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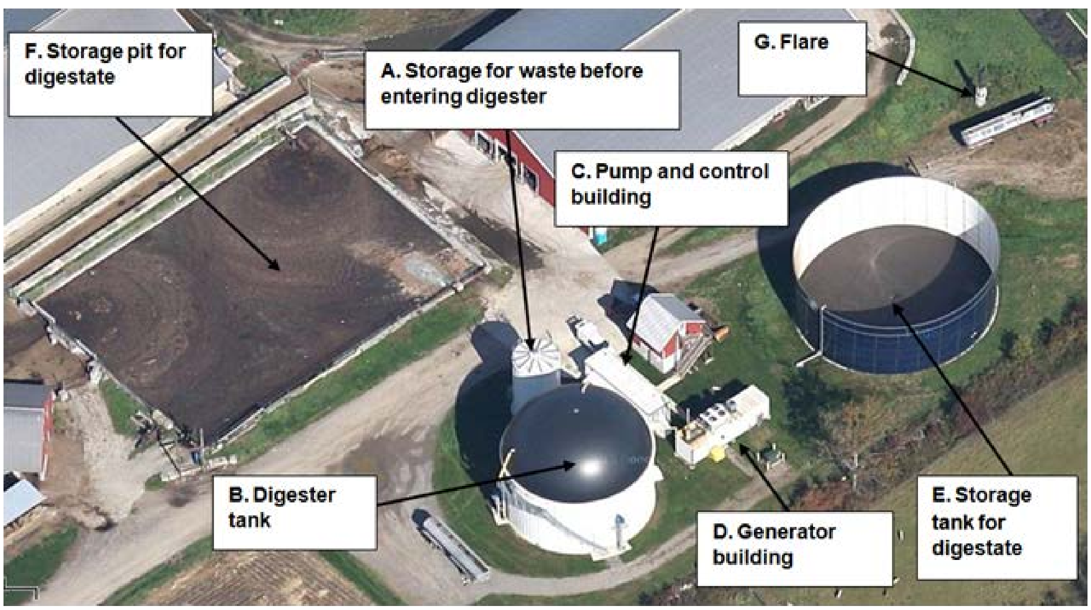
Base-Wide Biodigester for Basecamps in an Operational Environment

John L. Vavrin and Ian McNamara

September 2014



Arial view of the food waste and cow manure digester

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Abstract

Managing solid waste disposal at basecamps at contingency basecamps (CBs) in an operational environment is a challenging task because waste management places a large burden on the camp's logistics, fuel supply, and security. Base management must consider the complex interdependency between power, fuel, and solid waste management, all of which must be carefully managed under difficult and dangerous conditions. The U.S. Army Corps of Engineers has provided assistance and expertise to Army leadership in effective waste management techniques in contingency environments. As part of this effort, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) conducted this analytical study of the use of anaerobic digesters for food waste disposal. Anaerobic digesters can reduce the amount of solid waste requiring disposal, produce a net amount of electricity that can help power the base, and produce thermal energy for heating. This study determined that it was feasible and cost effective to install anaerobic digesters at large enduring CBs.

Executive Summary

Waste disposal in a contingency environment places a burden on the logistics, fuel supply, and security at contingency basecamps (CBs). Unlike their counterparts at fixed installations in the United States, personnel who live and work at basecamps are required to handle, treat, and dispose of all waste streams. These waste-handling efforts divert valuable resources from the primary mission(s) of the basecamp personnel and burden the entire logistical chain.

Bagram Airfield (BAF), Afghanistan provides one good example among the hundreds of basecamps ranging in all sizes throughout the entire combined joint operational area. BAF produces about 200 tons of solid waste daily. Its current solid waste disposal methods have included recycling, combustion using an Air Curtain Incinerator ("Burn Box"), burn pits, and combustion using an Advanced Combustion Systems CA 3000 Incinerator (Brent et al. 2010a). However, a recent fragmentary order (FRAGO) in the Combined/Joint Operations Area, Afghanistan (CJOA-A) (USFOR-A 2012) required all the burn pits to close not later than (NLT) 31 July 2013, or to continue operation contingent on having a temporary waiver in place. Consequently, BAF will rely on a combination of recycling, incineration, and removal by local nationals.

Bases in a contingency environment generate large amounts of food waste: 1.7 lb/Soldier/day at enduring base camps, and 1.1 lb/Soldier/day at temporary base camps (Cosper and Gerdes 2010). Food waste disposal places an especially large burden on CBs because of its high moisture content, which makes it harder than other solid waste to incinerate. Food waste also attracts unwanted insects and rodents, which can add health and sanitation risks. Anaerobic digestion offers a proven technology for food waste disposal that is "energy positive," i.e., that generates more energy than it consumes. Incorporating anaerobic digestion systems into contingency basecamp operations will reduce the burden of food waste disposal at CBs, and also reduce the amount of fuel required by the CB for power generation.

The analysis described in this report assumes a 10,000 personal (PAX) contingency basecamp. The 10,000 PAX includes U.S. service members, DoD civilians (Federal employees), coalition forces, contractors, local nationals, third country nationals, and transits. (Additional calculations will also be repeated for a 5,000 PAX CB and a 20,000 PAX CB.) This detailed analysis shows that an anaerobic digester at a 10,000 PAX basecamp will produce about 796,000 kWhrs of electricity annually using a 91 kW generator, will reduce solid waste by 3,100 tons per year, and will achieve a simple payback in 2.8 years.

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Preface

This study was conducted for U.S. Forces – Afghanistan (USFOR-A).” The technical reviewer was Stephen D. Cosper, CEERD-CN-E.

The work was managed and executed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was John L. Vavrin. At the time of publication, Andrew J. Nelson was Acting Chief, CEERD-CF-E, and L. Michael Golish was Chief, CEERD-CF. The associated Technical Director was Kurt Kinnevan, CEERD-CV-T. The Director of CERL was Dr. Ilker R. Adiguzel.

The Commander and Executive Director of ERDC was COL Jeffrey R. Eckstein, and the Director of ERDC was Dr. Jeffery P. Holland.

1 Introduction

1.1 Background

In a contingency environment, waste disposal places a burden on the logistics, fuel supply, and security. This is especially true at contingency basecamps (CBs). Unlike their counterparts at fixed installations in the United States, personnel who live and work at basecamps are required to handle, treat, and dispose of all waste streams. These waste-handling efforts divert valuable resources from the primary mission(s) of the basecamp personnel and burden the entire logistical chain.

Bagram Airfield (BAF), Afghanistan, which produces about 200 tons of solid waste daily, provides one good example among the hundreds of basecamps ranging in all sizes throughout the entire combined joint operational area. Current solid waste disposal methods at BAF have included recycling, combustion using an Air Curtain Incinerator ("Burn Box"), burn pits, and combustion using an Advanced Combustion Systems CA 3000 Incinerator (Brent et al. 2010a). However, a recent fragmentary order (FRAGO) in the CJOA-A required all the burn pits to close NLT 31 July 2013, or to continue operation contingent on having a temporary waiver in place (USFOR-A 2012). Since that date, BAF has relied on a combination of recycling, incineration, and removal by local nationals.

Food waste disposal can be especially problematic. Bases in a contingency environment generate large amounts of food waste: 1.7 lb/Soldier/day at enduring base camps, and 1.1 lb/Soldier/day at temporary base camps (Cosper and Gerdes 2010a). Food waste places an particularly large burden on CBs because of its high moisture content, which makes it harder than other solid waste to incinerate. Food waste also attracts unwanted insects and rodents, which can add health and sanitation risks.

Anaerobic digestion offers a promising alternative to incineration for food waste disposal. Anaerobic digestion is a proven technology for food waste disposal that is "energy positive," i.e., it generates more energy than it consumes. Incorporating anaerobic digestion systems into contingency basecamp operations can reduce the burden of food waste disposal at CBs, and reduce the amount of fuel required by the CB for power generation. This work was undertaken to analyze the feasibility and benefits of using anaerobic digesters for food waste disposal at a 10,000 personal (PAX) contingency basecamp, where the basecamp population includes U.S. service members, DoD civilians (Federal employees), coalition forces, contractors, local nationals, third country nationals, and transits.

1.2 Objectives

The overall objectives of this work were to analyze the feasibility and benefits of using anaerobic digesters for food waste disposal. Specific objectives included an analysis and estimate of anaerobic digesters' abilities to:

- reduce the volume of solid waste requiring disposal
- produce electricity to help meet base power needs
- produce thermal energy to help meet base heating needs.

1.3 Approach

The objectives of this work were met in the following steps:

1. The technical capabilities of food waste anaerobic digester systems were reviewed, including a review of cultural concerns that may arise when certain food wastes (i.e., pork products) are processed in locations where the local population may refuse to handle or use the resulting digested (compost or fertilizer) product.
2. Operational anaerobic digester systems were reviewed, and ERDC-CERL researchers visited the anaerobic digestion plant at the Jordan Dairy Farm in Rutland, MA to gain direct experience with daily operations of such systems.
3. Detailed plans for anaerobic digester systems were reviewed to estimate the optimal footprint, configuration, and placement of such systems in CBs in an operational environment.
4. Costs and saving were estimated for a baseline (10,000 PAX) Continental United States (CONUS) base, temporary location, and enduring base, and for 5,000 and 20,000 PAX bases of the same types.
5. Conclusions were drawn and recommendations made regarding the optimal, cost-effective use of anaerobic digester systems at CBs in an operational environment.

1.4 Scope

Although the primary analysis summarized in this report assumed a 10,000 PAX contingency basecamp, additional calculations were repeated for a 5,000 and 20,000 PAX CB.

1.5 Mode of technology transfer

This report will be made accessible through the World Wide Web (WWW) at URL: http://libweb.erdc.usace.army.mil

2 Discussion

2.1 Assumptions

Table 2-1 lists the facts and assumptions that underlie the cost and savings calculations in this document.

Table 2-1. Facts and assumptions used in this report.

Item	Value	Notes/Source
Inflation Factor	2.3%/year	Average inflation rate over the past 3 yrs (USDOL 2013)
Burden Factor – non-construction	3	An assumed factor used to increase the cost of goods and services used in Afghanistan, not construction, see below
Burden Factor - construction	2	Based on comparison of several DD 1391 construction costs for similar type buildings
Fully burdened cost (FBC) of solid waste disposal at BAF	$0.13/lb	Annual cost of $9,343,774 to dispose an estimated 39,420 tons of solid waste in 2010, with a 2.3% annual inflation rate (Brent et al. 2010b)
FBC of power at BAF	$0.70/kWh	USACE Reachback Operations Center (UROC) calculated value in 2012
Average efficiency of electric water heater	88%	Zhivov (2011)

2.2 Current configuration

2.2.1 Waste disposal

Current solid waste disposal methods at BAF have included recycling, burn pits, combustion using an Air Curtain Incinerator (“Burn Box”), and combustion using an Advanced Combustion Systems CA 3000 Incinerator (Brent et al. 2010a). However, a recent FRAGO in the CJOA-A (USFOR-A 2012) required all the burn pits to close NLT 31 July 2013 or have a temporary waiver in place. Since that date, BAF has relied on recycling, incineration, and removal by local nationals.

2.2.2 Food waste generation

Current estimates for the rate of food waste generation in a contingency environment are ~2 lb/day/Soldier (Cosper 2013). At enduring base camp locations such as BAF, food waste generation has been reported as 1.7

lb/Soldier/day; at a temporary base camp, as 1.1 lb/Soldier/day (Table 2-2). These food waste generation rates are both higher than the 0.6 lb/day/Soldier in the CONUS (Cosper and Gerdes 2010). This analysis uses the ("enduring base") value of 1.7 lb/Soldier/day for initial calculations, and repeats all calculations using the other two values.

At BAF, the FBC of disposing solid waste is estimated to be $0.13/lb. This estimate is based on an FBC of $9,343,774 to dispose an estimated 39,420 tons of solid waste in 2010 (Brent et al. 2010b), with a 2.3% annual inflation rate. Since its high moisture content makes food waste harder to incinerate than dry waste, the FBC is expected to greater for food waste than the average disposal cost for solid waste. Because information on the specific cost of disposing food waste does not currently exist, this analysis uses the solid waste disposal cost as a conservative estimate.

Table 2-2. Yearly amounts of food waste and various basecamp sizes and locations.

Type of Base	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	548 tons/yr	1,095 tons/yr	2,190 tons/yr
1.1 lb/Soldier/day Temporary base	1,004 tons/yr	2,008 tons/yr	4,015 tons/yr
1.7 lb/Soldier/day Enduring location	1,551 tons/yr	3,103 tons/yr	6,205 tons/yr

2.3 Recommended configuration

A food waste biodigester could also co-digest blackwater, producing more power and reducing the amount of blackwater needing treatment. However, the digester residual ("digestate") is valuable as fertilizer. Digesting human waste would add need for stringent safety checks to verify that the digestate is safe. In addition, the locals who receive the digestate for fertilizer might hesitate to use fertilizer derived from human waste. Because of these drawbacks of co-digesting food waste and blackwater, only food waste digestion will be considered here.

To secure the food waste from the dining facilities, separate receptacles will be needed to collect food waste. Since the digestate will be used as fertilizer or soil abatement, the food waste should be relatively free of contaminants such as plasticware or serving utensils (even though such contaminants will not damage the biodigester).

To collect the entire available food waste supply, staff and patrons should be asked to scrape their leftovers into the proper receptacles to separate waste food from non-biodegradable materials to ensure that the food collected after each meal is free of contaminants. Signs should be posted on or above each receptacle to alert the patrons to use the proper food- or the non-food waste bins, and especially, to avoid placing non-biodegradable items in the food waste bin.

Once the food is disposed of in the proper garbage can, workers will need to empty the waste food garbage trucks and haul the waste to the digester. Currently, the garbage bins are lined with 55-gal garbage bags, which, when full, are loaded into the garbage truck and taken to the incinerators. These 55-gallon bags could be used to hold the food waste on the way to the digester, but this would require the workers to empty the bags out at the digester as the plastic will not degrade. A better alternative is to use biodegradable bags, in which case the entire bag of food waste could be added to the digester.

To ensure that the food waste properly digested, the bag should be either opened before being added to the digester, or cut or torn up once placed in the digester. This could be accomplished by a worker using a pitchfork or similar device. Biodegradable bags will completely degrade in 12 weeks, per American Society for Testing and Materials (ASTM) standards (ASTM 2012). The use of 55-gal biodegradable bags is recommended since it will only add slightly add to the operational cost of the digester, and it will make loading of the digester easier. Because the additional expense of using biodegradable bags is slight, it will be neglected in this cost-benefit analysis.

2.4 Cultural concerns of particular food waste

One area of concern is the handling of pork, pork byproducts, and other foods forbidden by the local cultures. In most instances, food waste will have a certain amount of pork and other potentially forbidden foods. If local workers are employed, they will be handling the food waste including potentially forbidden items. In addition, the digestate, including decomposed pork products, will be given to the local farmers to spread it on the fields. Leadership will have to take into account this phenomenon and the local culture of dealing with pork products and other potentially forbidden food waste.

2.5 Anaerobic biodigester characteristics

2.5.1 Anaerobic digestion

Anaerobic digestion is a naturally occurring process where bacteria break down organic matter in the absence of oxygen (Moriarty 2013). The organic matter is turned into methane, carbon dioxide, inorganic nutrients, and compost (Arsova 2013). Anaerobic digestion is responsible for the methane produced naturally in swamps, animal intestines, and animal waste. The main benefits of using anaerobic digestion are that it converts some of the waste to methane (a fuel source), it reduces the amount of waste (Arsova 2013), and it can treat sewage waste (Mears and Anderson 2011).

2.5.2 Biodigester classification

Biodigesters are classified based on several criteria. An important characteristic for classification is the mean cell residence time (MCRT); the average amount of time that it takes the inputted feedstock to enter and exit the system. The MCRT of a biodigester is critical in determining the size of the system. For example, a 20-day MCRT digester would have to be twice as large as a 10-day MCRT digester as it holds the waste for twice as long (East Bay Municipal Utility District 2008).

Another biodigesters classification is based on the characteristics of the input, either “low solid” or “high solid” digesters (alternatively referred to as “wet” and “dry” systems). Low-solids (wet) digesters have a feedstock with a solid content typically in the range of 3% to 10% while high-solids (dry) digesters have a solid content greater than 15% (Moriarty 2013).

Biodigesters are also classified based on their predominant temperature ranges, mesophilic and thermophilic, and based on the predominate bacteria used. A mesophilic digester operates between 95 and 105 °F while a thermophilic digester operates between 125 and 140 °F. Note that a thermophilic digester produces more energy but is harder to operate than a mesophilic digester (Moriarty 2013).

Biodigesters are also classified based on how they are loaded, either as “batch” or “continuous” biodigesters. In a batch biodigester, the organic waste is added to the system in a single action at the start of the process; no more is added until digestion has finished. If a biodigester system has a

10 MCRT, then the system has to be either large enough to handle 10 days of waste at one time, or it could be comprised of 10 individual biodigesters, one of which could be loaded each day. As its name implies, a continuous digester has the organic material loaded continuously throughout the process (Moriarty 2013).

2.5.3 Biogas

Biogas is a naturally produced gas resulting from the process of anaerobic digestion. The valuable component of biogas is methane, which is a viable fuel source. The amount of methane in biogas can vary. Studies have reported biogas that contains:

- 60%–70% methane (Moriarty 2013)
- 65% (Mears 2011)
- between 59% to 67% from a food waste digester (USEPA 2008)
- 60% from a manure-based digester (Barker 2001).

The energy value of the biogas is proportional to the methane content. and Energy values have been reported as high as 8,937 Btu/lbm (652 Btu/ft^3) at standard temperature and pressure (STP) conditions for 60% methane biogas (Barker 2001), or as low as 600 Btu/ft^3 (HWMA 2010). This analysis uses an average methane content of 60% unless otherwise stated. The second largest component of biogas after methane is carbon dioxide (CO_2), which makes up at 30% to 40% (Moriarty 2013), followed by nitrogen (N_2), hydrogen sulfide (H_2S), and other trace gases (Mears 2011).

Excess hydrogen sulfide is corrosive and can damage the generators that run on biogas so it is normally removed (Moriarty 2013). Hydrogen sulfide levels can be reduced by adding controlled amounts of oxygen to the digestion system. This is done at the University of Wisconsin Oshkosh (UWO) digester (Goldstein 2012) and at the Jordan Dairy Farm, Rutland, MA food waste and manure wet digester that was toured as part of this study (see Appendix A, p 30). The capital cost of a hydrogen sulfide removal system is reported to be around $25,000 (Moriarty 2013).Other removal techniques include carbon filters (Goldstein 2012) or iron sponge filters (HWMA 2010). Such systems add minimal cost to the system. One study (HWMA 2010) reported a filter replacement cost of $4,200 per year.

2.5.4 Digestate

The digestate is the residue left over from the digestion process. The digestate commonly comes in two forms: a liquid with suspended solids from a wet digester and solid compost from a dry digester. For a wet digester, the solids can be separated out of the digester, with the solids being composted further or used for animal bedding. The liquid is normally applied to farm lands as fertilizer (Alexander 2012, Moriarty 2013). However, the solids need not be separated out. At the Jordan Dairy Farm's food waste and manure wet digester (see Appendix A, p 30), the digestate is applied directly to the fields as fertilizer. The facility manager reported that hay yields have doubled since they began using the digestate as fertilizer. Digestate from a dry digester can similarly be given or sold to local farmers to apply on their fields as fertilizer, or it may be furthered composted (Goldstein 2012).

2.5.5 Proven technology

Anaerobic digestion is a proven technology for waste disposal and for the conversion of waste to energy. It is a commercially available technology had has been used in the United States for over 30 years (Moriarty 2013). In the United States, AD is mainly used in wastewater treatment plants (WWTPs) and at livestock farms/facilities for manure disposal (Moriarty 2013). Its use continues to grow. The U.S. Environmental Protection Agency (USEPA) estimates that, from 2000 to 2009, the annual U.S. electrical production for manure-based anaerobic digesters increased from 14 million kWh to 331 million kWh. In the same period, non-electrical energy production (including waste heat capture, boiler heating using biogas, and upgrading the biogas into natural gas quality methane) increased from less than 1 million kWh to 54 million kWh (USEPA 2010).

Currently, the USEPA estimates that there are approximately 200 anaerobic digesters at operating livestock facilities (USEPA 2013). In the United States, some digesters (fewer than 10) handle food waste (Bohn 2013). Appendix B (p 41) lists food waste digesters in North American. Anaerobic digestion is more common in Europe. In 2006, there were reportedly more than 127 anaerobic digesters in Europe (Moriarty 2013). Figure 2-1 shows several food waste digesters.

Figure 2-1. Top left, Interior of a food waste digester at the UWO Photo Gallery — Biodigester 2011). Top right, dry digester by Kompogas (German Biogas Industry 2013). Bottom, dry digester by BIOFerm (Ecopolis).

2.5.6 Anaerobic digester misconceptions

It is a common misconception that biodigesters will produce offensive odors as they digest food. In fact, this is not the case. Since anaerobic digestion occurs without oxygen, the process is sealed off from the surrounding environment. This reduces the odors that the digester (and the facility) can emit. When the finished digestate exits the digester, it is already decomposed and has very little odor. Researchers who visited a food waste and cow manure digester reported that neither the digester nor the digestate produced offensive odors. Moreover, the entire digester, including the actual digester tanks or chambers, food handling areas, and generators, can be contained inside one building. This containment further reduces the potential to expose the facility's surroundings to the sight and odor of food waste (Figure 2-2). The plant building can be kept at negative pressure to prevent odors from escaping, and its ventilation systems can be fitted with filters that even further reduce odors (Arsova 2013).

Figure 2-2. The University of Wisconsin Oshkosh digester is complexly contained inside this building, helping to further reduce the smell as well as the sight of food waste (UWO Photo Gallery — Biodigester 2011).

Another common misconception is that anaerobic digesters need to be located in rural areas. This is true where digesters use animal manure as feedstock, and where it is most efficient to locate the digester close to the manure supply. However, anaerobic digesters can be (and are) located in urban areas, more commonly if they are designed to process food waste. For example, the UWO digester (Figure 2-3) is located in an urban area near residential houses. The Humboldt Waste Management Authority (HWMA) digester study (Figure 2-4) has also proposed an urban location for their digester (HWMA 2010).

Figure 2-3. Aerial view showing the location of the UWO digester; it is seen that the digester is located in an urban environment close to residential homes. Note: aerial view provided by Google Maps. Approximate address: 854-998 Dempsey Trail, Oshkosh, WI 54902Coordinates: +44° 1' 9.29", -88° 33' 29.18"

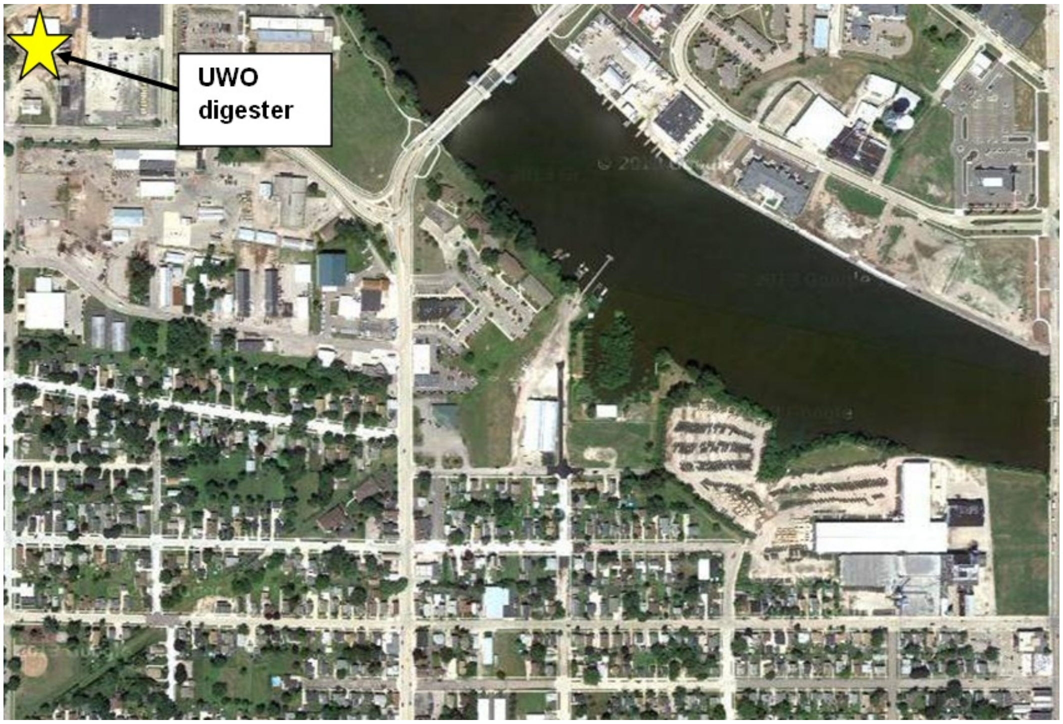

Figure 2-4. Aerial view showing the proposed location for the HWMA digester; it is seen that the digester is located in an urban environment close to a residential area. Note: Aerial view provided by Google Maps. Approximate address: 2400 Hilfiker Lane, Eureka, CA 95503. Coordinates: +40° 46' 7.80", -124° 11' 45.13"

2.6 Food waste biodigester

Food waste is a high quality source of organic material for a digester as it has a high volatile solid content (the waste that can undergo anaerobic digestion and produce methane) and a high volatile solid destruction rate (percentage of volatile solids that is digested) (Quinn 2009, USEPA 2012). For a given amount of organic waste, food waste produces more biogas than other waste sources. Food waste produces three times as much gas per weight of feedstock then biosolids (the solid waste from treated wastewater) (CH2MHILL Military Planning Group 2010) and 15 times more biogas than cow manure (USEPA 2012). In addition, a food waste digester handles less dangerous material that a sewage based digester.

Food waste digesters normally use dry digestion (Moriarty 2013), which offers several benefits over wet digestion:

- Since food waste has a high enough moisture content to supply all the water for a dry digester, there is no need to add water. A wet food waste digester, on the other hand, needs significant amounts of water added for the digester to work (Moriarty 2013).
- Dry digesters can have a modular design, which allows the digester plant capacity may be increased to handle more feedstock (Moriarty 2013).
- Dry digesters require less space (Moriarty 2013).
- One great advantage dry digesters have over wet digesters is that they can be designed so that the feedstock remains stationary from the time it is loaded until it is unloaded. This reduces the number of moving parts in the system, and reduces operation and maintenance (O&M) costs (BIOFerm 2009b). When the feedstock is stationary throughout the process, the feedstock does not have to be sorted for contaminants such as flatware that can damage moving parts (UWO 2013a).
- Systems with fewer moving parts require less energy to run. A recently constructed dry digester for food waste at the UWO consumed only 5% of the energy it produced for its own operations (UWO 2013a), half the typical value of 10% (Moriarty 2013).

Based on these advantages, if a food waste digester is added to a contingency basecamp, it is recommended that it be a dry type digester. The calculations here will assume a dry type digester.

As previously mentioned, UWO recently constructed a dry solid biodigester for food waste capable of handling 8,000 tons per year (Goldstein 2012). Although this is a larger amount of yearly waste than considered here, it does represent a 26,000 PAX CB; roughly equivalent to the current size of BAF.

The UWO digester is a dry (high solid) biodigester designed for feedstock with a moisture content of less than 75%. As food waste is reported to have a moisture content of 70% (Moriarty 2013), the UWO digester is well designed to handle food waste. The UWO digester is a batch type digester containing four digester chambers. One chamber will be loaded per week, while the other three chambers are sealed, giving a 21-day residence time (from the time the chamber is sealed till it is opened) (UWO 2013b).

2.6.1 Electrical energy generation

The UWO AD has a feedstock capacity of 8,000 tons per year (Goldstein 2012), producing 2,300 MWh of electricity (Goldstein 2012, Moriarty 2013). This gives an energy content of 290 kWh of electricity per ton. A study by the East Bay Municipal Utility District (EBMUD) found that, for a given ton of food waste delivered to their facility, 200 kWh per ton was produced at a 10-day MCRT and 280 kWh/ton at a 15-day MCRT (USEPA 2008). Both the HWMA study (HWMA 2010) and the National Renewable Energy Laboratory (NREL) study (Moriarty 2013) used a value of 250 kWh/ton.

Excluding the 10-day MCRT EBMUD data (assuming that the 15-day MCRT is more representative as it has a higher electrical generation rate and is closer to the UWO MCRT of 21 days), the average electrical production rate is 270 kWh/ton.

Table 2-3 lists the amount of electrical energy produced for each of three basecamp sizes and food waste rates using the average electrical generation rate of 270 kWh/ton and a 5% parasitic load (UWO 2013a). Table 2-4 lists the yearly power generations that correspond to power outputs. Table 2-5 lists the yearly value of the electricity produced at BAF, at a cost of $0.70 per kWh.

Table 2-3. Yearly power production of a food waste digester at various base sizes and food generation rates.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	140,000 kWh/yr	281,000 kWh/yr	562,000KWh/yr
1.1 lb/Soldier/day Temporary base	257,000 kWh/yr	515,000 kWh/yr	1,030,000 kWh/yr
1.7 lb/Soldier/day Enduring location	398,000 kWh/yr	796,000 kWh/yr	1,592,000 kWh/yr
Note: shaded cell represents expected value			

Table 2-4. Power generation rates from a food waste digester at various base sizes and food generation rates.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	16 kW	32 kW	64 kW
1.1 lb/Soldier/day Temporary base	29 kW	59 kW	118 kW
1.7 lb/Soldier/day Enduring location	45 kW	91 kW	182 kW
Note: shaded cell represents expected value			

Table 2-5. Value of power produced by a food waste digester at a cost of $0.70 per kWh.

Waste-Generation Rate	5,000 PAX	10,000 PAX	
0.6 lb/Soldier/day CONUS base	$98,000/yr	$197,000/yr	$393,000/yr
1.1 lb/Soldier/day Temporary base	$180,000/yr	$361,000/yr	$721,000/yr
1.7 lb/Soldier/day Enduring location	$279,000/yr	$557,000/yr	$1,114,000/yr
Note: shaded cell represents expected value			

2.6.2 Thermal energy savings

The AD process produces thermal energy as well as electricity. The UWO AD produces 2,700 MWh of thermal energy per year (UWO 2013d) on 8,000 tons of feedstock. This gives an energy content of 350 kWh of thermal heating per ton of feedstock. The NREL study reported a heat value of 1130 kWh per ton (Moriarty 2013), using a reported thermal efficiency of 30% (HWMA 2010), which equates to a thermal energy value of 340 kWh per ton. This analysis will use the average of these two values, 345 kWh per ton.

This heat will not be used onsite, but will have to be transferred to where it is most needed, most likely to heat water for dining facilities, shower buildings, and laundry facilities. It is estimated here that 50% of the net thermal energy will be lost in transportation.

If the thermal heat is used to heat water for dining facilities, showers, or laundry facilities, then, considering that, a standard electrical water heater has an efficiency of 88% (Zhivov 2011) and electricity cost of $0.70 per kWh, the value of the savings per ton of feedstock from using the thermal energy is:

Savings ($/ton) = thermal energy value (kWh/ton) * lost factor (%) * cost of electricity ($/kWh)/water heater efficiency (%) (2-1)

so that

Savings ($/ton) = (345 kWh) * (50%) * ($0.70/ kWh)/(88%) = $137/ton

At the calculated value of $180 per ton of feedstock, Table 2-6 lists the savings from thermal energy calculated for the different basecamp sizes and waste-generation rates.

Table 2-6. Energy and cost savings from using thermal energy from the digester at 50% efficiency using a cost of electricity of $0.70 kWh and a water heater efficiency of 88%.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$75,000/yr (107,000 kWh/yr)	$150,000/yr (215,000 kWh/yr)	$301,000/yr (429,000 kWh/yr)
1.1 lb/Soldier/day Temporary base	$138,000/yr (197,000 kWh/yr)	$275,000/yr (394,000 kWh/yr)	$551,000/yr (787,000 kWh/yr)
1.7 lb/Soldier/day Enduring location	$213,000/yr (304,000 kWh/yr)	$426,000/yr (608,000 kWh/yr)	$851,000/yr (1,216,000 kWh/yr)
Note: shaded cell represents expected value			

2.6.3 Waste disposal savings

The AD digestion process also yields significant savings by turning food waste into safe digestate, thereby deferring the cost of incinerating the food waste. Cost calculations must still account for the associated cost of handling the digestate, whether by removing it from the base for disposal, or giving it to the local populace as fertilizer. Since this cost is included in the estimated O&M cost, with the burden factor of 3 to account for the contingency environment, it will not be included here.

Table 2-7 lists the yearly savings from using the digester to dispose of food waste, at a cost savings of $0.13/lb of food waste.

Table 2-7. Savings from using the digester to dispose of food waste.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$142,000/yr	$285,000/yr	$569,000/yr
1.1 lb/Soldier/day Temporary base	$261,000/yr	$522,000/yr	$1,044,000/yr
1.7 lb/Soldier/day Enduring location	$403,000/yr	$807,000/yr	$1,613,000/yr
Note: shaded cell represents expected value			

2.6.4 O&M

2.6.4.1 Non-labor costs

An HWMA study of the construction of a 10,000 ton per year food waste biodigester calculated an annual cost of $370,000 per year for all plant O&M. This includes labor costs ($202,000), equipment maintenance ($110,000), and costs to dispose of the digestate plus other smaller costs ($37,000), for a total of $37 per ton of feedstock (HWMA 2010).

An NREL study (Moriarty 2013) reported $40–$55/ton of feedstock for the total O&M; the average used in the financial analysis was $48/ton. This analysis will use the more conservative NREL estimate of $48/ton over the HWMA estimate of $37/ton. Estimating that the labor costs constitute half the O&M costs (HWMA estimated 55%), the cost of non-labor O&M is $24/ton. With the non-construction burden factor of 3, the non-labor O&M is $72/ton.

2.6.4.2 Cost for workers

The HWMA study of a 10,000 ton per year food waste biodigester estimated a need for three laborers and one supervisor, at a cost of $202,000 (HWMA 2010). The 8,000 ton per year UWO digester was estimated to require 2-3 permanent employees to run the plant (ILSR 2010). However, the actual crew consists of one full-time employee, one part-time employee, and several part-time student interns. UWO uses the University facilities crew for maintenance (Langolf 2013). Langolf (2013) also reported that a similarly sized digester used one full-time employee and one backup employee, with all service and maintenance contracted out.

Since contingency basecamps will use even smaller digesters than those discussed here, it likely that a basecamps digester would require even fewer workers. However, since the workers will likely consist of local or third country nationals, who will probably be less efficient than their U.S. counterparts, this study will use the HWMA report of three laborers and one supervisor.

At BAF, the fully burdened cost of employing local nationals was reported as $35,600 a year, and the FBC for third country nationals was $67,600 (Brent et al. 2010a). Accounting for inflation at 2.3% per year, these costs are $38,100 and $72,400, respectively. Assuming that the labors are local nationals and that the supervisor is a third country national, the cost for labor is $187,000 a year.

2.6.4.3 Total O&M costs

Table 2-8 lists total O&M costs, consisting of non-labor costs at $72 per ton, plus $187,000 a year for 3 laborers and one supervisor for the different basecamp sizes and waste-generation rates.

Table 2-8. Total O&M costs for a digester at a contingency base.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$226,000	$266,000	$345,000
1.1 lb/Soldier/day Temporary base	$259,000	$332,000	$476,000
1.7 lb/Soldier/day Enduring location	$299,000	$410,000	$634,000
Note: shaded cell represents expected value			

2.6.5 Capital costs

The capital costs of several dry digesters are given below in Table 2-9. The average capital cost per ton is $480. However, if only the U.S. digesters and studies are used, the average price increases to $565 per ton, while the average European cost is $428 per ton. This difference in cost may be attributed to the fact that digesters are more common in Europe. This study will use this higher value of $565 per ton as a conservative estimate, although the calculations will also be repeated with the European cost of $428 per ton as well. The cost will be multiplied by the construction burden factor of 2 to account for the contingency environment, giving a value an expected value of $1130 per ton of annual feedstock, and a lower value of $856 per ton of annual feedstock.

Table 2-9. Breakdown of the capital cost reported from actual digesters and digester studies.

Location	Provider	Waste tons/yr	Waste	Installed cost ($)	Installed cost ($/ton)
St. Bernard, LA[4]	NREL Study	7,000	Food	$3,930,000	$561
Humboldt County, CA[1]	HWMA study	10,000	Food	$5.5 million[1]	$546
Oshkosh, WI[3]	Bioferm	8,000	Yard & food	$4.7 million	$588
Braunschweig, Germany[2]	Kompogas	17,640	food	$10.2 million	$578
Geneva, Switzerland[2]	Valorga	13,230	Yard	$5.1 million	$385
Lemgo, Germany[2]	BRV	37,485	Yard & food	$15.6 million	$416
Niederuzwil, Switzerland[2]	Kompogas	11,025	Yard & food	$4.1 million	$372
Otelfingen, Switzerland[2]	Kompogas	13,781	Yard	$5.35 million	$388

[1]Source: (HWMA 2010). Note: HWMA study added an additional 30% contingency cost.
[2]Source: (Zaher et al. 2007)
[4]Source: (Moriarty 2013)
[3]Source: (Goldstein 2012)

The capital costs will be based on the largest food generation rate, 1.7 lb/Soldier/day, to ensure that the digester is not undersized. In addition, 10% extra digester space will be added to the digester's capacity. Table 2-10 lists the capital costs.

Table 2-10. Expected digester capital costs at different contingency basecamp sizes

Parameter	5,000 PAX	10,000 PAX	20,000 PAX
Capacity	1706 tons/yr	3413 tons/yr	6826 tons/yr
Capital Costs at $1130 per ton (American cost)	$1.9 million	$3.9 million	$7.7 million
Capital Costs at $856 per ton (European costs)	$1.5 million	$2.9 million	$5.8 million
Note: shaded cell represents expected value			

2.6.6 Expected savings

Table 2-11 lists the yearly savings calculated as the value of electricity and thermal energy produced per year, plus the avoided cost of incinerating the food waste minus the cost of O&M.

Table 2-11. Expected yearly savings from a food waste digester.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$89,000 per year	$366,000 per year	$918,000 per year
1.1 lb/Soldier/day Temporary base	$320,000 per year	$825,000 per year	$1,840,000 per year
1.7 lb/Soldier/day Enduring location	$596,000 per year	$1,380,000 per year	$2,944,000 per year
Note: shaded cell represents expected value			

Table 2-12 lists the expected payback for the digester.

Table 2-12. The expected payback of a digester at the higher U.S. capital costs.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	21.3 yrs	10.7 yrs	8.4 yrs
1.1 lb/Soldier/day Temporary base	5.9 yrs	4.7 yrs	4.2 yrs
1.7 lb/Soldier/day Enduring location	3.2 yrs	2.8 yrs	2.6 yrs
Note: shaded cell represents expected value			

Table 2-13 lists the expected payback of a digester at the lower European capital costs. (If the lower European capital cost is used, the payback decreases.)

Table 2-13. The expected payback of a digester at the lower European capital costs.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	16.9	7.9	6.3
1.1 lb/Soldier/day Temporary base	4.7	3.5	3.2
1.7 lb/Soldier/day Enduring location	2.5	2.1	2.0

2.6.7 Anaerobic digester location

To obtain its full value on a contingency base, a digester will have to be sited near a location that can use the heating capabilities of the digester. At a contingency base, the most probable use is to heat water for dining facilities, shower buildings, and laundry facilities. The examples have shown that the entire digester can fit in a relatively small area. The 8,000 ton/yr year UWO digester is contained within an 18,000 sq ft facility (Goldstein 2012). A smaller digester at a contingency base will require even less space (Figure 2-5), allowing it to be sited near a building with a demand for thermal energy.

Figure 2-5. Aerial view of the UWO digester, showing the size of the facility.
Note: aerial view from Google Maps.

It is most efficient and cost effective to locate a digester near a facility that can use the digester's generated heat. If the digester is not sited near a location that can use the heat, the yearly savings decrease and the payback increases. If the digester is located next to a source that can use all the heat, yearly savings will be 50% greater than the baseline scenario, which estimates 50% heat utilization (Table 2-14), and 200% greater than the scenario that presume no heat utilization (Table 2-15).

Table 2-14. Expected savings and payback if the digester is located where the thermal energy can be fully used.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$164,000 (11.6 yrs)	$517,000 (7.5 yrs)	$1,218,000 (6.3 yrs)
1.1 lb/Soldier/day Temporary base	$457,000 (4.2 yrs)	$1,101,000 (3.5 yrs)	$2,391,000 (3.2 yrs)
1.7 lb/Soldier/day Enduring location	$809,000 (2.3 yrs)	$1,805,000 (2.2 yrs)	$3,796,000 (2.0 yrs)

Table 2-15. Expected savings and payback if the digester is located where the thermal energy cannot be used.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$14,000 (135.7 yrs)	$216,000 (18.1 yrs)	$617,000 (12.5 yrs)
1.1 lb/Soldier/day Temporary base	$182,000 (10.4 yrs)	$550,000 (7.1 yrs)	$1,289,000 (6.0 yrs)
1.7 lb/Soldier/day Enduring location	$383,000 (5.0 yrs)	$954,000 (4.1 yrs)	$2,093,000 (3.7 yrs)

2.7 Sensitivity analysis

The yearly savings and expected payback are influenced strongly by the cost of power, the cost to dispose of solid waste, and the burden factor. Because these parameters can vary significantly between different contingency environments, and between different basecamps within the same contingency environment, they affect the digester's calculated savings and payback.

2.7.1 Cost of power

The yearly savings associated with the digester will depend on the cost of power at the contingency base. This analysis used a value of $0.70 per kWh. The yearly savings and payback are calculated here for a cost of power of 50% and 150% of this value, or at a cost of $0.35 (Table 2-16) and $1.05 per kWh (Table 2-17).

Table 2-16. The yearly savings and expected payback at an electricity cost of $0.35 per kWh.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$3,000 (633 yrs)	$192,000 (20.3 yrs)	$571,000 (13.5 yrs)
1.1 lb/Soldier/day Temporary base	$161,000 (11.8 yrs)	$508,000 (7.7 yrs)	$1,203,000 (6.4 yrs)
1.7 lb/Soldier/day Enduring location	$349,000 (5.4 yrs)	$889,000 (4.4 yrs)	$1,962,000 (3.9 yrs)

Table 2-17. The yearly savings and expected payback at an electricity cost of $1.05 per kWh.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$176,000 (10.8 yrs)	$539,000 (7.2 yrs)	$1,265,000 (6.1 yrs)
1.1 lb/Soldier/day Temporary base	$479,000 (4.0 yrs)	$1,144,000 (3.4 yrs)	$2,475,000 (3.1 yrs)
1.7 lb/Soldier/day Enduring location	$841,000 (2.3 yrs)	$1,872,000 (2.1 yrs)	$3,927,000 (2.0 yrs)

2.7.2 Waste disposal costs

Since a significant portion of the yearly savings accrues from the avoidance of costs associated with the disposal of food waste, those savings depend on the cost of waste disposal. The yearly savings and payback are calculated here at a waste disposal cost of 50% (Table 2-18)and 150% (Table 2-19) of the current value of $0.13/lb.

Table 2-18. Yearly savings and payback at a waste disposal cost of $0.07/lb, 50% of the expected value.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$24,000 (79.2 yrs)	$234,000 (16.7 yrs)	$656,000 (11.7 yrs)
1.1 lb/Soldier/day Temporary base	$200,000 (9.5 yrs)	$584,000 (6.7 yrs)	$1,358,000 (5.7 yrs)
1.7 lb/Soldier/day Enduring location	$410,000 (4.6 yrs)	$1,007,000 (3.9 yrs)	$2,200,000 (3.5 yrs)

Table 2-19. Yearly savings and payback at a waste disposal cost of $0.20/lb, 150% of the expected value.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$166,000 (11.4 yrs)	$519,000 (7.5 yrs)	$1,225,000 (6.3 yrs)
1.1 lb/Soldier/day Temporary base	$461,000 (4.1 yrs)	$1,106,000 (3.5 yrs)	$2,402,000 (3.2 yrs)
1.7 lb/Soldier/day Enduring location	$814,000 (2.3 yrs)	$1,814,000 (2.1 yrs)	$3,813,000 (2.0 yrs)

2.7.3 Burden factor

For this analysis, a construction burden factor of 2 was assumed to account for the additional cost of building in a capital environment. For a sensitivity analysis, the yearly savings and payback are calculated here at a construction burden factor of 1.5 (Table 2-20) and 2.5 (Table 2-21).

Table 2-20. The yearly savings and expected payback at a construction burden factor of 1.5.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$89,000 (15.7 yrs)	$366,000 (7.9 yrs)	$918,000 (6.3 yrs)
1.1 lb/Soldier/day Temporary base	$320,000 (4.4 yrs)	$825,000 (3.5 yrs)	$1,840,000 (3.2 yrs)
1.7 lb/Soldier/day Enduring location	$596,000 (2.3 yrs)	$1,380,000 (2.1 yrs)	$2,944,000 (2.0 yrs)

Table 2-21. The yearly savings and expected payback at a construction burden factor of 2.5.

Waste-Generation Rate	5,000 PAX	10,000 PAX	20,000 PAX
0.6 lb/Soldier/day CONUS base	$89,000 (27.0 yrs)	$366,000 (13.1 yrs)	$918,000 (10.5 yrs)
1.1 lb/Soldier/day Temporary base	$320,000 (7.5 yrs)	$825,000 (5.8 yrs)	$1,840,000 (5.2 yrs)
1.7 lb/Soldier/day Enduring location	$596,000 (4.0 yrs)	$1,380,000 (3.5 yrs)	$2,944,000 (3.3 yrs)

3 Conclusions and Recommendations

3.1 Conclusions

This work concludes that the use of anaerobic digesters for food waste disposal at basecamps in contingency environments offers significant benefits. At the expected configuration of a 10,000 PAX basecamp (which includes U.S. service members, DoD civilians (Federal employees), coalition forces, contractors, local nationals, third country nationals, and transits), an anaerobic digester will produce about 796,000 kWhrs of electricity annually using a 91 kW generator, reduce solid waste by 3,100 tons per year. This will reduce the burden that power generation and waste dispose places on the logistics, fuel supply, and security at CBs in an operational environment. The anaerobic digester is also revenue positive, with a payback of 2.8 years. After the payback period, the digester will save $1.4 million dollars a year. It was also found that anaerobic digesters were feasible at smaller basecamps as well; a 5,000 PAX CB digester had a payback of only 3.2 years.

Sensitivity analysis showed that the digester is still feasible at higher cost of construction, at a 50% lower cost of power, or at a 50% lower cost of waste disposal. For each of these three cases, the expected payback is under 5 years.

In addition to the monetary and energy savings from implementing an anaerobic digester, there are other benefits whose importance should not be ignored. An anaerobic digester will employ three local nationals; helping to improve their standard of living as well as building trust between them and the U.S. forces. In addition, the digester will produce compost that can be given to local farmers to use as fertilizer. Employing the local nationals, improving their standard of living, and building mutual trust are key areas of the U.S. counter-insurgency efforts. Secondly, Army command has requested its base personnel to commit themselves to reducing the fossil fuel consumption; constructing digesters will demonstrate and further reinforce the command’s commitment to that principle of energy conservation.

3.2 Recommendations

It is recommended that an anaerobic digester be added to any large enduring CBs that are projected to have a significant personal level throughout the base's lifespan. For the expected size of a 10,000 PAX base, the payback is 2.8 years. A digester should be built if it will run for at least this long. This time decreases at larger bases and increases at smaller bases. It is recommended that separate trash bins be used to handle the food waste at the dining facilities at that biodegradable bags be used instead of standard trash bags as they will only had slightly add to the cost and will make loading of the digester easier.

As the digester size is based on the basecamp's PAX level, the projected PAX levels should be estimated to determine the correct size of the digester. If the digester is too small for the basecamp, some food waste will have to be disposed with the other solid waste, which will reduce the savings from the digester. If the digester is too large for the basecamp, yearly savings will take longer to pay off the initial capital costs, reducing the overall savings.

A significant portion of the savings comes from the thermal energy production. It is highly recommended that the digester be sited close to a location that has a high thermal energy demand that the digester can meet. Since the digester is still cost effective even if the thermal energy is not used, lack of demand for thermal energy should not keep the digester from being built.

Acronyms and Abbreviations

Term	Definition
ASTM	American Society for Testing and Materials
BAF	Bagram Airfield
Btu	British Thermal Unit
CB	Contingency Basecamp
CERL	Construction Engineering Research Laboratory
CJOA-A	Combined/Joint Operations Area, Afghanistan
CONUS	Continental United States
DoD	US Department of Defense
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
FBC	Fully Burdened Cost
FRAGO	Fragmentary Order
HWMA	Humboldt Waste Management Authority
MCRT	Mean Cell Residence Time
NLT	Not Later than
OMB	Office of Management and Budget
PAX	Personnel
PPM	parts per million
SF	Standard Form
STP	Standard Temperature and Pressure
TR	Technical Report
URL	Universal Resource Locator
UROC	USACE Reachback Operations Center
USACE	US Army Corps of Engineers
USDOL	U.S. Department of Labor
USEPA	US Environmental Protection Agency
USFOR-A	US Forces – Afghanistan
UWO	University of Wisconsin Oshkosh
WWW	World Wide Web

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Appendix A: Anaerobic Digester Trip Report – July 2013

Summary

ERDC-CERL researchers toured an anaerobic digestion plant at the Jordan Dairy Farm in Rutland, MA on 10 July 2013 to gain situational awareness and understanding of the operations of this type of plant. Ms. Shannon Carroll, the facility manager, provided the tour. Table A-1 summarized the technical information researchers elicited during the tour.

Table A-1. Tour of Anaerobic Digestion Plant in Rutland, MA on 10 July.

Questions	Response
Feedstock	
Amount (tons per day)	70 tons (45 tons processed waste/25 tons manure)
Ratio of food waste to manure	45 tons to 25 tons
Any separation, purification, sorting necessary	Comes already liquefied, no sorting done on site
Volatile solid content	N/A
Type of digester	
Wet or dry	Wet
How much outside water is needed if any	None
If outside water is used, where does it come from (tap, greywater, blackwater, etc.)	Not applicable
Temperature range, mesophilic and thermophilic	98 degrees for digester
Mean Cell Residence Time	29-30 days
Batch or continuous loading	Continuous
Capacity size	500,000 gal
Power generation	
Is hydrogen sulfide removed before using	Yes – Uses Oxygen
Is the biogas refined into biomethane	No – Co2 Remains
Is the generator meant for biogas, methane, or propane	Biogas
Size of the generator	300kW (upgrade to 500 kW planned)
What capacity is typically used	All, generated is undersized
Average power and energy output	300kW with 40kW parasitic load
Variations in power and energy output	Constant
Thermal power	

Questions	Response
Efficiency	Thermal efficiency is higher than electrical efficiency
Utilization	Currently not used
Digestate	
Ratio of solids (biosolids) to liquid	Unknown
Is the digestate separated into solids and liquids	No, liquid already, any solids present are suspended in the liquid and do not affect the flow
How is the digestate used	Fertilizer for 1,000 acres corn/hay (doubled production of hay compared to baseline of no fertilizer)
Is the digestate safe	Yes – not 100% compost – Human waste would be less safe
How much digestate is produced per feedstock input	3% reduction
Plant characteristics	
Footprint of plant (acres)	1 acre
Capital costs	$3.5 million (Construction Costs Only)
Operation	
Methane content of biogas	64%
Volume of biogas produced per input of feedstock	Unknown
Number of workers	2 ea – 1 plant manager/1 assistant manager & truck driver of food waste. Manager runs most of machines on phone app. and spends about 2 hours onsite a day
Operating cost ($/ton inputted of feedstock or $/kWh produced)	2 FTE + Maintenance (700 Cows)
Any catalyst required for operation	No
Quality checks	
Do they check digestate for pathogen contents or anything else	No
Do they check the methane content of the biogas	Yes
Skill level for safety checks	Unknown
Skill level to operate	
Safety	
Safety record including emergencies and responses to them	Low Pressure System – is safer – 2 in. water
Storage of methane	Very little – goes back into generator and excess is flared
Maintenance	
Annual maintenance costs	Unknown
Any full system shutdowns	1x a month generator O&M

Questions	Response
Expected lifespan	Unknown
Degradation in system performance	None
Typical maintenance schedule and activities	Oil Change
Skill level to maintain	Mechanic for generator/engine
Profitability	
Is the digester profitable	Yes
Net profit	$318,864 + Tipping from food waste drop off from commercialized facilities
Reasons why it is/is not profitable	N/A
Regional cost of power	$.14 kWh
Operation cost	People/Maintenance
Methane content	
Maintenance cost	
Payback period	10 yrs
There is also a cost benefit of not having to dispose of manure or food waste	

POC

Casella Organics
Shannon Carroll, Facility Manager AGreen Digester
51 Muschopauge Road
Rutland, MA 01543
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E-mail: Shannon.carroll@casella.com

Location

51 Muschopauge Road
Rutland, MA 01543
42.388059, -71.916370 (+42° 23' 17.01", -71° 54' 58.93")

Figure A-1 shows a (Google Maps) aerial view of the food waste and cow manure digester. The components are :

A. Storage for the feedstock before it enters the digester. This allows one large load of delivered waste to be slowly added to the digester.

B. The main digester tank. This is where all the digester occurs. The tank can hold 500,000 gal.

C. This building houses all the controls and pumps for the digester.

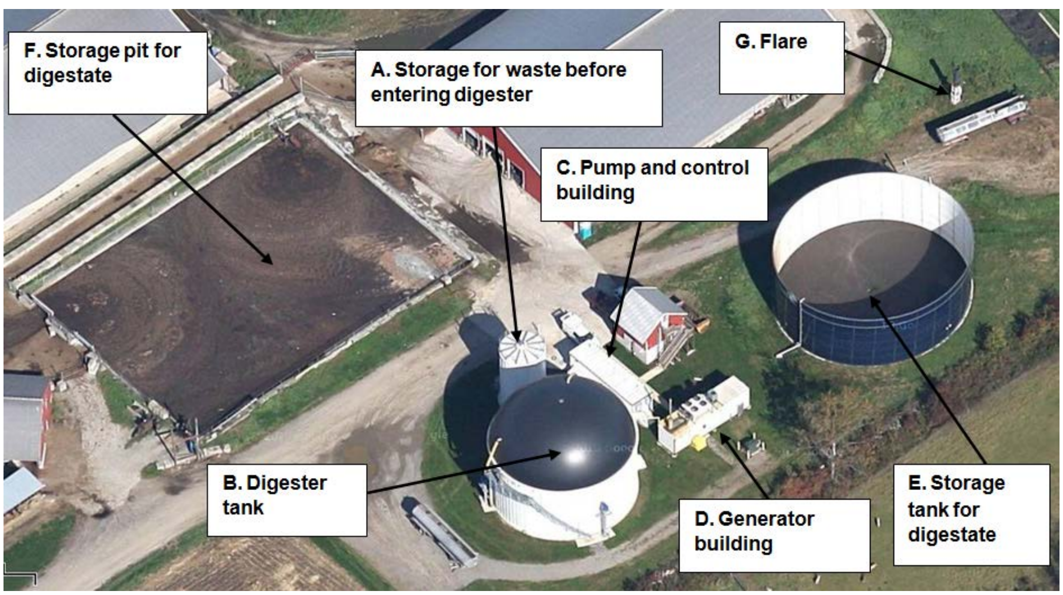
D. This building houses a 300 kW generator, which is currently undersized and will be upgraded to 500 kW.

E. This tank holds the liquid digestate that comes out of the digester. Storage is necessary as the digestate is applied as fertilizer to the 1,000 acres of farmland, but not during the growing season.

F. Additional storage space for the digestate.

G. Flare for burning off biogas, either excess biogas or when the generator is down for maintenance.

Figure A-1. Aerial view of the food waste and cow manure digester.



Figures A-2 to A-11 show details of the anaerobic digestion plant at the Jordan Dairy Farm in Rutland, MA.

Figure A-2. View of the digester.

Figure A-3. View of the digester tank and storage tank.

Figure A-4. View of the digester storage tank and the flare for burning excess methane.

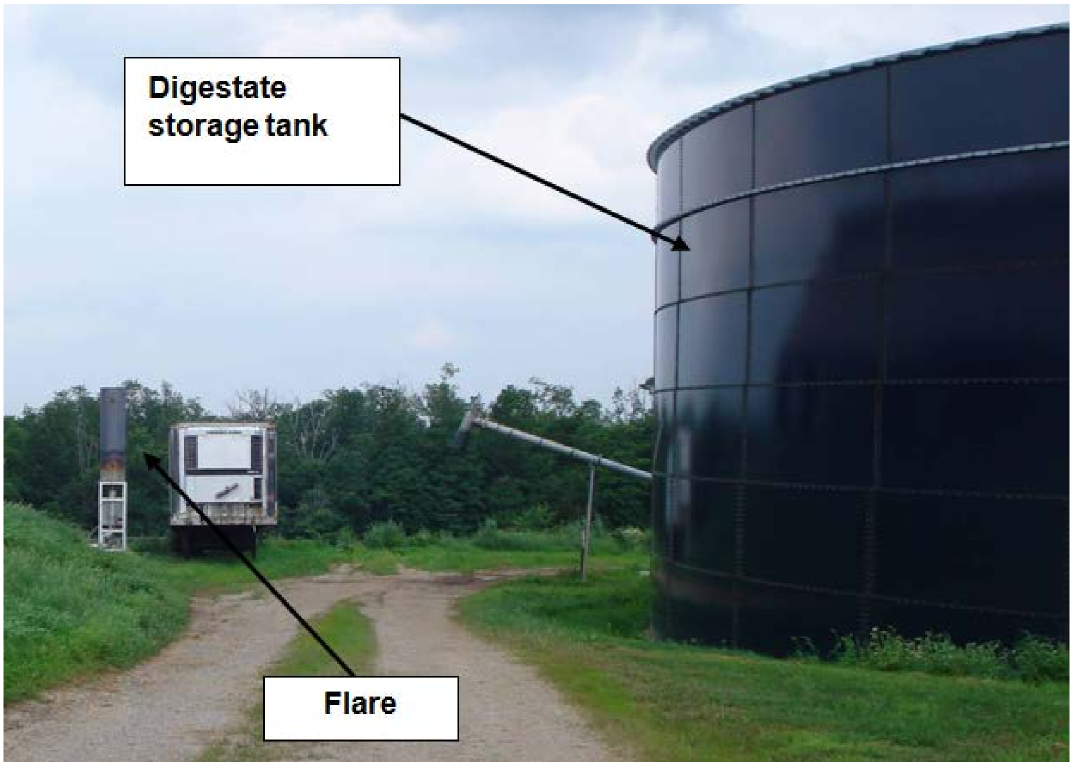


Figure A-5. View of the digestate leaving the digester. The brown crust on top of the digestate is manure from outside contamination, not from the digester.

Figure A-6. View of the digester. The people in the foreground give a reference to the size of the system.

Figure A-7. View of the digestate feeding tank.

Figure A-8 shows the digester monitoring station. The entire plan could be run from this station or remotely by smart phone. Details are:

A. Green line shows the biogas level. It is seen to regularly peak and crest. This is because the generator is currently undersized, so the biogas level builds up. Once it reaches a set value, the flare starts burning the excess biogas, dropping the levels.

B. The methane content of the biogas determines its energy value, here the methane content is holding constant at 64%.

C. The CO_2 level is holding constant at 31%.

D. The level of hydrogen sulfide (H2S) inside the digester averages between 20 and 40 parts per million (PPM).

Figure A-8. Digester monitoring station.

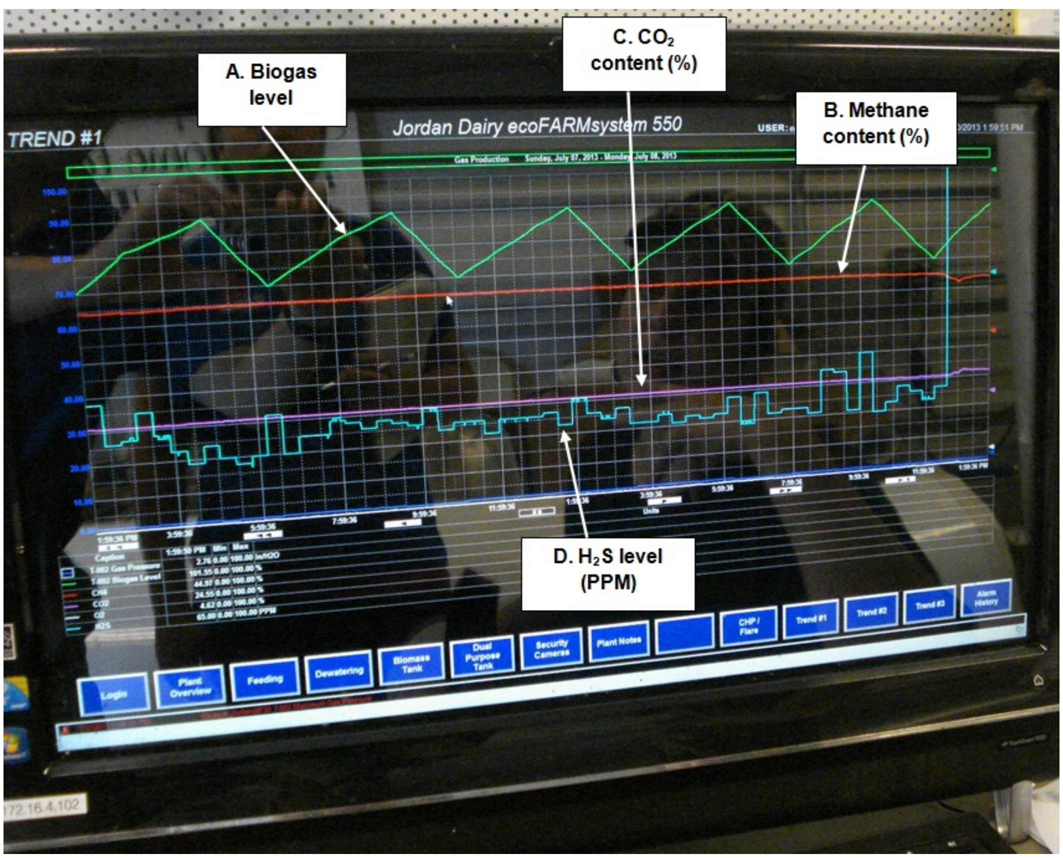


Figure A-9 shows the digester tank settings. Details are:

A. The tank level settings determine the maximum and minimum amounts of feedstock in the digester tank. The settings were 23.10 to 24 ft.

B. The temperature settings determine the maximum and minimum allowed temperatures in the tank. The settings are 95 and 99 °F.

C. Controls the range of pressures inside the tank.

D. The settings to control the desulfurization (removal of H_2S).

E. The current settings of the tank: they were a temperature of 98 °F, pressure of 2.81 in./H_2O, tank level of 23.69 ft, volume of 491,272 gal, and a biogas level of 100%. (The generator was down for routine maintenance so biogas level built up.)

Figure A-9. Digester tank settings.

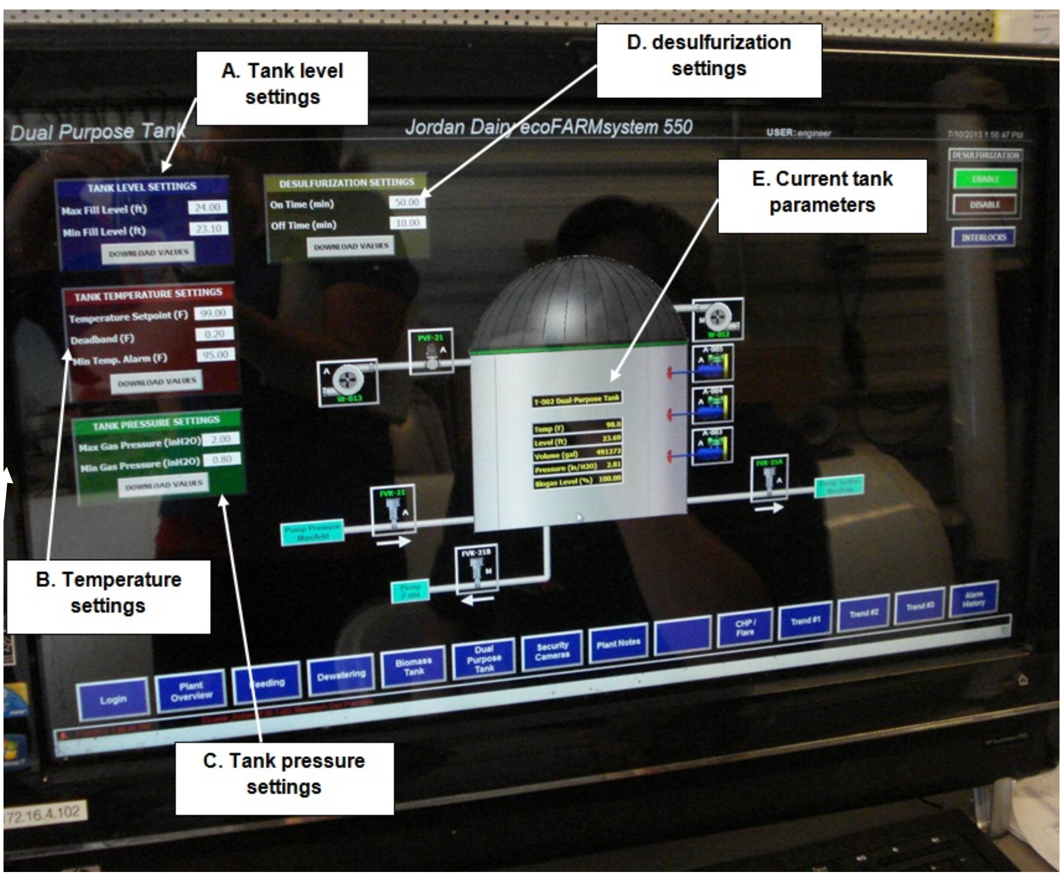


Figure A-10. Feedstock Receiving, Dosing, and Heating Controls. This screen controlled the flow of the feedstock in the plant, from pumping it from the delivery trucks to adding it to the digester tank.

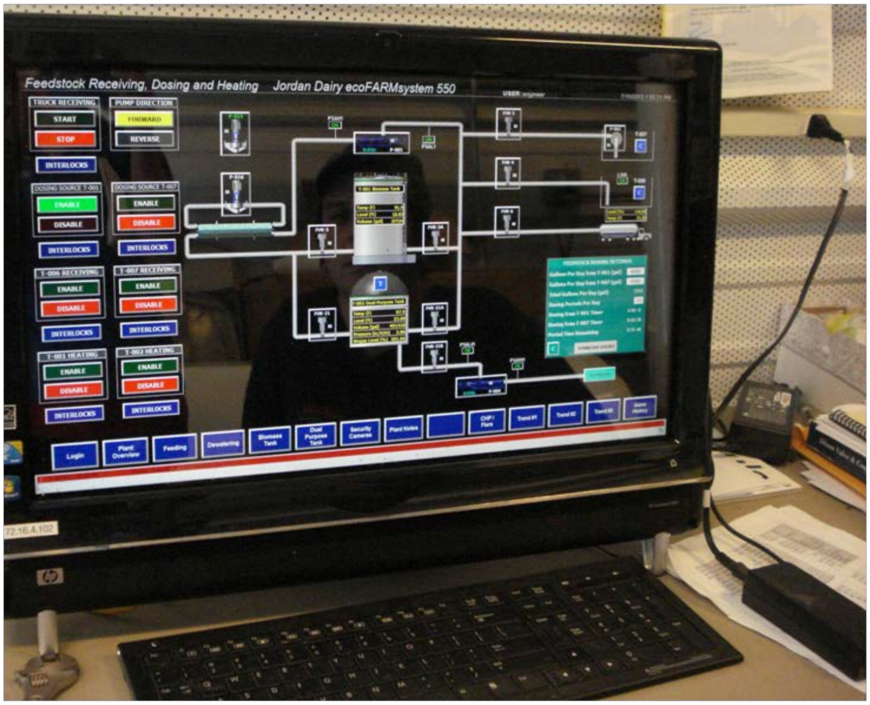


Figure A-11. The biogas was used to power a 300 kW generator. This generator was undersized and there were plans to replace it with a 500 kW generator. This generator was designed to run on biogas.

Appendix B: Food Waste Digester in North America

Table B-1. North American food waste digesters

Owner	City	State	Feedstock	AD type	Size (tons/yr)	Capital costs	Oper costs ($/ton)	Energy output
Gills Onions AD Project	Oxnard	CA	Pre-consumer food wastes[1]	Wet1				
San Jose Zero Waste (construction)	San Jose	CA	Food wastes, green wastes[1]	Dry (Kompoferm)[1]	270,000 (when completed)[3]			4,8000 kWe[3] and 6.28 MMBtu-per-hour thermal
Orange County Food Waste Pilot Plant	Orange	CA	Post-consumer food wastes[1]	Wet[1]				
Monterey Zero Waste AD Pilot Plant	Monterey	CA	Post-consumer food wastes, green wastes[1]	Dry (Kompoferm)[1]	5,000[2]			100 kW[2]
Inland Empire-Environ AD project	Chino	CA	Pre-consumer food wastes[1]	Wet[1]				3,000 kW[3]
University of Wisconsin	OshKosh	WI	Food wastes, green wastes[1]	Dry (BIOferm)[1]	6,000	$2.3 million		
City of Toronto	Toronto		Food wastes[1]	Wet[1]	40,000[1]	$18 million1	$901	

Sources:
[1]Moriarty (2013)
[2]Smartferm (2012)
[3]Cal Recycle (2012)

Appendix C: Recommended Footprint for 10,000 PAX Contingency Basecamp Base-Wide Anaerobic Digester Plant

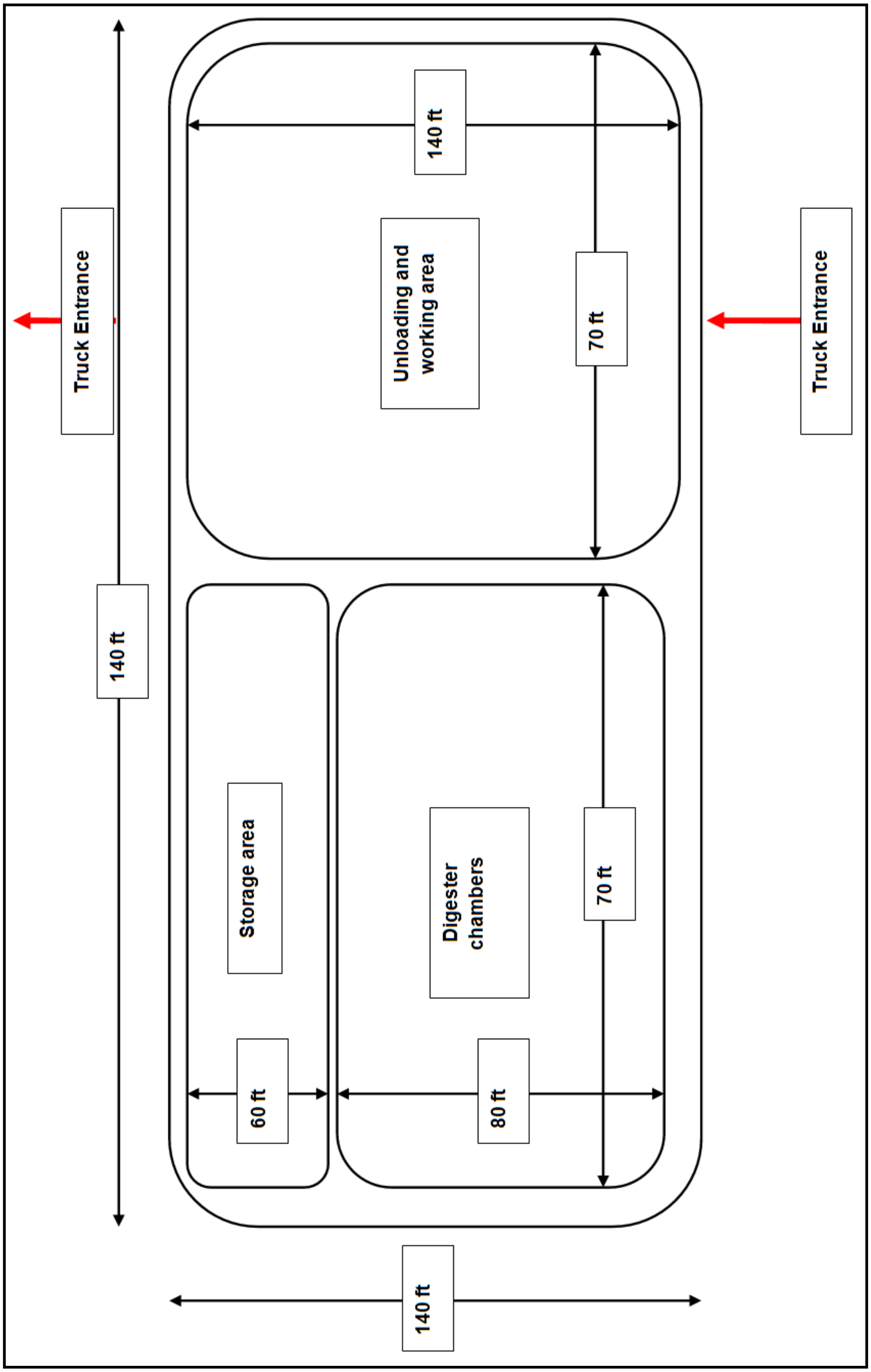


Figure C-1. Details of the Anaerobic Digester Facility (size is approximate).

Appendix D: Companies Offering Anaerobic Digesters

ArrowBio

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+972-484-11100
arrowbio@arrowecology.com
www.arrowecology.com

Bekon

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+49 089- 90 77 959-0
contact@bekon.eu
http://www.bekon.eu

BHS/Kompoferm

3592 West 5th Avenue
Eugene, OR 97402
USA
541-485-0999
http://bulkhandlingsystems.com

BioFERM

617 N. Segoe Road, Ste. 202
Madison, WI 53705
608-467-5523
http://www.biofermenergy.com

Biogas Energy, Inc.

815 301 3432
info@biogas-energy.com
http://www.biogas-energy.com/site/index.html

BTA International GmbH

Färberstraße 7
85276 Pfaffenhofen
Germany
49 8441 8086-600
http://bta-international.de/

Canada Composting/CCI Bioenergy

390 Davis Drive Suite 301
Newmarket, ON Canada L3Y 7T8
905-830-1160
kmatthews@canadacomposting.com
http://www2.ccibioenergy.com

Clean World Partners

2330 Gold Meadow Way
Gold River, CA 95670
800-325-3472
http://www.cleanworldpartners.com

DRANCO/OWS Inc.

7155 Five Mile Road
Cincinnati, OH 45230
USA
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norma.mcdonald@ows.be
http://www.ows.be/pages/index.php?menu=69&choose_lang=EN

Ecocorp

626-405-1463
jgingersoll@ecocorp.com
www.ecocorp.com

Enbasys

Parkring 18
8074, Grambach
Austria
43 (0) 316 4009-5600
http://www.enbasys.com/

Entec Biogas USA

Schilfweg 1
6972 Fussach Austria
Austria
+43-5578-7946
office@entec-biogas.at
http://www.entec-biogas.com/en/

GaiaRecycle

125 University Ave., Suite 150
Palo Alto, CA 94301
USA
650-585-4416
http://www.gaiarecycle.com/

GHD

PO Box 69
Chilton, WI 53014
920-849-9797
USA
http://www.ghdinc.net/

Harvest Power

221 Crescent St. Suite 402
Waltham, MA 02453
781-314-9500
http://www.harvestpower.com

New Bio

7679 Washington Ave S.
Edina, MN 55439
952-476-6194
http://www.newbio.com

Orgaworld

5123 Hawthorne Road
Gloucester, ON K1G 3N4
Canada
613-822-2056
http://www.orgaworld.nl

Qasar Energy Group

7624 Riverview Road
Cleveland, OH 44141
216-986-9999
http://www.schmackbioenergy.com

Ros Roca

Av. Cervera, s.n.
Terrega
Spain
34 973 50 81 08
http://www.rosroca.com/

Solum Gruppen

Vadsby Straede 6
DK-2640 Hedehusene
Denmark
45 4399 5020
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Valorga

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14. ABSTRACT
Managing solid waste disposal at basecamps at contingency basecamps (CBs) in an operational environment is a challenging task because waste management places a large burden on the camp’s logistics, fuel supply, and security. Base management must consider the complex interdependency between power, fuel, and solid waste management, all of which must be carefully managed under difficult and dangerous conditions. The U.S. Army Corps of Engineers has provided assistance and expertise to Army leadership in effective waste management techniques in contingency environments. As part of this effort, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) conducted this analytical study of the use of anaerobic digesters for food waste disposal. Anaerobic digesters can reduce the amount of solid waste requiring disposal, produce a net amount of electricity that can help power the base, and produce thermal energy for heating. This study determined that it was feasible and cost effective to install anaerobic digesters at large enduring CBs.

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base camps, waste management, anaerobic digester, solid wastes

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