automatic switchover for high purity applications featuring 316L stainless steel diaphragms; brass barstock regulator bodies; 70 PSIG (10 BAR) priority right / 50 PSIG (9 BAR) priority left switching pressure; two 36-inch, stainless steel-lined flexible hoses with integral check valve and CGA 350 cylinder connection; integral line regulator with 0-15 PSIG (7 BAR) maximum delivery pressure; 0-4000 PSI/0-28,000 kPa dual-scale inlet gauges; 30VAC-0-200 PSI/-100VAC-0-1400 kPa dual-scale outlet gauge; no alarm capability; and 3000 PSIG (210 BAR) maximum inlet pressure.		
5290031-01-350 Quantity Required: (4)	$212.00 / UNIT	Total Price $412.00
Stainless steel-lined flexible hose featuring 36-inch length; 1/4-inch MPT outlet; 3850 PSIG maximum inlet pressure; integral inlet check valve; and brass CGA 350 cylinder connection.		

1. **Please note the 526 manifold comes with (2) high pressure hoses, requirement requires an additional (2) hoses to complete the (4) cylinder manifold.**

<u>Quote for Hoses as follows:</u>

Hose #1 (Cylinder to Conditioning Unit) **Price: $625.00 / unit**
Size: ¼"
Pressure rating: 1000 psig (max)
Length: 10 ft
Core: SS, braided
Connection #1: To connect to the 526 Series Switchover ¼" NPT LP Port
Connection #2: To connect to the conditioning unit Natural Gas inlet, ¼" Swagelok Quick Connect Part # SS QF4 4PF

Hose #2 (Conditioning Unit to Fuel Cell) **Price: $625.00 / unit**
Size: ¼"
Pressure rating: 1000 psig (max)
Length: 10 ft
Core: SS, braided
Connection #1: To connect to the conditioning unit Natural Gas outlet, ¼" Swagelok Quick Connect Part # SS QF4 4PF
Connection #1: To connect to the Fuel Cell inlet, Yor-Lok Fitting 3/8" SS Tubing Adapter (see attached Spec)

2. **Lead time is 7-10 days**

3. **Bill To: Maryland Environmental Service**
259 Najoles Road
Millersville, MD 21108

Ship To: Bryce Selby
Maryland Environmental Service
Dundalk Marine Terminal
Dunmar North, Bldg 97C suite 115
Baltimore, MD 21222

Phone# 240-841-1354

Sincerely,

Ernest J. Glynn
Spec Air Specialty Gases
CP: 1-508-735-5848
Customer Service 1-800-292-6218

"TECHNOLOGY DRIVEN"

Atrex Energy, Inc.™

Remote Power Generation System

Atrex Energy Remote Power Generation System is a superior solution for providing continuous, unattended power for remote or off-grid applications. This field-proven power generation system operates in the harshest conditions with high levels of fuel efficiency. Based on state of the art solid oxide fuel cell technology, these generators use commercially available natural gas or propane to produce power without external reforming. With a power output range of 100 watts to 4500 watts at 2VDC to 60VDC these DC generators offer one of the highest power densities in the smallest package.

The power generator takes natural gas or propane and using an electrochemical process converts the fuel's energy into DC electricity. This process does not burn or combust fuel like other power generation technologies. This electrochemical process allows the generator to be inherently more efficient so it can deliver more usable energy for the same amount of fuel. In addition, as load requirements drop, the generator will "follow the load" and throttle back fuel consumption. Increased fuel efficiency translates into lower fuel consumption and reduced refueling visits resulting in significant cost savings.

Because the Atrex Energy generators do not burn fuel, the only emissions are small amounts of water vapor and CO2. No harmful NOx or SOx emissions contribute to air pollution. With an on-board computer each generator can be remotely monitored and controlled reducing site visits. A unique scalable feature offered on the 250 Watt and 1000 watt models provides the ability to upgrade power output by simply changing out the fuel cell bundle. Users can easily increase their generator's output as their load demand increases.

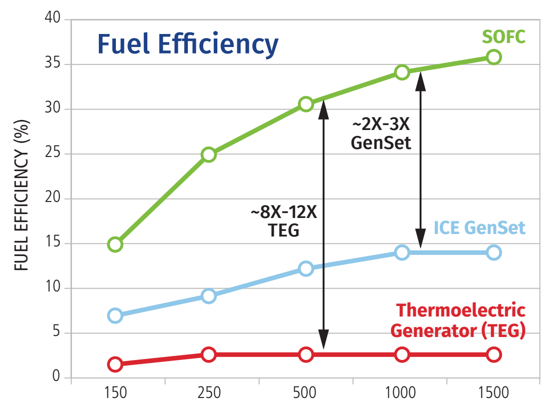
Atrex Energy offers a feature rich system with a full complement of options and accessories that allow user optimization to meet custom requirements. This flexible and highly efficient power generation system can be used in a wide variety of applications in the harshest conditions while delivering an attractive Total Cost of Ownership.

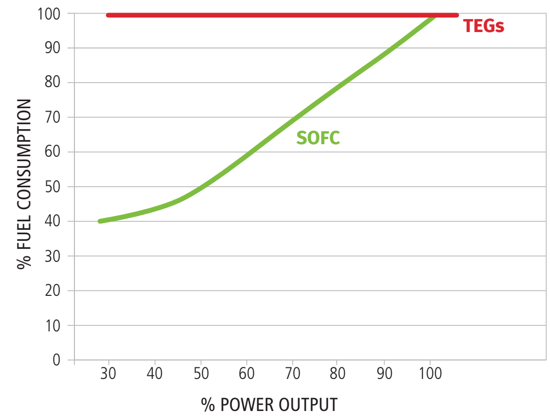
Applications:

- **Oil & Gas –** Cathodic Protection, SCADA & Instrumentation, Chemical Injection Pumps, Valve Actuation
- **Telecom & Radio –** Off-grid Microwave and Broadband Repeater Stations, Radio Transmitters, Cellular Base Stations
- **Rail –** Signaling and Control
- **Environmental Monitoring –** LIDAR, SODAR, Meteorology Stations
- **Mining & Construction –** Lighting, Surveillance

Key Benefits

- Competitive Total Cost of Ownership
- Multi-fuel flexibility with no external reformer
- High efficiency = low fuel consumption = significant fuel savings
- Remote monitoring and control
- Quiet, safe, clean with minimal emissions = Green
- Broad range of outputs for continuous operation





Atrex Energy provides clients with money-saving, smart and reliable power solutions.

Remote Power Generation System

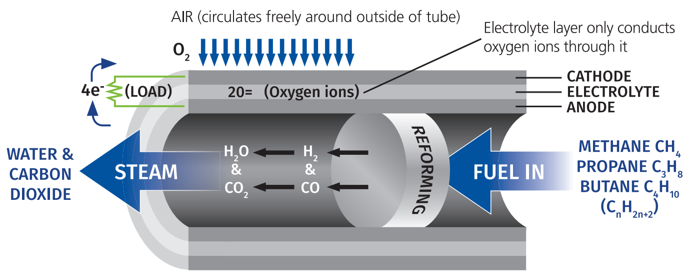
Product Specification

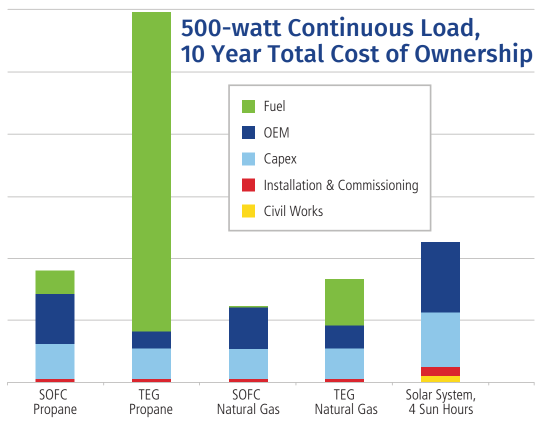
	RP250	RP500	RP1000	RP1500
Electricity Efficiency	~25%	~30%	~35%	~35%
DC Output Power Max	250W	500W	1000W	1500W
DC Output Voltage	12 or 24 VDC	2-60 VDC	2-60 VDC	2-60 VDC
DC Output Current Max[1]	25A	100A	100A	100A
Operating Modes	Current Control (CC), Voltage Control (VC), Battery Charge (Bx, x=12, 24 or 48 VDC)			
Start-up Time to Max Outpower Power	<60 minutes			
Propane Fuel Series P/N	RP250P	RP500P	RP1000P	RP1500P
Natural Gas Fuel Series P/N	RP250N	RP500N	RP1000N	RP1500N
Fuel Cell Inlet Supply Pressure	2 psig – 5 psig (13.8kPa – 34.5kPa)			
Fuel Supply Pressure with High Pressure Regulator Kit (RP-HWN/RP-HWP)	10 psig – 125 psig (68.9kPa – 861.8kPa)			
Max Sulfur Content	<60ppmw (42mg/m³)			
Max Water Content	non-condensing at operating temperature and pressure			
Fuel Consumption – Propane (HD5)	0.96G/day 3.4L/day	1.4G/day 5.8L/day	2.9G/day 10.8L/day	4.3G/day 16.8L/day
Fuel Consumption – Natural Gas	84ft³/day 2.4m³/day	137ft³/day 3.8m³/day	269ft³/day 7.7m³/day	403ft³/day 11.3m³/day
Operating Temperature	-40˚C to +50˚C (-40˚F to +122˚F)			
Storage Temperature	-40˚C to +55˚C (-40oF to +131˚F)			
Humidity	5% to 95% (non-condensing)			
Operating and Storage Altitude	0 to 10,000 feet (3,048 meters)			
Unit Dimensions (H x W x D)	22″ x 22″ x 39″ (559mm x 559mm x 991mm)		25″ x 28″ x 39″ (635mm x 711mm x 991mm)	
Unit Weight	280lbs (127kg)	293lbs (133kg)	351lbs (160kg)	358lbs (163kg)
Shipping Dimensions (H x W x D)	45″ x 46″ x 38″ (114cm x 117cm x 97cm)		48″ x 46″ x 38″ (122cm x 117cm x 97cm)	
Shipping Weight	346lbs (157kg)	359lbs (163kg)	419lbs (190kg)	426lbs (194kg)
Noise Levels (at 1m)	52dBA			
Fuel Connection – Propane	1/4″ MNPT			
Fuel Connection – Natural Gas	3/8″ Swagelok type compression tube fitting			
Data Interface	MODBUS RTU – DB9 female connector (requires RP-RS option)			
Local Computer Interface	RJ45 or wireless			
Electrical Interface	terminal block 2/0 – 8 AWG			
Enclosure IP Category	IP23			
Enclosure Construction	powder coated galvanized steel			
Warranty	12 months after installation or 13 months after date of shipment			

[1] Current will also be limited by maximum output power of unit

Solid Oxide Fuel Cell

SOLID STATE (CERAMIC) CONSTRUCTION





ATREX ENERGY
POWERFUL POSSIBILITIES

Atrex Energy, Inc. • 19 Walpole Park South, Suite 4 • Walpole, MA 02081
P 781.461.8251 • **Toll Free** 1.800.332.0277 • **atrexenergy.com**

Company Address 19 Walpole Park South
Suite 4
Walpole, MA 02081
US

Created Date 4/21/2017
Quote Number 2017042153
Quote Valid For 30 Days

Prepared By Mike Gagnon
Email mike.gagnon@atrexenergy.com

Account Name Maryland Environmental Service

Product	Product Code	Sales Price	Quantity	Total Price
ARP500-FS	Field Stand, ARP250/ARP500	$910.00	1.00	$910.00
ARP-HWN	High Pressure Regulator and Coalescing Filter Kit, Natural Gas	$940.00	1.00	$940.00
ARP-CENA	Cellular Modem And Signal Enhancer AT&T	$595.00	1.00	$595.00
ARP500N-RB	Replaceable Bundle, Natural Gas, 500W	$3,255.00	1.00	$3,255.00

Grand Total $5,700.00

Atrex Energy Terms & Conditions

1. ACCEPTANCE: The terms and conditions contained herein constitute the sole terms and conditions governing the purchase by the buyer ("Buyer") stated on the face hereof or as superseded in an accompanying signed quotation (the "Quotation") from Atrex Energy, Inc. ("Atrex Energy") of the equipment and other items specified on the face hereof or in the Quotation. Buyer may acknowledge its acceptance of these Terms and Conditions by executing and returning the attached acknowledgment copy to Atrex Energy and, in any event, Buyer shall be deemed to have accepted and agreed to these Terms and Conditions by its receipt of the Atrex Energy Product or placement of a purchase order. Any terms and conditions different from or in addition to those contained herein, including any contained in Buyer's purchase order or in any other document furnished by Buyer, shall be of no force or effect in connection with the sale of the Atrex Energy Product and Atrex Energy hereby objects to and rejects in their entirety all such terms and conditions, as Atrex Energy's agreement to sell the Atrex Energy Product is expressly made conditional upon the use of these Terms and Conditions.

2. TRANSPORTATION: All shipments of Atrex Energy Product shall be delivered Ex-Works, Atrex Energy dock, unless stated otherwise. All freight charges and other shipping costs shall be paid by Buyer including any Insurance, Custom's Fees, Taxes or Duties. Atrex Energy's prices do not include taxes, freight charges and other shipping costs. Shipping of Equipment returned to Atrex Energy shall be at Buyer's expense.

3. RISK OF LOSS: Title, risk of loss and damage to Atrex Energy Product shall pass to Buyer upon Buyer's removal of Product from Atrex Energy's dock.

4. RELEASE OF OBLIGATION: No payment, whether final or otherwise, shall operate to release Buyer from any obligations arising as a result of this order. Orders cannot be cancelled by Buyer without Atrex Energy's written consent, and then only upon terms that will compensate Atrex Energy for lost profits and all costs and expenses (including any engineering and/or fabrications charges) applicable to the cancelled order.

5. INDEMNITY: Buyer shall defend and indemnify Atrex Energy against all damages, liabilities, claims, losses, and expenses (including, without limitation, reasonable attorney's fees) arising out of or resulting in any way from any act or omission of Buyer, its agents, employees or subcontractors.

6. BUYER'S INSOLVENCY: If Buyer becomes bankrupt or insolvent, or if a petition in bankruptcy or insolvency is filed against Buyer, or if a receiver, trustee, or assignee for the benefit of creditors is appointed for Buyer, Atrex Energy shall have the right, at its sole election, to treat such occurrence as a breach hereof.

7. REMEDIES: In the event of a breach of any one or more of the provisions of this order, Atrex Energy shall have all the rights available to it at law and equity including, but not limited to, (a) to retain any money paid up to an amount which Atrex Energy determines is adequate to cover all damages resulting from Buyer's breach, (b) to assert any claim for damages and any expenses whatsoever, including, without limitation, reasonable attorney's fees, which may be incurred by Atrex Energy by reason of such breach, and (c) to terminate this order immediately upon written notice to Buyer. Such rights shall be in addition to any other remedies provided herein or provided by law or in equity, such remedies to be cumulative and not alternative.

8. PROPRIETARY INFORMATION: Any specifications, drawings, designs, manufacturing data or other information that may be transmitted to Buyer by Atrex Energy in connection with this order are the property of Atrex Energy and are disclosed in confidence upon the condition that they are not to be reproduced or copied or used in furnishing information or equipment to others, or for any purpose detrimental to the interest

of Atrex Energy. Atrex Energy shall retain all intellectual property rights in any items, features, adaptations, or modifications.

9. WAIVER: No waiver by Atrex Energy of any conditions appearing herein shall be deemed to constitute a waiver of any other conditions with regard to subsequent transactions or subsequent parts of the same transaction. No waiver of a breach of any provision of this order shall constitute a waiver of any other breach or of such provisions.

10. FORCE MAJEURE: In the event of a disruption of Atrex Energy's business in whole or in part by reason of governmental actions, acts of God, fires, strikes, floods, storms, earthquakes, epidemics, quarantines, wars, insurrections, riots, strikes, acts of civil or military authorities, transportation embargoes, shortages, wrecks, severe weather, labor shortages, Buyer acts or omissions, deliveries of components and materials, or delays by Atrex Energy's suppliers, or other causes beyond Atrex Energy's control, Atrex Energy shall have the option of canceling delivered orders in whole or in part. If cancelled by Atrex Energy, any deposits made in conjunction to such order shall be refunded in full to Buyer. Such cancellation shall not constitute a breach of this order.

11. PATENTS: Statements in Atrex Energy's literature concerning the products described therein are not to be construed as constituting a license under any Atrex Energy patent, or as recommendations for the infringement of any patent. Atrex Energy does not assume liability or responsibility for any damages growing out of an infringement of a patent, whether or not any allegedly infringing material was produced by Atrex Energy. Buyer shall defend, protect and indemnify Atrex Energy against all claims, damages, fees, or profits arising from claims of infringement of patents, designs, copyrights or trademarks with respect to (a) all Atrex Energy Product manufactured either in whole or in part to the Buyer's specifications, (b) the use of any product, device, equipment, or process not supplied by Atrex Energy, or (c) the furnishing to Atrex Energy by Buyer of any information, data, service, or applications assistance.

12. TIME OF DELIVERY: Statements as to time of delivery are estimates only and are based on conditions prevailing at the time of the Quotation. Atrex Energy shall not be liable for any consequences of delays in delivery. Atrex Energy reserves the right to make partial deliveries. Pro-rata payments become due as shipments are made.

13. TERMS OF PAYMENT: Buyer shall be responsible for payment to Atrex Energy, in full, of the amount invoiced, by pre-pay, or C.O.D., unless credit terms are agreed to in writing and signed by Atrex Energy prior to shipment. Buyer shall pay all invoices no later than thirty (30) days after the date of the invoice. Failure to pay on or before said date shall constitute a breach of this order, and in addition shall carry an interest charge at 18% per annum, or at the maximum legal rate if lower. Atrex Energy reserves the right to change terms of payment and discontinue further shipments without prejudice to any other lawful remedy until past due payments are made, or if Atrex Energy, in its sole discretion, deems Buyer to be non-credit worthy. Atrex Energy's prices for the Atrex Energy Products are exclusive of all sales, use, excise and similar taxes and duties and any such taxes and duties shall be the sole responsibility of Buyer.

14. INSPECTION AND DEFICIENT PARTS: All inspection or re-inspection performed by Buyer is at Buyer's own expense. Claims for incorrect Product or missing material, must be submitted to Atrex Energy within fourteen (14) days of receipt of Product by Buyer, and must be verified by an authorized agent of Atrex Energy. In such cases, Atrex Energy's liability is limited to the replacement or repair of such part or parts as Atrex Energy may decide. Shipping of parts returned as deficient shall be done at Buyer's expense.

15. HEADINGS: Headings are inserted for convenience only. In the event any provision of this order is not enforceable, such unenforceability does not affect the remainder of this order, as the remainder of this order shall remain in full force and effect.

16. APPLICABLE LAW: This order shall be covered by and shall be construed according to the laws of the Commonwealth of Massachusetts.

17. WARRANTY: The limited warranty provided by Atrex Energy in this Limited Warranty applies only to Original Equipment Atrex Energy-branded products that you ("Buyer") purchase in North America, directly from Atrex Energy OR Authorized Partners for Buyer's own use, and not for resale or for export outside of North America. For the warranty to be activated, the Buyer must return the Installation and Commissioning Checklist or Field Service Report within 10 days of installation or servicing.

The Atrex Energy Limited Warranty provides the Buyer with the following:

- Atrex Energy warrants that the Atrex Energy Products will be free from defects in workmanship and materials, under normal use, for twelve (12) months from installation or thirteen (13) months from the date of shipment, whichever is first to expire.
- Atrex Energy warrants that the Atrex Energy Products that qualify as Spare Stocking Parts will be free from defects in workmanship and materials, under normal use, for twelve (12) months from installation or thirty six (36) months from the date of shipment, whichever is first to expire.

The warranties set forth in this Standard do not apply to:

- Atrex Energy Products that are not installed by Atrex Energy approved personnel
- Any unauthorized third party products or services included with or used with the Atrex Energy Product.
- Damage that results from accident, abuse, misuse, neglect or any use of the Atrex Energy Product other than for its intended use.
- Damage that results from attempts to open, maintain, repair or modify the Atrex Energy Product by anyone other than Atrex Energy approved personnel.
- Atrex Energy Products (including Spare Stocking Parts) that are not stored in the original packaging in typical warehouse conditions such as indoor, dry and protected.
- Spare Parts that are installed without Atrex Energy confirming the compatibility with the system the parts are being installed in.
- Damage that results from the Atrex Energy Product being subjected to physical, thermal or electrical stress outside of specification including power fluctuations or other hazards.

- Atrex Energy Products, if the serial numbers or other identification marks that appear on the Atrex Energy Products as delivered are missing or altered.
- Atrex Energy Products that have not been subjected to the Preventive Maintenance schedule:

a.	Filter Kit	Once per year
b.	RP250 Desulfurizer Kit	Every 4 years
c.	RP500 Desulfurizer Kit	Every 3 years
d.	RP1000 Desulfurizer Kit	Every 18 months
e.	RP1500 Desulfurizer Kit	Once per year

Warranty Remedies and Procedures
As Buyer's sole and exclusive remedy and Atrex Energy entire liability under this warranty, Atrex Energy will, at its option, repair the Atrex Energy Product or replace it with a comparable Atrex Energy Product. Repair or replacement will be from Atrex Energy Factory. Replacement parts and factory warranty labor will be borne by Atrex Energy. Field warranty labor is not covered under this Warranty. Replacement Atrex Energy Products and parts used to repair the Atrex Energy Products may be new, refurbished or reconditioned. Repaired or replaced Atrex Energy Products are warranted for the unexpired portion of the original warranty period. All Atrex Energy Products and parts that are replaced become the property of Atrex Energy.

Buyer must contact Atrex Energy Technical Support when Atrex Energy Product fails to conform to specified operation or when an alarmed failure/field test suggests that the Product may be faulty, whether in or out of the warranty period. A full report of the difficulty must be sent to the Atrex Energy Customer Service Department. Upon receipt of this report, the Atrex Energy Service Department will provide the assistance required to repair or replace the Atrex Energy Product prior to the return of any Atrex Energy Product for service. Upon validation of Buyer's warranty entitlement, Atrex Energy will issue a Return Material Authorization (RMA) number along with return instructions. Buyer must ship the Atrex Energy Product to the designated location, freight pre-paid, in original or equivalent packaging within five (5) days after Atrex Energy issuance of an RMA number. Atrex Energy will not be responsible for any Atrex Energy Product damaged or lost in transit. Atrex Energy will return the repaired or replacement Atrex Energy Product to Buyer, freight pre-paid, in the United States. Atrex Energy will not be liable for any associated costs incurred by the Buyer, User or installing party as a direct or indirect result of failure or in the replacement of defective, in-warranty Product, unless Atrex Energy grants prior approval.
You may contact Atrex Energy at: 1.800.332.0277
This Limited Warranty Statement will be governed by and construed in accordance with the laws of the Commonwealth of Massachusetts, USA excluding its conflicts of law rules and principles. The United Nations Convention on Contracts for the International Sale of Goods will not apply.
Disclaimers
THE LIMITED WARRANTIES SET FORTH IN THIS LIMITED WARRANTY STATEMENT ARE IN LIEU OF AND ATREX ENERGY EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES AND CONDITIONS, EXPRESS OR IMPLIED, INCLUDING ANY IMPLIED WARRANTIES AND

CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT, AND ANY WARRANTIES AND CONDITIONS ARISING OUT OF COURSE OF DEALING OR USAGE OF TRADE. NO ADVICE OR INFORMATION, WHETHER

ORAL OR WRITTEN, OBTAINED FROM ATREX ENERGY OR ELSEWHERE WILL CREATE ANY WARRANTY OR CONDITION NOT EXPRESSLY STATED IN THIS LIMITED WARRANTY STATEMENT. SOME JURISDICTIONS DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LAST, SO THE ABOVE LIMITATION MAY NOT APPLY TO BUYER. ALL WARRANTIES IMPLIED BY STATUTE ARE LIMITED TO THE DURATION OF THE EXPRESS WARRANTIES SET FORTH ABOVE.

18. LIMITATION OF LIABILITY: IN NO EVENT WILL ATREX ENERGY LIABILITY TO BUYER ARISING OUT OF, RELATING TO, OR IN CONNECTION WITH THIS LIMITED WARRANTY STATEMENT, FROM ALL CAUSES OF ACTION AND UNDER ALL THEORIES OF LIABILITY, EXCEED THE ACTUAL AMOUNT PAID TO ATREX ENERGY BY BUYER FOR THE ATREX ENERGY PRODUCT GIVING RISE TO THE LIABILITY.
IN NO EVENT WILL ATREX ENERGY BE LIABLE TO BUYER FOR ANY SPECIAL, INCIDENTAL, EXEMPLARY, PUNITIVE OR CONSEQUENTIAL DAMAGES (INCLUDING LOSS OF USE, DATA, BUSINESS OR PROFITS) OR FOR the cost of procuring substitute products OR SERVICES ARISING OUT OF, RELATING TO, OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THE ATREX ENERGY PRODUCTS, WHETHER SUCH LIABILITY ARISES FROM ANY CLAIM BASED UPON CONTRACT, WARRANTY, TORT (INCLUDING NEGLIGENCE), STRICT LIABILITY OR OTHERWISE, AND WHETHER OR NOT ATREX ENERGY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH LOSS OR DAMAGE. THE PARTIES AGREE THAT THESE LIMITATIONS WILL SURVIVE AND APPLY EVEN IF ANY LIMITED REMEDY SPECIFIED IN THIS LIMITED WARRANTY STATEMENT IS FOUND TO HAVE FAILED OF ITS ESSENTIAL PURPOSE. SOME JURISDICTIONS DO NOT ALLOW THE LIMITATION OR EXCLUSION OF LIABILITY FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION OR EXCLUSION MAY NOT APPLY TO CUSTOMER.

19. NON-ASSIGNMENT: Buyer shall not assign any of its rights or obligations hereunder.

20. ENTIRE AGREEMENT: The quote, These Terms and Conditions, the provisions on the face hereof and the accompanying signed quotation and any other documents incorporated by reference on the face hereof are the sole and exclusive statement of the agreement between the parties concerning the purchase and sale of the Atrex Energy Product and supersede any prior agreements, orders, quotations, demonstration, samples, proposals or understandings in connection therewith. These Terms and Conditions may only be amended, modified, waived or revoked by a written instrument executed by both parties hereto.

Atrex Energy, Inc.™

ARP Series Remote Power Generators

Atrex Energy's ARP Series Remote Power Generation System is a superior solution for providing continuous, unattended power for remote or off-grid applications. This field-proven power generation system operates in the harshest conditions with high levels of fuel efficiency. Based on state of the art solid oxide fuel cell technology, these generators use commercially available natural gas or propane to produce power without external reforming. With a power output range of 150 watts to 4500 watts at 5VDC to 60VDC these DC generators offer one of the highest power densities in the smallest package.

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Because the Atrex Energy generators do not burn fuel, the only emissions are small amounts of water vapor and CO_2. No harmful NOx or SOx emissions contribute to air pollution. A state of the art User Interface Panel with touchpad and LED screen increases the ability to remotely monitor, control and adjust system parameters, reducing site visits. An industrial grade computer and 4G communication system improves on-line availability to systems deployed in the field.

Atrex Energy offers a feature rich system with a full complement of options and accessories that allow user optimization to meet custom requirements. This flexible and highly efficient power generation system can be used in a wide variety of applications in the harshest conditions while delivering an attractive Total Cost of Ownership.

Applications:

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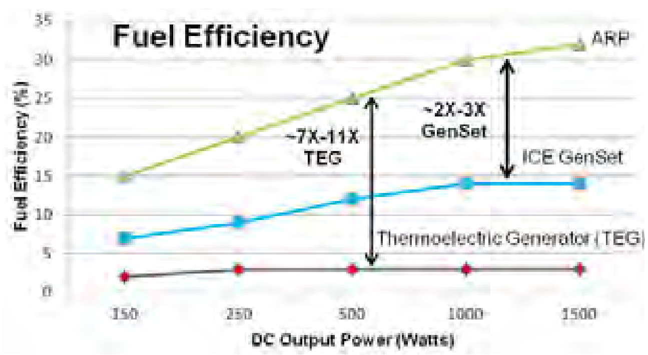
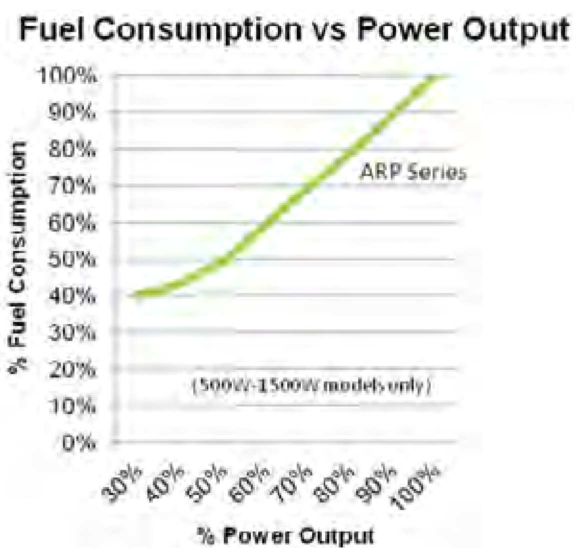
- **Telecom & Radio –** Off-grid Microwave and Broadband Repeater Stations, Radio Transmitters, Cellular Base Stations
- **Rail –** Signaling and Control
- **Environmental Monitoring –** LIDAR, SODAR, Meteorology Stations
- **Mining & Construction –** Lighting, Surveillance

User Interface Panel

Key Benefits

- Competitive Total Cost of Ownership
- Natural gas and propane models
- High efficiency = low fuel consumption = significant fuel savings
- Remote monitoring and control
- Quiet, safe, clean with minimal emissions = Green
- CSA Certified to FC-1 standard





Atrex Energy provides clients with money-saving, smart and reliable power solutions.

Remote Power Generation System

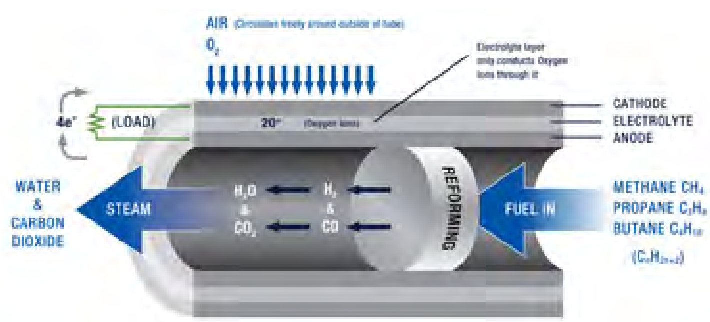
Product Specification

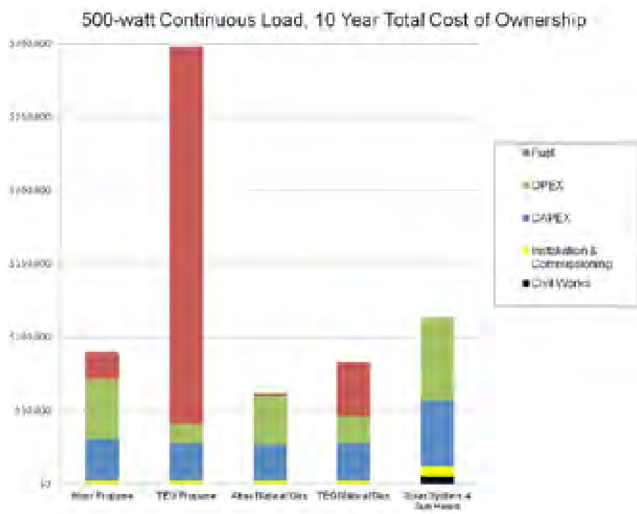
	ARP500	ARP1000	ARP1500
Electricity Efficiency	~25%	~30%	~35%
DC Output Power Max	500W	1000W	1500W
DC Output Voltage	5-60VDC	5-60VDC	5-60VDC
DC Output Current Max [1]	100A	100A	100A
Operating Modes	Current Control (CC) , Voltage Control (VC), Battery Charge (Bx, x=12, 24 or 48VDC)		
Start-up Time to Max Output Power	<60 minutes		
ARP Series P/N [2]	ARP500xy	ARP1000xy	ARP1500xy
CSA Certified	Yes	Yes	Yes
Fuel Cell Inlet Supply Pressure	2 psig - 5 psig (13.8kPa - 34.5kPa)		
Fuel Supply Pressure with High Pressure Regulator Kit (RP-HWN/RP-HWP)	5 psig - 125 psig (35.5kPa - 861.8kPa)		
Max Sulfur Content	<60ppmw (42mg/m3)		
Max Water Content	<5000ppmv for standard system, non-condensing at operating temperature and pressure		
Fuel Consumption-Propane (HD5)	2.4G/day 9L/day	3.6G/day 13.5L/day	5.2G/day 19.6L/day
Fuel Consumption-Natural Gas	185ft3/day 5.3m3/day	298ft3/day 8.4m3/day	398ft3/day 11.3m3/day
Operating Temperature	-40°C to +50°C (-40°F to +122°F)		
Storage Temperature	-40°C to +55°C (-40°F to +131°F)		
Humidity	5% to 95% (non-condensing)		
Operating & Storage Altitude	0 to 8,000 feet (2,438 meters)		
Unit Dimensions (H x W x D)	26” x 22” x 39” (66cm x 56cm x 99cm)	26” x 28” x 39” (66cm x 71cm x 99cm)	
Unit Weight	293lbs (133kg)	351lbs (160kg)	358lbs (163kg)
Shipping Dimensions (H x W x D)	45" x 46" x 38" (114cm x 117cm x 97cm)	48" x 46" x 38" (121cm x 117cm x 96cm)	
Shipping Weight	359lbs (163kg)	419lbs (190kg)	426lbs (194kg)
Noise Levels (at 1m)	52dBA		
Fuel Connection to ARP-HWP (Propane)	1/2" FNPT		
Fuel Connection to ARP-HWN (Natural Gas)	1/2" FNPT		
Data Interface	MODBUS RTU via Terminal Strip (requires ARP-RSC8 option)		
Local Computer Interface	RJ45		
Electrical Interface	Terminal Block 2/0 - 8 AWG		
Enclosure IP Category	IP23		
Enclosure Construction	powder coated galvanized steel		
Warranty	12 Months after installation or 13 months after date of shipment		

[1] - Current will also be limited by maximum output power of unit
[2] - x = Fuel (P=Propane, N=Natural Gas); y = CSA Certification (C=CSA certified, U=no CSA certification)

Solid Oxide Fuel Cell

SOLID STATE (CERAMIC) CONSTRUCTION





Atrex Energy, Inc. • 19 Walpole Park South, Suite 4 • Walpole, MA 02081
P 781.461.8251 • **Toll Free** 1.800.332.0277 • **atrexenergy.com**

 FM370A

Company Address	19 Walpole Park South Suite 4 Walpole, MA 02081 US	Created Date	4/19/2017
		Quote Number	2017041951
		Quote Valid For	30 Days
Prepared By	Mike Gagnon	Account Name	Maryland Environmental Service
Email	mike.gagnon@atrexenergy.com		

Product	Product Code	Sales Price	Quantity	Total Price
ARP500NU	Remote Power Generator Base Unit, Natural Gas, 500W	$22,680.00	1.00	$22,680.00

Grand Total $22,680.00

Atrex Energy Terms & Conditions

1. ACCEPTANCE: The terms and conditions contained herein constitute the sole terms and conditions governing the purchase by the buyer ("Buyer") stated on the face hereof or as superseded in an accompanying signed quotation (the "Quotation") from Atrex Energy, Inc. ("Atrex Energy") of the equipment and other items specified on the face hereof or in the Quotation. Buyer may acknowledge its acceptance of these Terms and Conditions by executing and returning the attached acknowledgment copy to Atrex Energy and, in any event, Buyer shall be deemed to have accepted and agreed to these Terms and Conditions by its receipt of the Atrex Energy Product or placement of a purchase order. Any terms and conditions different from or in addition to those contained herein, including any contained in Buyer's purchase order or in any other document furnished by Buyer, shall be of no force or effect in connection with the sale of the Atrex Energy Product and Atrex Energy hereby objects to and rejects in their entirety all such terms and conditions, as Atrex Energy's agreement to sell the Atrex Energy Product is expressly made conditional upon the use of these Terms and Conditions.

2. TRANSPORTATION: All shipments of Atrex Energy Product shall be delivered Ex-Works, Atrex Energy dock, unless stated otherwise. All freight charges and other shipping costs shall be paid by Buyer including any Insurance, Custom's Fees, Taxes or Duties. Atrex Energy's prices do not include taxes, freight charges and other shipping costs. Shipping of Equipment returned to Atrex Energy shall be at Buyer's expense.

3. RISK OF LOSS: Title, risk of loss and damage to Atrex Energy Product shall pass to Buyer upon Buyer's removal of Product from Atrex Energy's dock.

4. RELEASE OF OBLIGATION: No payment, whether final or otherwise, shall operate to release Buyer from any obligations arising as a result of this order. Orders cannot be cancelled by Buyer without Atrex Energy's written consent, and then only upon terms that will compensate Atrex Energy for lost profits and all costs and expenses (including any engineering and/or fabrications charges) applicable to the cancelled order.

5. INDEMNITY: Buyer shall defend and indemnify Atrex Energy against all damages, liabilities, claims, losses, and expenses (including, without limitation, reasonable attorney's fees) arising out of or resulting in any way from any act or omission of Buyer, its agents, employees or subcontractors.

6. BUYER'S INSOLVENCY: If Buyer becomes bankrupt or insolvent, or if a petition in bankruptcy or insolvency is filed against Buyer, or if a receiver, trustee, or assignee for the benefit of creditors is appointed for Buyer, Atrex Energy shall have the right, at its sole election, to treat such occurrence as a breach hereof.

7. REMEDIES: In the event of a breach of any one or more of the provisions of this order, Atrex Energy shall have all the rights available to it at law and equity including, but not limited to, (a) to retain any money paid up to an amount which Atrex Energy determines is adequate to cover all damages resulting from Buyer's breach, (b) to assert any claim for damages and any expenses whatsoever, including, without limitation, reasonable attorney's fees, which may be incurred by Atrex Energy by reason of such breach, and (c) to terminate this order immediately upon written notice to Buyer. Such rights shall be in addition to any other remedies provided herein or provided by law or in equity, such remedies to be cumulative and not alternative.

8. PROPRIETARY INFORMATION: Any specifications, drawings, designs, manufacturing data or other information that may be transmitted to Buyer by Atrex Energy in connection with this order are the property of Atrex Energy and are disclosed in confidence upon the condition that they are not to be reproduced or copied or used in furnishing information or equipment to others, or for any purpose detrimental to the interest of Atrex Energy. Atrex Energy shall retain all intellectual property rights in any items, features, adaptations, or modifications.

9. WAIVER: No waiver by Atrex Energy of any conditions appearing herein shall be deemed to constitute a waiver of any other conditions with regard to subsequent transactions or subsequent parts of the same transaction. No waiver of a breach of any provision of this order shall constitute a waiver of any other breach or of such provisions.

10. FORCE MAJEURE: In the event of a disruption of Atrex Energy's business in whole or in part by reason of governmental actions, acts of God, fires, strikes, floods, storms, earthquakes, epidemics, quarantines, wars, insurrections, riots, strikes, acts of civil or military authorities, transportation embargoes, shortages, wrecks, severe weather, labor shortages, Buyer acts or omissions, deliveries of components and materials, or delays by Atrex Energy's suppliers, or other causes beyond Atrex Energy's control, Atrex Energy shall have the option of canceling delivered orders in whole or in part. If cancelled by Atrex Energy, any deposits made in conjunction to such order shall be refunded in full to Buyer. Such cancellation shall not constitute a breach of this order.

11. PATENTS: Statements in Atrex Energy's literature concerning the products described therein are not to be construed as constituting a license under any Atrex Energy patent, or as recommendations for the infringement of any patent. Atrex Energy does not assume liability or responsibility for any damages growing out of an infringement of a patent, whether or not any allegedly infringing material was produced by Atrex Energy. Buyer shall defend, protect and indemnify Atrex Energy against all claims, damages, fees, or profits arising from claims of infringement of patents, designs, copyrights or trademarks with respect to (a) all Atrex Energy Product manufactured either in whole or in part to the Buyer's specifications, (b) the use of any product, device, equipment, or process not supplied by Atrex Energy, or (c) the furnishing to Atrex Energy by Buyer of any information, data, service, or applications assistance.

12. TIME OF DELIVERY: Statements as to time of delivery are estimates only and are based on conditions prevailing at the time of the Quotation. Atrex Energy shall not be liable for any consequences of delays in delivery. Atrex Energy reserves the right to make partial deliveries. Pro-rata payments become due as shipments are made.

13. TERMS OF PAYMENT: Buyer shall be responsible for payment to Atrex Energy, in full, of the amount invoiced, by pre-pay, or C.O.D., unless credit terms are agreed to in writing and signed by Atrex Energy prior to shipment. Buyer shall pay all invoices no later than thirty (30) days after the date of the invoice. Failure to pay on or before said date shall constitute a breach of this order, and in addition shall carry an interest charge at 18% per annum, or at the maximum legal rate if lower. Atrex Energy reserves the right to change terms of payment and discontinue further shipments without prejudice to any other lawful remedy until past due payments are made, or if Atrex Energy, in its sole discretion, deems Buyer to be non-credit worthy. Atrex Energy's prices for the Atrex Energy Products are exclusive of all sales, use, excise and similar taxes and duties and any such taxes and duties shall be the sole responsibility of Buyer.

14. INSPECTION AND DEFICIENT PARTS: All inspection or re-inspection performed by Buyer is at Buyer's own expense. Claims for incorrect Product or missing material, must be submitted to Atrex Energy within fourteen (14) days of receipt of Product by Buyer, and must be verified by an authorized agent of Atrex Energy. In such cases, Atrex Energy's liability is limited to the replacement or repair of such part or parts as Atrex Energy may decide. Shipping of parts returned as deficient shall be done at Buyer's expense.

15. HEADINGS: Headings are inserted for convenience only. In the event any provision of this order is not enforceable, such unenforceability does not affect the remainder of this order, as the remainder of this order shall remain in full force and effect.

16. APPLICABLE LAW: This order shall be covered by and shall be construed according to the laws of the Commonwealth of Massachusetts.

17. WARRANTY: The limited warranty provided by Atrex Energy in this Limited Warranty applies only to Original Equipment Atrex Energy-branded products that you ("Buyer") purchase in North America, directly from Atrex Energy OR Authorized Partners for Buyer's own use, and not for resale or for export outside of North America. For the warranty to be activated, the Buyer must return the Installation and Commissioning Checklist or Field Service Report within 10 days of installation or servicing.

The Atrex Energy Limited Warranty provides the Buyer with the following:

- Atrex Energy warrants that the Atrex Energy Products will be free from defects in workmanship and materials, under normal use, for twelve (12) months from installation or thirteen (13) months from the date of shipment, whichever is first to expire.
- Atrex Energy warrants that the Atrex Energy Products that qualify as Spare Stocking Parts will be free from defects in workmanship and materials, under normal use, for twelve (12) months from installation or thirty six (36) months from the date of shipment, whichever is first to expire.

The warranties set forth in this Standard do not apply to:

- Atrex Energy Products that are not installed by Atrex Energy approved personnel
- Any unauthorized third party products or services included with or used with the Atrex Energy Product.
- Damage that results from accident, abuse, misuse, neglect or any use of the Atrex Energy Product other than for its intended use.
- Damage that results from attempts to open, maintain, repair or modify the Atrex Energy Product by anyone other than Atrex Energy approved personnel.
- Atrex Energy Products (including Spare Stocking Parts) that are not stored in the original packaging in typical warehouse conditions such as indoor, dry and protected.
- Spare Parts that are installed without Atrex Energy confirming the compatibility with the system the parts are being installed in.
- Damage that results from the Atrex Energy Product being subjected to physical, thermal or electrical stress outside of specification including power fluctuations or other hazards.
- Atrex Energy Products, if the serial numbers or other identification marks that appear on the Atrex Energy Products as delivered are missing or altered.
- Atrex Energy Products that have not been subjected to the Preventive Maintenance schedule:

    a. Filter Kit   Once per year

b. RP250 Desulfurizer Kit Every 4 years
c. RP500 Desulfurizer Kit Every 3 years
d. RP1000 Desulfurizer Kit Every 18 months
e. RP1500 Desulfurizer Kit Once per year

Warranty Remedies and Procedures

As Buyer's sole and exclusive remedy and Atrex Energy entire liability under this warranty, Atrex Energy will, at its option, repair the Atrex Energy Product or replace it with a comparable Atrex Energy Product. Repair or replacement will be from Atrex Energy Factory. Replacement parts and factory warranty labor will be borne by Atrex Energy. Field warranty labor is not covered under this Warranty. Replacement Atrex Energy Products and parts used to repair the Atrex Energy Products may be new, refurbished or reconditioned. Repaired or replaced Atrex Energy Products are warranted for the unexpired portion of the original warranty period. All Atrex Energy Products and parts that are replaced become the property of Atrex Energy.

Buyer must contact Atrex Energy Technical Support when Atrex Energy Product fails to conform to specified operation or when an alarmed failure/field test suggests that the Product may be faulty, whether in or out of the warranty period. A full report of the difficulty must be sent to the Atrex Energy Customer Service Department. Upon receipt of this report, the Atrex Energy Service Department will provide the assistance required to repair or replace the Atrex Energy Product prior to the return of any Atrex Energy Product for service. Upon validation of Buyer's warranty entitlement, Atrex Energy will issue a Return Material Authorization (RMA) number along with return instructions. Buyer must ship the Atrex Energy Product to the designated location, freight pre-paid, in original or equivalent packaging within five (5) days after Atrex Energy issuance of an RMA number. Atrex Energy will not be responsible for any Atrex Energy Product damaged or lost in transit. Atrex Energy will return the repaired or replacement Atrex Energy Product to Buyer, freight pre-paid, in the United States. Atrex Energy will not be liable for any associated costs incurred by the Buyer, User or installing party as a direct or indirect result of failure or in the replacement of defective, in-warranty Product, unless Atrex Energy grants prior approval.

You may contact Atrex Energy at: 1.800.332.0277

This Limited Warranty Statement will be governed by and construed in accordance with the laws of the Commonwealth of Massachusetts, USA excluding its conflicts of law rules and principles. The United Nations Convention on Contracts for the International Sale of Goods will not apply.

Disclaimers

THE LIMITED WARRANTIES SET FORTH IN THIS LIMITED WARRANTY STATEMENT ARE IN LIEU OF AND ATREX ENERGY EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES AND CONDITIONS, EXPRESS OR IMPLIED, INCLUDING ANY IMPLIED WARRANTIES AND

CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT, AND ANY WARRANTIES AND CONDITIONS ARISING OUT OF COURSE OF DEALING OR USAGE OF TRADE. NO ADVICE OR INFORMATION, WHETHER

ORAL OR WRITTEN, OBTAINED FROM ATREX ENERGY OR ELSEWHERE WILL CREATE ANY WARRANTY OR CONDITION NOT EXPRESSLY STATED IN THIS LIMITED WARRANTY STATEMENT. SOME JURISDICTIONS DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LAST, SO THE ABOVE LIMITATION MAY NOT APPLY TO BUYER. ALL WARRANTIES IMPLIED BY STATUTE ARE LIMITED TO THE DURATION OF THE EXPRESS WARRANTIES SET FORTH ABOVE.

18. LIMITATION OF LIABILITY: IN NO EVENT WILL ATREX ENERGY LIABILITY TO BUYER ARISING OUT OF, RELATING TO, OR IN CONNECTION WITH THIS LIMITED WARRANTY STATEMENT, FROM ALL CAUSES OF ACTION AND UNDER ALL THEORIES OF LIABILITY, EXCEED THE ACTUAL AMOUNT PAID TO ATREX ENERGY BY BUYER FOR THE ATREX ENERGY PRODUCT GIVING RISE TO THE LIABILITY.

IN NO EVENT WILL ATREX ENERGY BE LIABLE TO BUYER FOR ANY SPECIAL, INCIDENTAL, EXEMPLARY, PUNITIVE OR CONSEQUENTIAL DAMAGES (INCLUDING LOSS OF USE, DATA, BUSINESS OR PROFITS) OR FOR the cost of procuring substitute products OR SERVICES ARISING OUT OF, RELATING TO, OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THE ATREX ENERGY PRODUCTS, WHETHER SUCH LIABILITY ARISES FROM ANY CLAIM BASED UPON CONTRACT, WARRANTY, TORT (INCLUDING NEGLIGENCE), STRICT LIABILITY OR OTHERWISE, AND WHETHER OR NOT ATREX ENERGY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH LOSS OR DAMAGE. THE PARTIES AGREE THAT THESE LIMITATIONS WILL SURVIVE AND APPLY EVEN IF ANY LIMITED REMEDY SPECIFIED IN THIS LIMITED WARRANTY STATEMENT IS FOUND TO HAVE FAILED OF ITS ESSENTIAL PURPOSE. SOME JURISDICTIONS DO NOT ALLOW THE LIMITATION OR EXCLUSION OF LIABILITY FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION OR EXCLUSION MAY NOT APPLY TO CUSTOMER.

19. NON-ASSIGNMENT: Buyer shall not assign any of its rights or obligations hereunder.

20. ENTIRE AGREEMENT: The quote, These Terms and Conditions, the provisions on the face hereof and the accompanying signed quotation and any other documents incorporated by reference on the face hereof are the sole and exclusive statement of the agreement between the parties concerning the purchase and sale of the Atrex Energy Product and supersede any prior agreements, orders, quotations, demonstration, samples, proposals or understandings in connection therewith. These Terms and Conditions may only be amended, modified, waived or revoked by a written instrument executed by both parties hereto.

Appendix E

Data Logs

Week	Day	Date	Time	Algae Tank Decrease (inches)	Total Volume added to Digester #1 (calculated in gallons)	Effluent Volume Leaving Digester# 3 (gallons)	Digester Gas bag number 1				Digester Gas bag number 2				Digester Gas bag number 3		
							CH_4 (%)	CO_2 (%)	H_2S (ppm)	O2(%)	CH_4 (%)	CO_2 (%)	H_2S (ppm)	O2(%)	CH_4 (%)	CO_2 (%)	H_2S (ppm)
1	M																
	W																
	F	8/18/2017	3:30	7	53.8	-	41.8	16.1	19		-	-	-		-	-	-
2	M	8/21/2017	4:30	7	53.8	-	57.6	15.1	2		-	-	-		-	-	-
	W	8/23/2017	11:15	7	53.8	-	63.7	13	1		-	-	-		-	-	-
	F	8/25/2017	10:15	7	53.8	-	65.02	12.41	1	0.1							
3	M	8/28/2017	11:20	7	53.8	-	72.31	10.07	0	0.1	19.5	4.3	1	0.1	7.1	2.72	0
	W	8/30/2017	9:30	7	53.8	-	71.93	8.12	0	0.1	21.23	4	1	0.2	7.77	2.48	1
	F	9/1/2017	2:00	11	84.5	-	69.33	8.61	0	0.1	21.42	4.57	1	0.1	7.93	3.1	1
4	M	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	W	9/5-6/2017	2:30 / 12:00	10	76.9	-	70.98	9.14	0	0.1	28.43	5.08	1	0.1	8.58	3.81	1
	F	9/8/2017	4:00	7	53.8	-	67.77	7.92	0	1.1	30.58	4.36	0	0.1	8.94	2.97	0
5	M	9/11/2017	3:30	7	53.8	-	69.72	8.05	0	1.2	31.63	4.17	0	0.3	9.66	2.85	0
	W	9/13/2017	2:30	7	53.8	-	74.22	8.66	0	0.1	32.75	4.27	0	0.1	8.81	2.78	0
	F	15-Sep	-	No feed	-	-	73.32	8.45	0	0.1	33.32	4.92	0	0.2	8.06	3.51	0
6	M	9/18/2017	12:30	7	53.8	-	74.41	9.65	0	0.1	36.38	4.9	0	0.1	7.97	3.22	1
	W	9/20/2017	11:30	7	53.8	-	73.22	11.13	2	0.1	38.88	5.34	1	0.1	8.03	3.12	1
	F	9/22/2017	9:10	7	53.8	-	72.5	13.84	115	0.1	45.19	7.11	118	0.1	10.45	3.64	5
7	M	9/25/2017	10:50	7	53.8	-	75.99	18.26	1	0.2	56.22	8.74	1	0.2	17.69	4.25	0
	W	9/27/2017					74.28	19.96	0	0.1	61.27	10.88	0	0.1	23.74	4.7	0
	F	9/29/2017	9:20	-	52	-	75.67	20.35	2	0.1	65.32	11.74	8	0.1	31	4.24	1
8	M	10/2/2017		no feed, innoculum	-	-											
	W	10/4/2017	10:00	-	53	-	72.51	16.81	4	0.1	69.49	15.01	458	0	62.33	12.27	568
	F	10/6/2017	10:40	-	52	-	71.66	17.65	107	0.1	70.31	16.46	244	0.1	68.46	12.28	422
9	M	10/9/2017															
	Tu	10/10/2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	W	10/11/2017					69.74	17.5	1	0.1	70.52	9.82	1	0.2	70.18	6.8	31
	F	10/13/2017	9:45	10	76.9	-	63.32	10.47	0	0.2	64.23	3.74	0	0.5	61.7	3.89	0
10	M	10/16/2017	10:20	-	54	-	55.76	10.82	0	0.1	52.79	3.38	0	0.9	35.2	2.14	0
	W	10/18/2017	9:30	-	53	-	66.64	8.77	49	0.2	51.52	2.62	1	1.1	31.53	1.68	1
	Th	10/19/2017		-	-	-	68.92	10.76	664	0.2	53.03	3.89	8	0.3	32.83	2.9	10
	F	10/20/2017	9:30	-	53	-	70.11	11.85	1467	0.2	56.22	4.21	1	0.1	35.72	3.01	2
11	M	10/23/2017	10:20	10	76.9	-	72.98	15.25	3570	0.1	58.98	6.78	468	0	41	4.65	81
	Tu	10/24/2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	W	10/25/2017	9:30	14*	see comment	-	74.29	18.18	5614	0	63.2	9.24	1243	0	44.52	5.69	376
	Th	10/26/2017		6"	see comment	-	-	-	-	-	-	-	-	-	-	-	-
	F	10/27/2017	8:20	7"	53.8	-	71.6	18.99	8841	0	53.23	3.12	0	0.5	41.9	1.3	0
12	M	10/30/2017	8:30	5"	38.43		76.55	20.53	8122	0.1	55.26	1.81	0	0.2	54.77	1.88	0
	Tu	10/31/2017	10:00	5"	38.43	-	-	-	-	-	-	-	-	-	-	-	-
	W	11/1/2017	9:45	4"	30.74	-	76.18	19.92	7922	0	54.25	1.7	0	0.1	50.62	1.74	0
	Th	11/2/2017	10:45	4"	30.74	-	-	-	-	-	-	-	-	-	-	-	-
	F	11/3/2017	9:30	5"	38.43	-	-	-	-	-	-	-	-	-	-	-	-
13	M	11/6/2017	10:20	5"	38.43	-	75.31	21.8	7588	0	57.12	1.56	1	0.2	53.36	2.59	3
	Tu	11/7/2017	11:00	4"	30.74	-											
	W	11/8/2017	3:00	5"	38.43	-	74.25	22.07	7820	0	56.69	1.27	1	0.2	50.78	2.43	2
	Th	11/9/2017	10:00	11"	84.5	-	75.05	21.66	7744	0	56.33	1.65	1	0.1	49.09	1.95	1
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	F	11/10/2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	M	11/13/2017	10:15	20"		-	76.78	20.08	7221	0.1	50.54	1.18	0	0.2	47.25	3.52	0
	Tu	11/14/2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	W	11/15/2017	-	-	-	-	77.48	19.25	6757	0	47.53	1.92	1	0.1	46.51	2.31	0
	Th	11/16/2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	F	11/17/2017	11:30	4"	30.74	-	77.22	19.38	6281	0.1	49.54	1.88	0	0.1	47.53	2.22	1
15	M	11/20/2017		6"	46.11	-	76.61	19.11	6146	0	50.12	1.91	1	0.1	46.88	2.29	1
	Tu	11/21/2017	11:10	5"	38.43	-	-	-	-	-	-	-	-	-	-	-	-
	W	11/22/2017	10:45	15"	115.29	-	77.3	19.09	6006	0	54.55	4.63	905	0	46.1	1.37	0
	F	11/24/2017	-	-	No feed	-	-	-	-	-	-	-	-	-	-	-	-
16	M	11/27/2017	10:15	4"	30.74	-	75.72	20.73	6440	0	65.2	12.37	5176	0	51.17	1.72	0
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tu	11/28/2017	10:50	4"	30.74	-	-	-	-	-	-	-	-	-	-	-	-
	Wed	11/29/2017	10:00	5"	38.43	-	75.53	21.45	5881	0	67.27	13.97	4802	0.1	53.73	1.72	0
	Th	11/30/2017	9:00	4"	30.74	-	-	-	-	-	-	-	-	-	-	-	-
	F	12/1/2017	11:00	~4"	30.74	-	79.65	19.94	5152	0	75.7	17.1	4622	0	59.15	2.15	0
17	Tu	12/5/2017	-	-	-	-	75.4	21.59	4543	0	74.44	19.05	3866	0	61.99	1.73	0
	W																
	F																

Week	Day	Date	Biogas Volume						Sample point					Personnel	Notes
			O2(%)	Time of Staring meter	Initial Meter Reading	Final Meter Reading	Quantity Biogas collected (M^3)	Gas from Digester	Algae Tank (volume collected)	Digester # 1 inlet (volume collected)	Digester #2 inlet (volume collected)	Digester #3 inlet (volume collected)	Digester# 3 Outlet (volume collected)		
1	M														
	W														
	F	8/18/2017							-	-	-	-	-	Andrew Blair	Landtec Biogas analyzer
2	M	8/21/2017							-	-	-	-	-	Andrew Blair	Landtec Biogas analyzer
	W	8/23/2017							-	-	-	-	-	Bryce Selby	First readings with Optima Biogas analyzer
	F	8/25/2017		10:20am	4.115	4.436	0.321	1						AB, BS	
3	M	8/28/2017	0.2						1 L at 9:25am	1 L at 9:25am				AB, BS	
	W	8/30/2017	0.1												
	F	9/1/2017	0.1											AB, BS	
4	M	Off	-	-	-	-	-		-	-	-	-	-	-	
	W	9/5-6/2017	0.2	-	-	-	-		-	-	-	-	-	AB, BS, BT	Digesters were fed on Tues 9/5. Biogas was sampled Wed 9/6.
	F	9/8/2017	0.2											AB, BT	
5	M	9/11/2017	0.2											AB, BS	
	W	9/13/2017	0.6											AB, BS	
	F	15-Sep	0.2											AB, BS	
6	M	9/18/2017	0.1											AB, BS	
	W	9/20/2017	0.1											AB, BS	
	F	9/22/2017	0.1	10:30	4.438	5.035	0.597	1						BS	
7	M	9/25/2017	0.1											BS	
	W	9/27/2017	0.1	2:30pm	5.035	5.631	0.596	1						BS	
	F	9/29/2017	0.1											BS	Contents added were measured using flow meter
8	M	10/2/2017			5.631	6.318	0.687	1: (moved on Tuesday 10/3)						AB, BS	
	W	10/4/2017	0	1:15	6.32	6.773	0.453	2						BS	Contents added were measured using flow meter
	F	10/6/2017	0	10:40	6.773	7.114	0.341	2						BS	
9	M	10/9/2017		3:10	6.32	6.773	0.453	3						BS	
	Tu	10/10/2017	-	10:15	7.365	7.961	0.596	2						BS	
				1:45	7.961	8.567	0.606	1						BS	
	W	10/11/2017	0.1	8:40										BS	
	F	10/13/2017	0.6	9:45										BS	
10	M	10/16/2017	5.2	10:30	8.58		0.58	1						BS	
	W	10/18/2017	5.4											BS	
	Th	10/19/2017	3.4											BS	
	F	10/20/2017	2.2											BS	
11	M	10/23/2017	0.1	10:35	9.292	9.755	0.463	1						BS	
	Tu	10/24/2017	-	9:45	9.755	10.252	0.497	2						BS	
	W	10/25/2017	0.1	10:00	10.252	10.459	0.207	3						BS	
	Th	10/26/2017	-	1:30	10.459	10.711	0.252	1						BS	
	F	10/27/2017	1.4											BS	
12	M	10/30/2017	0.5											BS	
	Tu	10/31/2017	-											BS	
	W	11/1/2017	0.3	10:00	10.711	11.01	0.299	1						BS	
	Th	11/2/2017	-	2:00	11.01	11.23	0.220	1						BS	
	F	11/3/2017	-											BS	
13	M	11/6/2017	0.2	9:55	11.23	11.503	0.273	1						BS	
	Tu	11/7/2017													
	W	11/8/2017	0.2	3:00	11.503	11.623	0.120	2							
	Th	11/9/2017	0.4	10:15	11.623	11.911	0.288	1							
	-	-	-	11:00	11.911	12.188	0.277	2							
	F	11/10/2017	-	-	-	-	-	-							Holiday - off
14	M	11/13/2017	0.2												
	Tu	11/14/2017	-	-	-	-	-	-							
	W	11/15/2017	0.1	2:00	12.188	12.406	0.218	2							
	Th	11/16/2017	-	7:40	12.406	13.056	0.650	1							
	F	11/17/2017	0.1												
15	M	11/20/2017	0.2	10:30	13.056	13.457	0.401	2							
	Tu	11/21/2017	-	11:10	13.457	13.602	0.145	1							
	W	11/22/2017	0.1	10:45	13.602	13.918	0.316	3							
	F	11/24/2017	-	-	-	-	-	-							
16	M	11/27/2017	0.2	9:50	13.918	14.312	0.394	1							
	-	-	-	11:10	14.312	14.568	0.256	2							
	Tu	11/28/2017	-	10:50	14.568	14.738	0.170	3							
	Wed	11/29/2017	0.2												
	Th	11/30/2017	-												
	F	12/1/2017	0.1												Final feeding. Remainder of tank emptied into digester 1. Fuel cell is shut down today
17	Tu	12/5/2017	0.1	2:00	15.149	15.531	0.382	1,2,3							
	W														
	F														

*All data recorded in grams

	Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C) (g)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
Week 2	PBD - 1	8/25/2017	27.116	37.25	10.134	27.409	27.42	27.411	27.411	27.356	27.362	27.362	2.910993	29.109927	0.483520821	4.83520821	2.956743232	29.56743232	0.545999812	5.45999812
	PBD - 1	8/25/2017	28.354	38.379	10.025	28.653	28.655	x	28.655	28.594	28.594	28.594	3.002494	30.0249377	0.608478803	6.08478803				
	PBD - 2	8/25/2017	27.967	38.01	10.043	28.021	28.022	x	28.022	28.012	28.012	28.012	0.547645	5.47645126	0.099571841	0.995718411	0.541440761	5.41440761	0.094388954	0.943889535
	PBD - 2	8/25/2017	25.724	35.813	10.089	25.778	25.778	x	25.778	25.767	25.769	25.769	0.535236	5.35236396	0.089206066	0.89206066				
	PBD - 5	8/25/2017	27.276	37.484	10.208	28.164	28.172	28.158	28.158	27.957	27.958	27.958	8.640282	86.4028213	1.959247649	19.59247649	8.663881277	86.63881277	1.966362887	19.66362887
	PBD - 5	8/25/2017	30.74	40.317	9.577	31.573	31.587	31.572	31.572	31.39	31.383	31.383	8.68748	86.8748042	1.973478125	19.73478125				
	PBD - 6	8/25/2017	28.417	38.679	10.262	28.5	28.504	x	28.504	28.487	28.488	28.488	0.847788	8.47787956	0.155915026	1.559150263	0.862132869	8.621328689	0.164586131	1.645861312
	PBD - 6	8/25/2017	27.124	36.936	9.812	27.207	27.21	x	27.21	27.193	27.193	27.193	0.876478	8.76477782	0.173257236	1.73257236				
	PBD - 7	8/25/2017	18.582	28.504	9.922	18.659	18.659	x	18.659	18.646	18.646	18.646	0.776053	7.76053215	0.131021971	1.310219714	0.783101005	7.831010047	0.142473531	1.424735306
	PBD - 7	8/25/2017	19.071	28.816	9.745	19.147	19.148	x	19.148	19.133	19.133	19.133	0.790149	7.90148794	0.15392509	1.539250898				

	Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C) (g)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
Week 6	PBD - 1	9/18/2017	27.963	38.056	10.093	28.43	28.422	28.424	28.424	28.324	28.321	28.321	4.567522	45.6752204	1.020509264	10.20509264	4.567225589	45.67225589	1.022065656	10.22065656
	PBD - 1	9/18/2017	30.741	40.901	10.16	31.21	31.205	31.205	31.205	31.104	31.101	31.101	4.566929	45.6692913	1.023622047	10.23622047				
	PBD - 2	9/18/2017	20.181	30.219	10.038	20.268	20.27	x	20.27	20.255	20.255	20.255	0.886631	8.86630803	0.149432158	1.494321578	0.850023576	8.500235758	0.13999023	1.399902303
	PBD - 2	9/18/2017	32.458	42.416	9.958	32.543	32.539	x	32.539	32.527	32.526	32.526	0.813416	8.13416349	0.130548303	1.305483029				
	PBD - 3	9/18/2017	18.581	28.575	9.994	18.645	18.645	x	18.645	18.637	18.635	18.635	0.640384	6.40384231	0.100060036	1.00060036	0.500588988	5.005889884	0.100140261	1.001402605
	PBD - 3	9/18/2017	27.145	37.123	9.978	27.182	27.181	x	27.181	27.171	27.171	27.171	0.360794	3.60793746	0.100220485	1.002204851				
	PBD - 5	9/18/2017	26.944	37.346	10.402	27.714	27.714	x	27.714	27.538	27.514	27.51	7.402423	74.0242261	1.961161315	19.61161315	7.390223602	73.90223602	1.838375184	18.38375184
	PBD - 5	9/18/2017	28.5	38.584	10.084	29.244	29.244	x	29.244	29.075	29.071	29.071	7.378025	73.7802459	1.715589052	17.15589052				
	PBD - 6	9/18/2017	27.27	37.177	9.907	27.451	27.45	x	27.45	27.415	27.414	27.414	1.816897	18.1689714	0.363379429	3.633794287	1.778726037	17.78726037	0.355745207	3.557452073
	PBD - 6	9/18/2017	29.167	38.934	9.767	29.339	29.337	x	29.337	29.304	29.303	29.303	1.740555	17.4055493	0.348110986	3.48110986				
	PBD - 7	9/18/2017	19.077	29.194	10.117	19.199	19.198	x	19.198	19.176	19.174	19.174	1.196007	11.9600672	0.237224474	2.372244737	1.211436507	12.11436507	0.264172644	2.641726444
	PBD- 7	9/18/2017	26.486	36.104	9.618	26.605	26.604	x	26.604	26.579	26.576	26.576	1.226866	12.2686629	0.291120815	2.911208151				

	Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C) (g)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
Week 8	PBD - 1	10/2/2017	26.707	36.592	9.885	26.796	26.797	x	26.797	26.783	26.785	26.785	0.91047	9.1047041	0.121396055	1.213960546	0.916159101	9.161591012	0.137518677	1.375186767
	PBD - 1	10/2/2017	29.151	38.914	9.763	29.242	29.241	x	29.241	29.228	29.226	29.226	0.921848	9.21847793	0.153641299	1.536412988				
	PBD - 2	10/2/2017	29.084	39.128	10.044	29.159	29.159	x	29.159	29.149	29.148	29.148	0.746714	7.46714456	0.10951812	1.095181203	0.744032681	7.440326812	0.111390032	1.113900321
	PBD - 2	10/2/2017	28.412	38.124	9.712	28.484	28.484	x	28.484	28.474	28.473	28.473	0.741351	7.41350906	0.113261944	1.13261944				
	PBD - 3	10/2/2017	18.146	28.379	10.233	18.211	18.209	x	18.209	18.203	18.202	18.202	0.615655	6.15655233	0.068406137	0.68406137	0.619677928	6.196779284	0.07578311	0.757831101
	PBD - 3	10/2/2017	27.522	37.142	9.62	27.582	27.582	x	27.582	27.575	27.574	27.574	0.623701	6.23700624	0.083160083	0.831600832				
	PBD - 5	10/2/2017	28.451	38.672	10.221	28.591	28.58	28.584	28.584	28.562	28.561	28.561	1.301243	13.0124254	0.225026905	2.250269054	1.298569434	12.98569434	0.210219922	2.102199219
	PBD - 5	10/2/2017	28.817	38.54	9.723	28.947	28.943	x	28.943	28.925	28.924	28.924	1.295896	12.9589633	0.195412938	1.954129384				
	PBD - 6	10/2/2017	28.505	38.545	10.04	28.636	28.638	x	28.638	28.613	28.613	28.613	1.324701	13.247012	0.249003984	2.490039841	1.33956317	13.3956317	2.589105942	2.589105942
	PBD - 6	10/2/2017	18.559	28.231	9.672	18.691	18.69	x	18.69	18.665	18.664	18.664	1.354425	13.5442514	0.268817204	2.688172043				

												TS (%)	TS (g/kg)			Average TS (%)	Average TS (g/kg)
Sample for Dr. Kangas	10/6/2017	27.827	38.39	10.563	29.254	28.323	x	28.323				4.695636	46.9563571			5.79	57.86
Sample 1	10/6/2017	25.72	35.377	9.657	26.575	26.384	x	26.384				6.875841	68.7584136				
Sample 1 duplicate																	

	Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C) (g)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
Week 9	PBD - 1	10/9/2017	19.069	29.402	10.333	19.325	19.331	x	19.331	19.272	19.221	19.221	2.535566	25.3556566	1.064550469	10.64550469	2.52461918	25.2461918	0.816246627	8.162466272
	PBD - 1	10/9/2017	27.114	36.622	9.508	27.345	27.353	x	27.353	27.301	27.299	27.299	2.513673	25.136727	0.567942785	5.67942785				
	PBD - 2	10/9/2017	26.483	36.206	9.723	26.656	26.66	x	26.66	26.615	26.612	26.612	1.820426	18.2042579	0.493674792	4.936747917	1.879322528	18.79322528	0.554731601	5.547316014
	PBD - 2	10/9/2017	29.19	39.096	9.906	29.38	29.382	x	29.382	29.326	29.321	29.321	1.938219	19.3821926	0.615788411	6.157884111				
	PBD - 3	10/9/2017	17.431	27.449	10.018	17.565	17.566	x	17.566	17.529	17.527	17.527	1.347574	13.4757437	0.389299261	3.892992613	1.347863544	13.47863544	0.390183232	3.901832316
	PBD - 3	10/9/2017	27.462	37.179	9.717	27.592	27.593	x	27.593	27.558	27.555	27.555	1.348153	13.4815272	0.391067202	3.910672018				
	PBD - 5	10/9/2017	29.151	39.311	10.16	29.407	29.407	x	29.407	29.323	29.321	29.321	2.519685	25.1968504	0.846456693	8.464566929	2.348450115	23.48450115	0.676392903	6.763929034
	PBD - 5	10/9/2017	29.165	39.04	9.875	29.377	29.38	x	29.38	29.333	29.33	29.33	2.177215	21.7721519	0.506329114	5.063291139				
	PBD - 6	10/9/2017	28.815	39.232	10.417	29.052	29.058	x	29.058	28.986	28.983	28.983	2.332725	23.3272535	0.719976961	7.199769607	2.389020539	23.89020539	0.813971146	8.139711465
	PBD - 6	10/9/2017	32.456	42.148	9.692	32.688	32.693	x	32.693	32.61	32.605	32.605	2.445316	24.4531572	0.907965332	9.079653322				
	PBD - 7	10/9/2017	25.632	36.094	10.462	25.855	25.858	x	25.858	25.801	25.799	25.799	2.160199	21.6019881	0.563945708	5.639457083	2.112269584	21.12269584	0.512508325	5.125083252
	PBD - 7	10/9/2017	27.126	36.669	9.543	27.316	27.323	x	27.323	27.279	27.279	27.279	2.06434	20.6434035	0.461070942	4.610709421				

	Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C) (g)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
Week 10	PBD - 1	10/16/2017	24.595	35.166	10.571	25.044	25.045	x	25.045	24.944	24.944	24.944	4.256929	42.5692933	0.95544414	9.554441396	4.256230763	42.56230763	0.938320848	9.383208482
	PBD - 1	10/16/2017	28.786	38.773	9.987	29.21	29.211	x	29.211	29.12	29.119	29.119	4.255532	42.5553219	0.921197557	9.211975568				
	PBD - 2	10/16/2017	29.051	39.372	10.321	29.274	29.273	x	29.273	29.233	29.233	29.233	2.150954	21.5095436	0.387559345	3.87559345	2.13346294	21.3346294	0.376892592	3.768925921
	PBD - 2	10/16/2017	26.335	36.165	9.83	26.544	26.543	x	26.543	26.507	26.507	26.507	2.115972	21.1597152	0.366225839	3.662258393				
	PBD - 3	10/16/2017	27.412	37.56	10.148	27.526	27.526	x	27.526	27.505	27.505	27.505	1.123374	11.2337406	0.206937328	2.069373276	1.104108483	11.04108483	0.1853436	1.853435998
	PBD - 3	10/16/2017	29.437	39.208	9.771	29.544	29.543	x	29.543	29.526	29.527	29.527	1.084843	10.848429	0.163749872	1.637498721				
	PBD - 5	10/16/2017	28.146	38.143	9.997	28.303	28.301	x	28.301	28.279	28.278	28.278	1.550465	15.5046514	0.230069021	2.300690207	1.538668029	15.38668029	0.220509146	2.205091462
	PBD - 5	10/16/2017	28.531	38.486	9.955	28.683	28.683	x	28.683	28.661	28.662	28.662	1.526871	15.2687092	0.210949272	2.109492717				
	PBD - 6	10/16/2017	25.954	36.332	10.378	26.115	26.114	x	26.114	26.091	26.091	26.091	1.541723	15.4172288	0.221622663	2.216226633	1.533868402	15.33868402	0.218349226	2.18349226
	PBD - 6	10/16/2017	26.119	35.883	9.764	26.27	26.268	x	26.268	26.247	26.247	26.247	1.526014	15.2601393	0.215075789	2.150757886				
	PBD - 7	10/16/2017	28.746	39.038	10.292	28.902	28.898	x	28.898	28.874	28.873	28.873	1.476875	14.7687524	0.242907112	2.429071123	1.469387857	14.69387857	0.236603251	2.366032508
	PBD - 7	10/16/2017	23.596	33.583	9.987	23.745	23.742	x	23.742	23.72	23.719	23.719	1.4619	14.6190047	0.230299389	2.302993892				

Week 11

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	**10/23/2017**	18.571	28.97	10.399	19.702	18.897	x	18.891	18.821	18.818	24.804	3.077219	30.7721896	-56.86123666	-568.6123666	3.065847857	30.65847857	-41.28356259	-412.8356259
PBD - 1	**10/23/2017**	26.239	35.766	9.527	26.565	26.533	x	26.53	26.465	26.462	28.979	3.054477	30.5447675	-25.70588853	-257.0588853				
PBD - 2	**10/23/2017**	26.7	36.83	10.13	26.838	26.825	x	26.823	26.804	26.803	28.268	1.214215	12.142152	-14.26456071	-142.6456071	1.210582786	12.10582786	-7.049042399	-70.49042399
PBD - 2	**10/23/2017**	27.123	36.734	9.611	27.594	27.241	x	27.239	27.219	27.218	27.223	1.20695	12.0695037	0.166475913	1.66475913				
PBD - 3	**10/23/2017**	18.138	27.766	9.628	27.24	27.218	x	27.216	27.199	27.196	27.067	94.28749	942.874948	1.547569589	15.47569589	47.69399657	476.9399657	-27.77687966	-277.7687966
PBD - 3	**10/23/2017**	23.597	33.229	9.632	24.496	23.704	x	23.703	23.688	23.686	29.203	1.100498	11.0049834	-57.1013289	-571.013289				
PBD - 5	**10/23/2017**	27.103	37.272	10.169	18.342	18.342	x	18.338	18.293	18.292	27.359	#REF!	#REF!	-88.71078769	-887.1078769	#REF!	#REF!	11.0259577	110.259577
PBD - 5	**10/23/2017**	27.825	37.488	9.663	28.493	28.221	x	28.217	28.11	28.107	17.514	#REF!	#REF!	110.7627031	1107.627031				
PBD - 6	**10/23/2017**	29.154	39.472	10.318	30.011	29.314	x	29.306	29.277	29.274	29.564	#REF!	#REF!	-2.50048459	-25.0048459	#REF!	#REF!	1.571954041	15.71954041
PBD - 6	**10/23/2017**	19.063	28.506	9.443	20.335	19.209	x	19.201	19.177	19.175	18.668	#REF!	#REF!	5.644392672	56.44392672	#REF!	#REF!	38.04057803	380.4057803
PBD - 7	**10/23/2017**	25.631	35.728	10.097	26.75	25.786		25.78	25.753	25.751	18.668	1.475686	14.7568585	70.4367634	704.367634	0.537611076	5.376110762	86.98885277	869.8885277
PBD - 7	**10/23/2017**	28.531	38.02	9.489	29.495	28.496		28.493	28.467	28.462	18.668	-0.40046	-4.0046369	103.5409421	1035.409421	-0.400463695	-4.004636948	103.5409421	1035.409421

Week 12

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	**10/30/2017**	19.069	29.402	10.333	20.385	19.325	x	19.331	19.272	19.271	19.271	2.535566	25.3556566	0.580663892	5.806638924	2.52461918	25.2461918	0.56378588	5.637858797
PBD - 1	**10/30/2017**	27.114	36.622	9.508	27.654	27.345	x	27.353	27.301	27.301	27.301	2.513673	25.136727	0.546907867	5.469078671				
PBD - 2	**10/30/2017**	26.483	36.206	9.723	27.444	26.656	x	26.66	26.615	26.612	26.612	1.820426	18.2042579	0.493674792	4.936747917	1.879322528	18.79322528	0.554731601	5.547316014
PBD - 2	**10/30/2017**	29.19	39.096	9.906	30.322	29.38	x	29.382	29.326	29.321	29.321	1.938219	19.3821926	0.615788411	6.157884111				
PBD - 3	**10/30/2017**	17.431	27.449	10.018	20.228	17.565	x	17.565	17.529	17.527	17.527	1.337592	13.3759233	0.379317229	3.79317229	1.344960098	13.44960098	0.396120884	3.961208835
PBD - 3	**10/30/2017**	27.462	37.149	9.687	30.148	27.592	x	27.593	27.558	27.553	27.553	1.352328	13.5232786	0.412924538	4.12924538				
PBD - 5	**10/30/2017**	29.151	39.311	10.16	31.418	29.407	x	29.407	29.323	29.321	29.321	2.519685	25.1968504	0.846456693	8.464566929	2.348450115	23.48450115	0.676392903	6.763929034
PBD - 5	**10/30/2017**	29.165	39.04	9.875	31.651	29.377	x	29.38	29.333	29.33	29.33	2.177215	21.7721519	0.506329114	5.063291139				
PBD - 6	**10/30/2017**	28.815	39.232	10.417	30.079	29.052	x	29.058	28.986	28.983	28.983	2.332725	23.3272535	0.719976961	7.199769607	2.389020539	23.89020539	0.813971146	8.139711465
PBD - 6	**10/30/2017**	32.456	42.148	9.692	33.763	32.688	x	32.693	32.61	32.605	32.605	2.445316	24.4531572	0.907965332	9.079653322				
PBD - 7	**10/30/2017**	25.632	36.094	10.462	27.775	25.855		25.858	25.801	25.799	25.799	2.160199	21.6019881	0.563945708	5.639457083		21.12269584	10.99139337	109.9139337
PBD - 7	**10/30/2017**	27.126	36.669	9.543	27.679	27.316		27.323	27.279	25.279	25.279	2.06434	20.6434035	21.41884104	214.1884104				

Week 13

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	11/6/2017	28.819	39.188	10.369	30.312	29.177	29.174	29.174	29.092	29.092	29.092	3.423667	34.236667	0.790818787	7.908187868	3.461476279	34.61476279	8.085903769	8.085903769
PBD - 1	11/6/2017	29.16	38.962	9.802	30.616	29.503	29.503	29.503	29.421	29.422	29.422	3.499286	34.9928586	0.826361967	8.263619669				
PBD - 2	11/6/2017	27.956	38.574	10.618	31.408	28.856	28.854	28.854	28.651	28.651	28.651	8.457337	84.573366	1.911847806	19.11847806	5.144000107	51.44000107	11.10137414	11.10137414
PBD - 2	11/6/2017	28.541	38.592	10.051	30.8	28.728	28.725	28.725	28.692	28.694	28.694	1.830664	18.3066362	0.308427022	3.084270222				
PBD - 3	11/6/2017	32.467	42.61	10.143	33.977	32.669	32.673	32.673	32.627	32.63	32.63	2.030957	20.3095731	0.423937691	4.23937691	2.006332314	20.06332314	3.948956748	3.948956748
PBD - 3	11/6/2017	28.497	38.337	9.84	31.411	28.696	28.692	28.692	28.655	28.656	28.656	1.981707	19.8170732	0.365853659	3.658536585				
PBD - 4	11/6/2017	27.294	37.274	9.98	28.691	27.413	27.415	27.415	27.395	27.396	27.396	1.212425	12.1242485	0.190380762	1.903807615	1.052685787	10.52685787	1.654221456	1.654221456
PBD - 4	11/6/2017	26.887	36.854	9.967	29.013	26.977	26.976	26.976	26.961	26.962	26.962	0.892947	8.92946724	0.14046353	1.404635296				
PBD - 5	11/6/2017	27.494	37.736	10.242	29.758	27.745	27.742	27.742	27.69	27.691	27.691	2.421402	24.2140207	0.497949619	4.979496192	2.450536393	24.50536393	5.049732033	5.049732033
PBD - 5	11/6/2017	28.52	38.481	9.961	32.032	28.77	28.767	28.767	28.715	28.716	28.716	2.479671	24.7967072	0.511996787	5.119967875				
PBD - 6	11/6/2017	28.834	38.67	9.836	30.112	28.978	28.975	28.975	28.951	28.952	28.952	1.43351	14.3350956	0.233834892	2.338348922	1.439169425	14.39169425	2.356705386	2.356705386
PBD - 6	11/6/2017	27.902	38.007	10.105	30.694	28.053	28.048	28.048	28.023	28.024	28.024	1.444829	14.4482929	0.237506185	2.375061851				
PBD - 7	11/6/2017	25.679	35.637	9.958	29.144	25.828	25.824	25.824	25.798	25.8	25.8	1.456116	14.5611569	0.241012251	2.410122515	1.454715219	14.54715219	2.399566533	2.399566533
PBD - 7	11/6/2017	27.15	37.196	10.046	29.623	27.299	27.296	27.296	27.271	27.272	27.272	1.453315	14.5331475	0.238901055	2.389010551				

Week 14

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	11/13/2017	29.0579	39.253	10.1951	29.763	29.429	29.426	29.426	29.343	29.345	29.345	3.610558	36.1055801	0.794499318	7.944993183	3.612811061	36.12811061	8.149143599	3.612811061
PBD - 1	11/13/2017	26.3618	36.298	9.9362	26.831	26.721	26.721	26.721	26.637	26.638	26.638	3.615064	36.1506411	0.835329402	8.353294016				
PBD - 2	11/13/2017	17.4183	27.495	10.0767	18.495	17.549	17.549	17.549	17.531	17.531	17.531	1.297052	12.9705161	0.178629909	1.786299086	1.282440229	12.82440229	1.636018006	1.282440229
PBD - 2	11/13/2017	29.438	39.534	10.096	30.843	29.567	29.566	29.566	29.549	29.551	29.551	1.267829	12.6782884	0.148573693	1.485736926				
PBD - 3	11/13/2017	27.629	37.489	9.86	27.755	27.747	27.749	27.749	27.734	27.735	27.735	1.217039	12.1703854	0.14198783	1.419878296	1.22216924	12.2216924	1.508183012	1.22216924
PBD - 3	11/13/2017	26.743	36.765	10.022	27.655	26.864	26.866	26.866	26.849	26.85	26.85	1.2273	12.2729994	0.159648773	1.596487727				
PBD - 4	11/13/2017	27.266	37.462	10.196	28.335	27.464	27.463	27.463	27.429	27.43	27.43	1.93213	19.3213025	0.323656336	3.236563358	1.926006598	19.26006598	3.150629038	3.150629038
PBD - 4	11/13/2017	26.1328	36.248	10.1152	27.117	26.33	26.327	26.327	26.295	26.296	26.296	1.919883	19.1988295	0.306469472	3.064694717				

Week 15

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	11/20/2017	24.595	34.918	10.323	25.085	25.088	25.082	25.082	24.943	24.944	24.944	4.717621	47.1762085	1.336820692	13.36820692	4.714559697	47.14559697	13.37775228	13.37775228
PBD - 1	11/20/2017	27.418	37.054	9.636	27.873	27.872	27.872	27.872	27.74	27.743	27.743	4.711499	47.1149855	1.338729763	13.38729763				
PBD - 2	11/20/2017	28.864	39.156	10.292	29.202	29.204	29.203	29.203	29.132	29.136	29.136	3.29382	32.9382044	0.650991061	6.50991061	3.278123149	32.78123149	6.527608199	6.527608199
PBD - 2	11/20/2017	27.453	37.231	9.778	27.77	27.773	27.772	27.772	27.703	27.708	27.708	3.262426	32.6242585	0.654530579	6.545305789				
PBD - 3	11/20/2017	28.774	39.192	10.418	28.989	28.993	28.989	28.989	28.947	28.95	28.95	2.063736	20.6373584	0.374352083	3.743520829	2.04513052	20.4513052	3.622423545	3.622423545
PBD - 3	11/20/2017	30.733	40.158	9.425	30.926	30.926	30.924	30.924	30.888	30.891	30.891	2.026525	20.265252	0.350132626	3.50132626				
PBD - 4	11/20/2017	28.156	38.26	10.104	28.301	28.303	28.303	28.303	28.276	28.279	28.279	1.454869	14.5486936	0.237529691	2.375296912	1.45282328	14.5282328	2.275731358	2.275731358
PBD - 4	11/20/2017	25.972	35.622	9.65	26.11	26.113	26.112	26.112	26.086	26.091	26.091	1.450777	14.507772	0.21761658	2.176165803				

Week 16

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	11/29/2017	20.174	30.297	10.123	20.872	20.631	20.636	20.636	20.631	20.636	20.51	4.563864	45.6386447	1.244690309	12.44690309	4.504045448	45.04045448	12.30605726	12.30605726
PBD - 1	11/29/2017	27.514	37.707	10.193	27.971	27.966	27.967	27.967	27.965	27.967	27.843	4.444226	44.4422643	1.216521142	12.16521142				
PBD - 2	11/29/2017	28.5	39.123	10.623	29.342	29.083	29.085	29.085	29.083	29.085	28.942	5.506919	55.0691895	1.346135743	13.46135743	5.612778926	56.12778926	13.84088694	13.84088694
PBD - 2	11/29/2017	28.819	38.664	9.845	29.478	29.38	29.382	29.382	29.38	29.382	29.242	5.718639	57.186389	1.422041646	14.22041646				
PBD - 3	11/29/2017	27.629	37.575	9.946	28.477	28	27.999	27.999	28	27.999	27.92	3.720088	37.2008848	0.794289161	7.942891615	3.738801754	37.38801754	8.179862641	8.179862641
PBD - 3	11/29/2017	27.298	37.278	9.98	28.218	27.67	27.673	27.673	27.67	27.673	27.589	3.757515	37.5751503	0.841683367	8.416833667				
PBD - 4	11/29/2017	28.525	38.643	10.118	30.22	28.785	28.79	28.79	28.785	28.79	28.735	2.619095	26.1909468	0.543585689	5.435856889	2.608954456	26.08954456	5.336505519	5.336505519
PBD - 4	11/29/2017	26.131	36.251	10.12	27.267	26.393	26.394	26.394	26.393	26.394	26.341	2.598814	25.9881423	0.523715415	5.23715415				

Week 17

Sample Name	Date	Cruc. Weight = Empty (g)	Cruc. + Sample = Full (g)	Sample Weight (g)	Dry 1 (105C)	Dry 2 (105 C)	Dry 3 (105 C)	Final dry weight (g)	Ash 1 (550 C) (g)	Ash 2 (550 C)	Final ash weight (g)	TS (%)	TS (g/kg)	VS (% of total)	VS (g/kg)	Average TS (%)	Average TS (g/kg)	Average VS (%)	Average VS (g/kg)
PBD - 1	12/6/2017	27.118	37.397	10.279	27.327	27.348	27.34	27.34	27.302	27.299	27.299	2.159743	21.5974317	0.398871486	3.988714856	2.151105949	21.51105949	4.223829967	4.223829967
PBD - 1	12/6/2017	29.193	38.388	9.195	29.4	29.399	29.39	29.39	29.352	29.349	29.349	2.142469	21.4246873	0.445894508	4.458945079				
PBD - 2	12/6/2017	26.927	37.002	10.075	27.349	27.348	27.34	27.34	27.263	27.254	27.254	4.099256	40.9925558	0.853598015	8.535980149	4.058455315	40.58455315	8.511991885	8.511991885
PBD - 2	12/6/2017	28.546	37.382	8.836	28.906	28.908	28.901	28.901	28.831	28.826	28.826	4.017655	40.1765505	0.848800362	8.488003622				
PBD - 3	12/6/2017	19.064	29.435	10.371	19.203	19.2	19.191	19.191	19.181	19.179	19.179	1.224569	12.2456851	0.115707261	1.157072606	1.231351526	12.31351526	1.455548272	1.455548272
PBD - 3	12/6/2017	28.36	38.052	9.692	28.488	28.488	28.48	28.48	28.467	28.463	28.463	1.238135	12.3813454	0.175402394	1.754023937				

		Unacidifed Samples					Acidified samples						
		Unifiltered					Unfilited		Filtered				
Sample Name		TS	VS	COD	C:N	Sample location	TN-TP	Sample location	Filtering done to .45	Filtering done to .2	NH4 (.45)	VFAs (.2)	Sample location
PBD - 1 - 8.25.2017		done	done			Freezer		Fridge					freezer
PBD - 2 - 8.25.2017		done	done			Freezer		Fridge					
PBD - 3 - 8.25.2017		done	done			Freezer		Fridge	X	X	X		
PBD - 5 - 8.25.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 6 - 8.25.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 7 - 8.25.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 1 - 9.18.2017		done	done			Freezer		Fridge					
PBD - 2 - 9.18.2017		done	done			Freezer		Fridge					
PBD - 3 - 9.18.2017		done	done			Freezer		Fridge					
PBD - 5 - 9.18.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 6 - 9.18.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 7 - 9.18.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 1 - 10.2.2017		done	done			Freezer		Fridge					
PBD - 2 - 10.2.2017		done	done			Freezer		Fridge					
PBD - 3 - 10.2.2017		done	done			Freezer		Fridge					
PBD - 5 - 10.2.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 6 - 10.2.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
PBD - 7 - 10.2.2017		done	done	X	X	Freezer	X	X	X	X	X	X	X
		DONE	DONE			Freezer		Fridge					
PBD - 1 - 10.9.2017		DONE	DONE			Freezer		Fridge					
PBD - 2 - 10.9.2017		DONE	DONE			Freezer							
PBD - 3 - 10.9.2017		DONE	DONE			Freezer							
PBD - 5 - 10.9.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 6 - 10.9.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 7 - 10.9.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 1 - 10.16.2017		DONE	DONE			Freezer		Fridge					
PBD - 2 - 10.16.2017		DONE	DONE			Freezer		Fridge					
PBD - 3 - 10.16.2017		DONE	DONE			Freezer							
PBD - 5 - 10.16.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 6 - 10.16.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 7 - 10.16.2017		DONE	DONE	X	X	Freezer	X	X	X	X	X	X	X
PBD - 1 - 10.23.2017		DONE	DONE			Fridge		Fridge					
PBD - 2 - 10.23.2017		DONE	DONE			Fridge		Fridge					
PBD - 3 - 10.23.2017		DONE	DONE			Fridge							
PBD - 4 - 10.23.2017		DONE	DONE			Fridge							
PBD - 5 - 10.23.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X
PBD - 6 - 10.23.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X
PBD - 7 - 10.23.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X

		Unacidifed Samples					Acidified samples						
		Unifiltered					Unfilited		Filtered				
Sample Name		TS	VS	COD	C:N	Sample location	TN-TP	Sample location	Filtering done to .45	Filtering done to .2	NH4 (.45)	VFAs (.2)	Sample location
PBD - 1 - 10.30.2017		DONE	DONE			Fridge		Fridge					
PBD - 2 - 10.30.2017		DONE	DONE			Fridge		Fridge					
PBD - 3 - 10.30.2017		DONE	DONE			Fridge		Fridge					
PBD - 4 - 10.30.2017		DONE	DONE			Fridge							
PBD - 5 - 10.30.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X
PBD - 6 - 10.30.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X
PBD - 7 - 10.30.2017		DONE	DONE	X	X	Fridge	X	X	X	X	X	X	X
PBD - 1 - 11.6.2017		Done	done			Fridge							
PBD - 2 - 11.6.2017		Done	done			Fridge							
PBD - 3 - 11.6.2017		Done	done			Fridge							
PBD - 4 - 11.6.2017		Done	done			Fridge							
PBD - 5 - 11.6.2017		Done	done	X	X	Fridge	X	X	X	X			
PBD - 6 - 11.6.2017		Done	done	X	X	Fridge	X	X	X	X			
PBD - 7 - 11.6.2017		Done	done	X	X	Fridge	X	X	X	X			
PBD - 1 - 11.13.2017													
PBD - 2 - 11.13.2017													
PBD - 3 - 11.13.2017													
PBD - 4 - 11.13.2017													
PBD - 5 - 11.13.2017													
PBD - 6 - 11.13.2017													
PBD - 7 - 11.13.2017													
PBD - 1 - 11.20.2017													
PBD - 2 - 11.20.2017													
PBD - 3 - 11.20.2017													
PBD - 4 - 11.20.2017													
PBD - 5 - 11.20.2017													
PBD - 6 - 11.20.2017													
PBD - 7 - 11.20.2017													
PBD - 1 - 11.29.2017													
PBD - 2 - 11.29.2017													
PBD - 3 - 11.29.2017													
PBD - 4 - 11.29.2017													
PBD - 5 - 11.29.2017													
PBD - 6 - 11.29.2017													
PBD - 7 - 11.29.2017													

	Biogas collected (L)	% CH4	Algae added (L/wee	VS (g/kg)	Density kg/L	VS of algae added (g/	VS of algae added (kg/we	assume biogas in one week L CH4/kg VS
8/25/2017	0.321	65.8527273	600	5.45999812	1	3276	3.275998872	0.064526046
9/18/2017			600	10.2206566	1	6132	6.132393933	
10/2/2017			600	1.37518677	1	825	0.82511206	
10/9/2017			600	8.162	1	4897	4.8972	
	Target							
	138 L Ch4/kg VS					AVERAGE	3.782676216	

	Biogas Collected	Days	Daily Production	Weekly Produ	CH4	Methane weekly	L CH4/kg VS	
9/27/2017	596	5	119.2	834.4	0.7599	634.06056	194	Based on 8/25/17 VS values
							103	Based on 9/18./17 VS values
							768	Based on 10/2/17 VS values
9/27/2017	596	5	119.2	834.4	0.7599	634.06056	129	Based on average VS of three samples
1/0/1900	687	6	114.5	801.5	0.7251	581.16765	119	Based on average VS of three samples
1/0/1900	453	1	453	3171	0.7251	2299.2921	470	Based on average VS of three samples
1/3/1900	341	2	170.5	1193.5	0.7166	855.2621	175	Based on average VS of three samples

Week	Day	Date	Biogas Volume						
			O2(%)	Time of Staring meter	Initial Meter Reading	Final Meter Reading	Quantity Biogas collected (M^3)	Gas from Digester	Time between samplings
1	M								
	W								
	F	8/18/2017							
2	M	8/21/2017							
	W	8/23/2017							
	F	8/25/2017		10:20am	4.115	4.436	0.321	1	6
3	M	8/28/2017	0.2						
	W	8/30/2017	0.1						
	F	9/1/2017	0.1						
4	M	Off	-	-	-	-	-		
	W	9/5-6/2017	0.2	-	-	-	-		
	F	9/8/2017	0.2						
5	M	9/11/2017	0.2						
	W	9/13/2017	0.6						
	F	15-Sep	0.2						
6	M	9/18/2017	0.1						
	W	9/20/2017	0.1						
	F	9/22/2017	0.1	10:30	4.438	5.035	0.597	1	
7	M	9/25/2017	0.1						
	W	9/27/2017	0.1	2:30pm	5.035	5.631	0.596	1	
	F	9/29/2017	0.1						
8	M	10/2/2017			5.631	6.318	0.687	1: (moved on Tuesday 10/3)	
	W	10/4/2017	0	1:15	6.32	6.773	0.453	2	
	F	10/6/2017	0	10:40	6.773	7.114	0.341	2	
9	M	10/9/2017		3:10	6.32	6.773	0.453	3	
	Tu	10/10/2017	-	10:15	7.365	7.961	0.596	2	
				1:45	7.961	8.567	0.606	1	
	W	10/11/2017	0.1	8:40					
	F	10/13/2017	0.6	9:45					

m^3 of biogas per we	L of biogas
0.321	321

Days between reading	Biogas (m3)/week	Biogas (L)/week	% CH4	CH4 (L)/week	L CH4/ g VS
			% CH4	L CH4/week	L CH4/ g VS
28	0.14925	149.25	0.725	108.20625	28.6057394
5	0.8344	834.4	0.7599	634.06056	167.622213
6	0.8015	801.5	0.7409	593.83135	156.987095
7	2.449	2449	0.6974	1707.9326	451.514352

	Biogas Collect	Days	Daily Producti	Weekly Produ	CH4	Methane wee	L CH4/kg VS	
9/27/2017	596	5	119.2	834.4	0.7599	634.06056	3	Based on 8/25/17 VS values
							#DIV/0!	Based on 9/18./17 VS values
							#DIV/0!	Based on 10/2/17 VS values
9/27/2017	596	5	119.2	834.4	0.7599	634.06056	168	Based on average VS of three samples
1/0/1900	687	6	114.5	801.5	#VALUE!	#VALUE!	#VALUE!	Based on average VS of three samples
1/0/1900	453	1	453	3171	#VALUE!	#VALUE!	#VALUE!	Based on average VS of three samples
1/0/1900	341	2	170.5	1193.5	0.00409722	4.89003472	1	Based on average VS of three samples

Labeling System	
PBD - 1	Inflow to AD1
PBD -2	Inflow to AD2
PBD - 3	Inflow to AD3
PBD - 4	Outflow of AD3
PBD - 5	Decant Lowest Valve
PBD - 6	Decant Middle Valve
PBD - 7	Decant Highest Valve

			YSI						In Lab		Acidified Samples	
		Time	**Temp. (°C)**	**Pressure (mmhg)**	**DO (ms/c)**	**Conductivity**	**pH**	**ORP (mV)**	**pH**	**Temp. (°C)**	**Acid Added (mL)**	**pH after acid**
Week 2	**PBD - 1 - 8/25/17**	9:13	28	765.8	1.04	7241	7.2	-174.8	7.3	17.5	10	1.82
	PBD - 2 - 8/25/17	9:09	27.7	765.9	0.68	8088	7.3	-169.1	7.33	17.3	10	1.83
	PBD - 3 - 8/25/17	9:03	27.3	766	0.89	8691	7.4	-146				
	PBD - 4 - 8/25/17	9:00	25.1	766.1	1.13	4415	7.39	-42.4				
	PBD - 5 - 8/25/17								7.05	19.1		
	PBD - 6 - 8/25/17								7.14	20		
	PBD - 7 - 8/25/17								7.21	19.6		

			YSI						In Lab		Acidified Samples	
		Time	**Temp. (°C)**	**Pressure (mmhg)**	**DO (ms/c)**	**Conductivity**	**pH**	**ORP (mV)**	**pH**	**Temp. (°C)**	**Acid Added (mL)**	**pH after acid**
Week 6	**PBD - 1 - 9/18/17**		25.6	764.6	0.78	11062	6.81	-201.2	6.7		10	1.74
	PBD - 2 - 9/18/17		27.8	764.5	0.55	8969	7.27	-255.5	7.13		10	1.45
	PBD - 3 - 9/18/17		27.9	764.4	0.71	8421	7.43	-182.9	7.47		10	1.6
	PBD - 4 - 9/18/17											
	PBD - 5 - 9/18/17											
	PBD - 6 - 9/18/17											
	PBD - 7 - 9/18/17											

			YSI						In Lab		Acidified Samples	
		Time	**Temp. (°C)**	**Pressure (mmhg)**	**DO (ms/c)**	**Conductivity**	**pH**	**ORP (mV)**	**pH**	**Temp. (°C)**	**Acid Added (mL)**	**pH after acid**
Week 8	**PBD - 1 - 10/2/17**		26.4									
	PBD - 2 - 10/2/17		30									

			YSI						In Lab		Acidified Samples	
		Time	**Temp. (°C)**	**Pressure (mmhg)**	**DO (ms/c)**	**Conductivity**	**pH**	**ORP (mV)**	**pH**	**Temp. (°C)**	**Acid Added (mL)**	**pH after acid**
Week 9	**PBD - 1 - 10/9/17**		29.5	759.7	0.81	10148	7.02	-168.6			15	1.92
	PBD - 2 - 10/9/17		30	759.7	0.46	10420	7.38	-223.5			14	1.85
	PBD - 3 - 10/9/17		29.6	759.8	0.37	10659	7.51	-246.1				

			YSI						In Lab		Acidified Samples	
		Time	**Temp. (°C)**	**Pressure (mmhg)**	**DO (ms/c)**	**Conductivity**	**pH**	**ORP (mV)**	**pH**	**Temp. (°C)**	**Acid Added (mL)**	**pH after acid**
Week 10	**PBD - 1 - 10/16/17**		25.2	764.9	2.67	10585	7.25	-122.5			10	1.39
	PBD - 2 - 10/16/17		26.9	764.8	1.98	11168	7.95	-79.3			10	1.6
	PBD - 3 - 10/16/17		27.1	764.8	1.36	10941	8.13	-26.3				

			YSI						In Lab		Acidified Samples	
		Time	Temp. (°C)	Pressure (mmhg)	DO (ms/c)	Conductivity	pH	ORP (mV)	pH	Temp. (°C)	Acid Added (mL)	pH after acid
Week 11	**PBD - 1 - 10/23/17**		21.7	768.6	3.32	4202	7.57	-122.1		22.1	10	1.53
	PBD - 2 - 10/23/17		22.1	768.5	1.72	7866	6.97	-219		22.6	10	1.48
	PBD - 3 - 10/23/17		25.9	768.5	1.58	8156	7.46	-221.8		24.7	10	1.59

			YSI						In Lab		Acidified Samples	
		Time	Temp. (°C)	Pressure (mmhg)	DO (ms/c)	Conductivity	pH	ORP (mV)	pH	Temp. (°C)	Acid Added (mL)	pH after acid
Week 12	**PBD - 1 - 10/30/17**		19.3	753.4	2.61	14661	6.85	-200.6			10	1.49
	PBD - 2 - 10/30/17		26.6	753.4	4.12	15533	8.1	79.8			10	1.6
	PBD - 3 10/30/17		32	753.5	3.85	16753	8.16	-73.3			10	1.62

			YSI						In Lab		Acidified Samples	
		Time	Temp. (°C)	Pressure (mmhg)	DO (ms/c)	Conductivity	pH	ORP (mV)	pH	Temp. (°C)	Acid Added (mL)	pH after acid
Week 13	**PBD - 1 - 11/6/17**		20.6	761.8	5.87	8224	6.8	-164.3			10	1.67
	PBD - 2 - 11/6/17		23.8	761.9	3.02	13720	7.18	-212			10	1.49
	PBD - 3 11/6/17		30.3	761.9	1.57	15448	7.77	-206.9			10	1.5

Week 14 **PBD - 1 - 11/13/17**
PBD - 2 - 11/13/17
PBD - 3 11/13/17

Week 15 **PBD - 1 - 11/20/17**
PBD - 2 - 11/20/17
PBD - 3 11/20/17

Wek 16 **PBD - 1 - 11/29/17**
PBD - 2 - 11/29/17
PBD - 3 11/29/17
PBD - 4 11/29/2017

Week 17 **PBD - 1 - 12/6/17**
PBD - 2 - 12/6/17
PBD - 3 12/6/17

Sample	Date	COD mg\L
PBD 1	18-Sep	
PBD 2	18-Sep	5300
PBD 3	18-Sep	1050
PBD 1	9-Oct	10670
PBD 2	9-Oct	1740
PBD 1	16-Oct	6280
PBD 2	16-Oct	4530
PBD 2	23-Oct	5060
PBD 3	23-Oct	1780
PBD 1	23-Oct	2240
PBD 1	30-Oct	4710
PBD 2	30-Oct	1590
PBD 3	30-Oct	1880
PBD 1	6-Nov	12790
PBD 2	6-Nov	5080
PBD 3	6-Nov	3120
PBD 4	6-Nov	1800
PBD 1	13-Nov	9870
PBD 2	13-Nov	5450
PBD 3	13-Nov	9570
PBD 4	13-Nov	2830
PBD 1	28-Nov	1433
PBD 2	28-Nov	1448
PBD 3	28-Nov	1446
PBD 4	28-Nov	544
PBD 2	29-Nov	1461
PBD 3	29-Nov	1446
PBD 4	29-Nov	544
PBD 1	29-Nov	885
PBD 1	6-Dec	1195
PBD 2	6-Dec	1290
PBD 3	6-Dec	340

Optima 7	Date	CH4 (%)	CO2 (%)	H2S (ppm)		SUM
PBD - 1 - 8/25/17	8/25/2017	63.1	13.7	0		76.8
PBD - 2 - 8/25/17	8/25/2017	16.2	5.4	0		21.6

Landtec	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	SUM
PBD - 1 - 8/25/17	8/25/2017	65.02	12.41	1	0.1	78.53

	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	
PBD - 1 - 10/2/17	10/2/2017	77.5	18.11	1	0.1	96.71
PBD - 2 - 10/2/17	10/2/2017	69.46	10.17	1	0	80.63

	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	
PBD - 1 - 10/9/17	10/9/2017	72.7	21.7	85	0.2	
PBD - 2 - 10/9/17	10/9/2017	73.3	19.8	145	0	
PBD - 3 - 10/9/17	10/9/2017	70.1	15.8	341	0.1	

	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	Balance	SUM
PBD - 1 - 10/16/17	10/16/2017	53.7	12	0	0.1	34.2	100
PBD - 2 - 10/16/17	10/16/2017	49.6	4.3	1	0.8	45.3	100
PBD - 3 - 10/16/17	10/16/2017	33	2.9	0	5	59.1	100

	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	Balance	SUM
PBD - 1 - 10/23/17	10/23/2017	73.1	16.6	3368	0.2	10.1	100
PBD - 2 - 10/23/17	10/24/2017	56.8	7.9	517	0	35.3	100
PBD - 3 - 10/23/17	10/25/2017	38.9	5.6	116	0.1	55.4	100

GC Values (10/23)	CO2 (%)	CH4 (%)
PBD - 1	14.85	72.28
PBD - 2	6.15	57.53

	Date	CH4 (%)	CO2 (%)	H2S (ppm)	02 (%)	Balance	SUM
PBD - 1 - 10/30/17	10/30/2017	76.4	22.1	8171	0.1	1.5	100.1
PBD - 2 - 10/30/17	10/31/2017	51.8	2.7	1120	0.1	45.4	100
PBD - 3 - 10/30/17	11/1/2017	51.8	2.7	1120	0.1	45.4	100

Sample	Lachat cup #	Lachat (NH4+NH3)-N (mg N/L)	
PBD 1 10/23	89	211	
PBD 1 10/09	90	215	
PBD 2 10/09	91	285	
PBD 2 10/16	92	252	
PBD 3 9/18	93	204	
PBD 2 11/16	94	290	
PBD 3 11/13	95	197	
PBD 4 11/13	96	268	
PBD 3 10/30	97	399	
PBD 1 9/18	98	130	
PBD 1 10/16	99	162	
PBD 2 10/23	100	236	
PBD 1 11/13	101	257	
PBD 2 11/6	102	338	
PBD 2 10/30	103	342	
PBD 2 9/18	104	192	
PBD 3 11/6	105	351	
PBD 11/13	106	324	
PBD 1 10/09	119	206	Duplicate
PBD 2 10/23	120	209	Duplicate