# Turning Waste into Heat: Designing an Anaerobic Digester to Extend the Growing Season for Small Scale Urban Farmers

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science


**BY**

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# I. ABSTRACT

We designed and constructed a 275-gallon anaerobic digester capable of producing and collecting methane rich biogas for a small urban farm, Nuestro Huerto. Our design focused on safety, cost, efficiency, and output. Our goal was to collect enough biogas to heat a small greenhouse and extend the growing season for urban farmers.

# II. Acknowledgements

The team would like to thank our project advisors Profs. Robert Hersh and Derren Rosbach for their guidance in the IQP process and in the writing of this report. In addition, we would like to thank Amanda Barker and Scott Guzman for their cooperation in the design of the digester and for their willingness to contribute their space and materials to the project. While Alden Kelsey had to take a leave of absence, we would also like to thank him for his contribution to the literature review and design process that occurred during the first half of the project timeline.

# III. Executive Summary

Urban farmers face many challenges ranging from poor soil quality, to lack of affordable land and funding. Regardless of the constraints, an increasing number of individuals and community groups including our sponsor Nuestro Huerto Farm (figure 1) are working together to turn the abandoned and contaminated urban lots into centers for healthy food production and community awareness.

*Figure 1 Nuestro Huerto Farm in Worcester, Massachusetts*

We built an anaerobic digester to explore the feasibility of heating Nuestro Huerto's hoop-house with the goal of helping to extend their growing season, which would ultimately lead to more early season crops, and higher crop yields. Common cold hardy crops include broccoli, kale, lettuce, and spinach. These and many other ethnically relevant crops are grown locally by a culturally diverse group of community gardeners and agricultural enthusiasts. Community sponsored research projects can help link agricultural programs to local schools and institutions, promote food and energy awareness, and encourage community involvement in a more localized and self-sustaining food system.

Our goals changed throughout the project as our team was confronted with many challenges including poor team dynamics and difficulty satisfying sponsor requirements. Our focus shifted from the broad goal of heating a 600 square foot greenhouse to a more subtle approach of simply understanding the challenges faced by local organizations in their mission to promote interest and value in community agriculture and try to equip them with a small food waste digester to serve as a learning tool for exploring the benefits of combining waste reduction, renewable energy, and local food production.

Anaerobic digesters use different species of bacteria to symbiotically convert food waste into methane rich biogas. Proper feeding practices and experience are necessary to optimize biogas production and maintain healthy bacteria culture in a clean and safe way. We constructed a digester outside of the Nuestro Huerto hoop house and generated a general operations manual. Using manure from a local farm we filled the digester but were unable to get all systems running for startup. A new team has picked up the project where we left off and will proceed to attempt operating the digester and continue to develop a relevant source of information that can be used to inform local farmers and community gardeners on the benefits and drawbacks of anaerobic digestion. Future work includes operating the digester and testing a system for gas cleaning, long-term storage, and pressurization.

# IV. AUTHORSHIP

All members of the IQP group contributed to the outline and early drafts of this paper. Kyle Gagnon wrote the final draft of this paper, and edited feedback. Corey Bloniasz led the efforts in constructing the digester, and contributed heavily to the information used in this paper. He also aided in the final revisions and authored the executive summary and operation manual. Sherman Peoples assisted in the design and initial drafts of the paper as well as the final revision

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# 1 INTRODUCTION

Nuestro Huerto, a small urban farm in Worcester, seeks to extend their growing season, but doesn't have the resources to fuel a heater for its hoop-house. One way to create supplemental heat is to use a biodigester. Biodigesters use bacterial digestion, similar to the process of a human stomach, to digest organic material and produce methane rich biogas that can potentially be used as heating fuel.

The goal of this project was to design and build in collaboration with our sponsor, Nuestro Huerto, an anaerobic digester that would use food waste to help heat its hoop house. We considered how to optimize methane production and implement existing designs. We constructed a safe, replicable, and cheap digester using materials readily available in the community. However, it is not completely tested and functioning, and it does not meet the heating requirements of our sponsor.

# 2 Background

## 2.1 FOOD SECURITY

Food Security exists in a community when all members have access to sufficient, safe, and nutritious food to meet their dietary needs for a healthy life, but as the world's population continues to drastically increase, so does the number of malnourished (FAO, 2010). The number of malnourished people has been estimated at 840 million people worldwide (FAO, 2013, Cordell, D., 2010). With nearly 8.5% of the world population experiencing inability to secure a proper source of food, the world must address the ability to help those in need.

The issue of food security relates closely to the cost of basic staples, the financial situation of those involved, and the ability to get these resources to them. The world experienced a food crisis when basic staples increased sevenfold between 2005 and 2008 (FAO, 2010). While 191 countries in the United Nations have made progress on reducing the number of poor and malnourished, the issue still remains in many countries (FAO, 2013). Since 2008 the food insecurity rate has grown 43% in Massachusetts. In Worcester alone, the number of hungry people is six times more prevalent than the average community in the state. One in three children in Worcester live in a family unable to meet basic food needs (WAFC, 2010). Organizations like The Community Harvest Project and the Worcester County Food Bank serve approximately 99,000 people every year in the Worcester area (CHP, 2012).

In urban communities, low-income residents have limited access to supermarkets and other locations to purchase the staples they require. These so called "food deserts" exist when the sources of food within the city is not within walking distance, or not easily reachable by public transportation. Proximity to supermarkets is not the only cause of food insecurity.

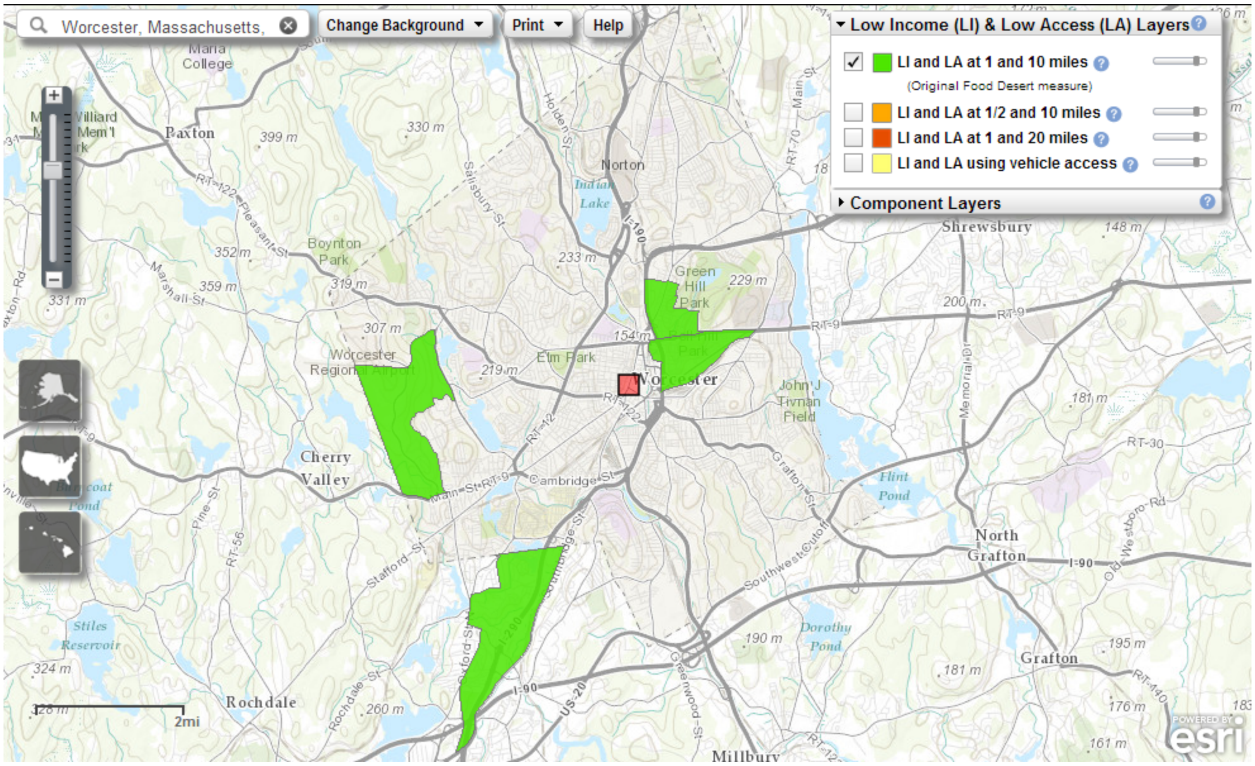



*Figure 2: Food Deserts in Worcester (United States Department of Agriculture, 2014).*

In addition, low-income residents must possess the financial means to purchase the basic staples they need. According to the USDA food desert locator, there are five food deserts in Worcester, and these areas also have a higher presence of poverty (Kaczmarek, 2013). While residents may have limited access to supermarkets, many studies have shown that persons living in food deserts often turn to fast food restaurants for inexpensive meals, a diet that can lead to increased rates of obesity and diabetes (Galvez, 2008). In one study, it was shown that Worcester residents have an elevated rate of health complications linked to unhealthy diets compared to other communities in Massachusetts (Kaczmarek, 2013). Awareness of these health issues has caused an increase in support for urban agriculture.

Urban agriculture allows production, distribution, and marketing inside a metropolitan community (Hodgson, 2011). This includes both urban farms and gardens throughout Worcester County, and the farmer markets that sell and distribute these locally grown produce. The REC has helped create 62 community gardens located in poor and minority neighborhoods (Kaczmarek, 2013). Foods raised in these gardens provide a more nutritional source of food for many residents in the city (Moustier, 2010).

Despite the growth of farmers markets and community gardens in Worcester, many farms in the area still do not produce enough to become profitable. Since many of these farms cannot expand their land area. To increase the profitability of small land plots, the yield per area must increase.  Extending the growing season could increase crop yield for small scale farmers. A longer growing season can allot the growers to plant another harvest, or give crops time to catch up in development (Linderholm, 2006). In addition, the farmers have more crop choices since they could possibly grow profitable crops with longer life cycles. Investing in a longer growing season that extends further into the spring and fall months can help increase the productivity on farms.

Due to the colder climate of Worcester, many of the farms must consider risks associated with growing past September. In colder environments earlier frosts can kill off crops, so most farmers in the Worcester region do not grow food after the autumn harvest (Yadav, 2011). To grow crops year round requires a heated greenhouse, but heat sources such as oil or natural gas can be too expensive for many small-scale farmers.  One alternative to heat a greenhouse at lower cost is to use food waste as a fuel to produce heat in a biodigester.

## 2.2 ROLE OF DIGESTERS IN URBAN AGRICULTURE

Anaerobic digestion has many possibilities for energy generation especially in agricultural settings. An anaerobic digester processes a diluted organic feed source that includes materials such as manure, leaves, grass, fruit, and food wastes (Purdue University, 2008). The digester makes use of a culture of bacteria inside the vessel to digest the materials through anaerobic respiration.

Methane could heat greenhouses and protect crops toward the end or start of winter when they are vulnerable to frosts. Digestion of ruminant manure or municipal waste sources can be combined with commercial food waste without affecting vital agricultural resources (El Mashad, H. M. 2009). In fact, Massachusetts food waste and organics make up 20-25% of waste going into landfills, so digesters offer the potential to utilize a portion of commercial food waste (Cordell, D. 2010). Recycling of these currently unusable resources would prove beneficial for both the world, and the communities harvesting the energy from the waste. With such a vast amount of organic waste entering landfills there is a huge potential to increase the use of this technology. With the Massachusetts Department of Environmental Protection placing a ban in July, 2014 on commercial businesses that dispose of more than a ton of food per week from placing their food waste into landfills, this further opens access to these resources, and could further increase the recycling of food waste into anaerobic digesters both on the urban farm scale and in bigger commercial recycling facilities (DEP, 2013).

## 2.3 BIODIGESTER FUNCTION

Digesters are autonomous bacterial systems that take the influent feed and produce methane rich biogas and nitrogen rich fertilizer as effluent. While requiring minimum maintenance, an operator must understand the biology and operation of a digester system. There are many factors that affect the rate of gas production in an anaerobic digester such as the type of organic material input, and the system operation temperature.

There are two main types of bacteria categorized for anaerobic digestion. Mesophilic bacteria comprise of a wide set of species that prefer a temperature averaging at $35^0$C, and the other type, thermophilic, are extremophiles that prefer an average temperature of $55^0$C (Kim, 2002). Thermophilic bacteria have a faster metabolic rate allowing them to process the organic influent faster, but extremophiles are a smaller specialized category of bacteria that are only stable in high temperature conditions. Disruption of the vessel temperature can negatively impact the bacteria inside the digester by inhibiting metabolism, or lowering the number of bacteria present. Thermophilic bacterial have less diversity and are more easily affected by conditions occurring inside the vessel, so a thermophilic digester requires more attention by the operator than its mesophilic counterpart (Kim, 2002).

The digestion process that occurs within the vessel is not a fast reaction, and requires a number of days to successfully generate methane gas. This residence time depends on the type of feed input, and the conditions the bacteria operate at. Digesters using thermophilic bacteria have a residence time on average of four days, and mesophilic conditions require on average of 17 days to process the influent (Cassie, 2010). This prolonged processing time occurs because inside the vessel two different processes take place called acidogenesis and Methanogenesis. The digestible content of the digester feed is called volatile solids that compose of fats, proteins, and carbohydrates that are hydrolyzed into fatty acids, amino acids, and monosaccharide molecules respectively. These molecules are then used by acidogenic bacteria to perform acidogenesis, and the products of acidogenesis then get converted by methanogens into methane gas and other byproducts. While these two different bacteria groups act symbiotically in this system they have different sensitivity to the pH (Sbarciog, 2012). The system should be kept at close to neutral pH to balance the two different steps in this reaction. If acidogenesis occurs too quickly then the acids produced will lower the pH of the system preventing the function of the methanogens. The final gas product consists of 60% Methane, 40% carbon dioxide, and less than 1% nitrogen, oxygen, and hydrogen sulfide gas (American Biogas Council, 2010). Different feeds take longer to process relative to each other due to the exact composition, percent volatile solids, and presence of unwanted substances such as disinfectants, pesticides, ammonia, and indigestible soil (Purdue University, 2008). These unwanted substances can adjust the pH or lower the counter of bacteria in the system which in turn would affect the yield and residence time of the feed.

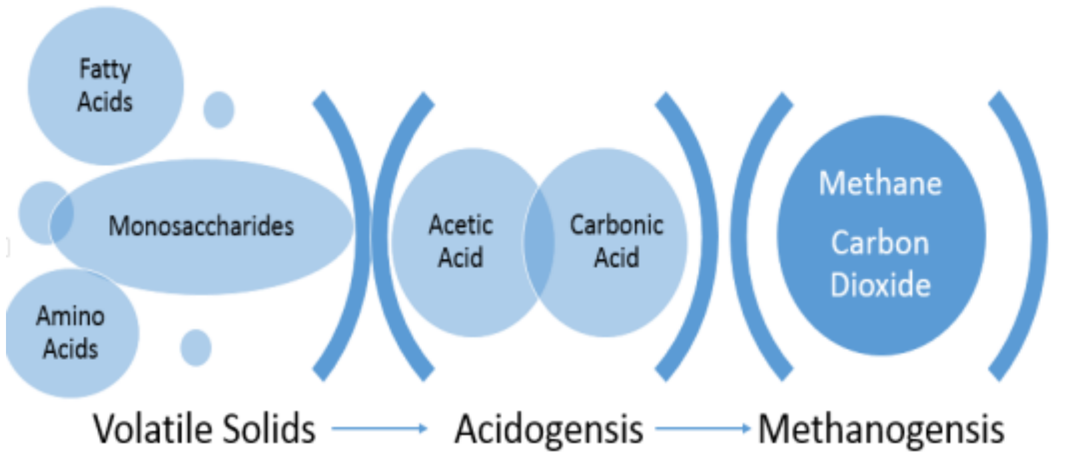



*Figure 3: One possible pathway of methane production from an initial feed containing Volatile Solids*

Since it takes a long time to digest the material a plug flow reactor style is more efficient than a batch reactor. In a batch reactor feed would be placed into a vessel, allowed to fully digest, and then replaced with a new batch. However, the medium contains the bacteria that act as a catalyst to provide the conversion, so complete replacement of an entire batch requires replenishment of bacteria. In a plug flow reactor feed slowly passes through the inside the vessel and is displaced by new incoming feed which in for a small digester would occur in small manual daily feedings. This allows the digester to maintain a healthy culture of bacteria, and operate at steady state conditions (Budhijanto, 2012). The ability to successfully manipulate these independent variables to impact methane generation requires construction of a reliable digester.

### 2.4 DIGESTER STRUCTURE

To construct a plug flow digester consideration must be given to the location, size, heating, and insulation of the digester. The volume of a digester controls how much material can get processed, so in order to meet a desired output an adequate amount of space must be allocated to the digester. Depending on the target volume consideration might be given to the number of reaction vessels needed to process the digestate, and additional consideration should be given whether the vessels will run in parallel or in series. Common applications for small, single vessel digesters include stove usage, lighting, small motors, and integration into gas lines (Volunteers in Technical Assistance, 1980).

*Figure 4: Pictures of an in ground Digester (Warren Weisman, 2012)*

Figure 3 shows a 2 cubic meter home built digester that utilizes a permanent ceramic structure. It collects gas above the digested material with a rubber cover that expands as gas forms. A gas line goes from the top of the digester over to a modified stove that can burn the biofuel (Warren Weisman, 2012). A team from the University of Malaya created a portable digester that could also be used for cooking. However, this model uses a gas displacement mechanism to store the methane gas. As gas was formed it would travel into the gas tank where it would rise into the middle chamber. Gas would then exert a pressure and move the water up the sides of the vessel. A cork was used to measure the pressure inside the gas tank to monitor the pressure, and determine when enough gas had been collected to burn (Zakaria, 2012).

Figure 5: Two Barrel Digester used for cooking (Zakaria, 2012)

Many home digesters use common affordable items to run very small-scale digesters. Almost all of these small-scale digesters are used for cooking, and have an average volume of 50 gallons. Most use water displacement as a cheap way to store biogas, and it allows the operator to easily judge the gas pressure. In order to collect more than 20 minutes worth of biogas the digester would require more volume (Hermans, 2011). Unfortunately, methane gas cannot liquefy as easily as propane, and becomes much harder to store under pressure. These designs do not have any sources of heat except for the metabolic process of the bacteria. During a Worcester winter, these water reliant systems would cease to function. As mentioned in the previous section, the bacteria also require a warm environment. Finding a way to keep the vessels operational could enable the system to generate methane in winter.

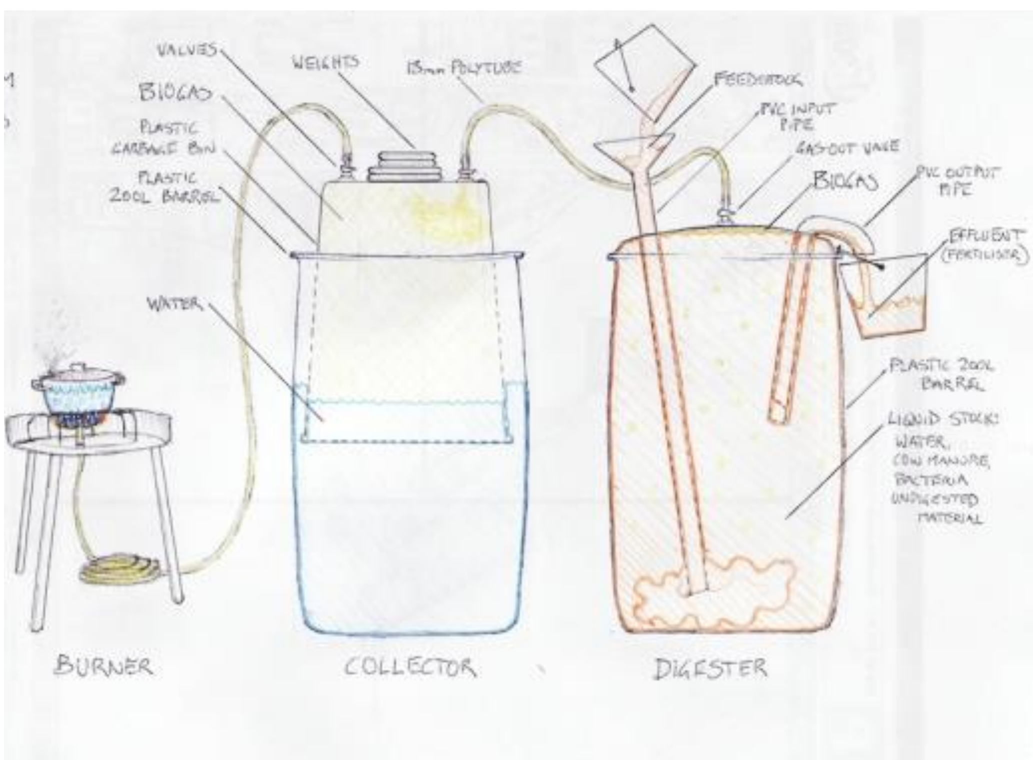



*Figure 6: A two-barrel digester design sketch that uses low cost options (Hermans, 2011).*

While the metabolism by the bacteria is an exothermic process the vessel will require insulation and heating to ensure a stable operating temperature. This heating requirement will vary depending on the time of year operated, and colder climates where temperatures are far below mesophilic operating conditions require a more rigorous heating method than warmer climates. Small, buried vessels can use the ground to effectively insulate itself without the investment of additional resources (Volunteers in Technical Assistance, 1980). If burying is not an option, fiberglass insulations can provide additional thermal resistance to the vessel instead. If the operator plans to run the digester in the winter, investment into a heating element should be considered to supply any heat the digestion process cannot supply. In the summer the temperature could also rise above the desired range, and adjustments to the design to remove excess heat might become necessary.

Digesters function by performing gas capture through segregation and flow of gas through the different chambers. To segregate the main vessel from the atmosphere in a single vessel system a vertical pipe can feed the influent and go down below the water line. The gas forming inside will build up pressure seen as a water column in the feed pipe since the gas cannot pass through the digestate to reach the atmosphere. This can also provide a measure of how much gas is stored inside of the vessel through pressure change (Volunteers in Technical Assistance, 1980). The gas must then transfer from the vessel to either the burner or a storage system. A pump system can be used to manipulate the pressure gradient and transfer gas from an area of higher pressure to lower pressure, but higher pressures come with greater risks of fires and gas leaks. The Department of Environmental Protection does not require any small scale digesters to remove trace gases, but it behooves the operators to consider inserting a filter system (DEP, 2013). One of the byproduct gases, hydrogen sulfide, is corrosive, flammable, and poisonous, so implementation of an iron oxide filter can remove sulfides from the gas stream (American Biogas Council, 2010).

## 2.5 IMPLEMENTATION FOR NUESTRO HUERTO

> *“Nuestro Huerto’s mission is to serve as a community asset that offers equitable access to healthy produce, educational opportunities and an environment that fosters a diverse, open and inter-generational community.” ~ Amanda Barker, Founder*

Nuestro Huerto is a small community farm near South Worcester Industrial Park that had previously been used as a storage grounds. A local church, Iglesia Casa de Oración, owns the land. The farm has developed a Community Supported Agriculture program where members contribute a combination of funds and labor to the farm. For example members can work for 5 hours a week for a share of the crops, or pay $525 and work 5 hours an entire season. The farm grows mixed vegetables, perennial herbs, and both perennial and annual flowers which go to shareholders, local restaurants, and farmer markets (personal communication, Barker, 2013). Amanda Barker founded the organization in 2009, and it has grown from 10 raised beds to over a quarter acre.

*Figure 7: Inside the Nuestro Huerto hoop-house at The Shop, with a total length of 34 feet.*

Nuestro Huerto requested that the team construct a biodigester to heat a hoop-house at an offsite location called The Shop. The Shop offers a location for people to work on different projects together and consists of a warehouse, metalworking shop, a kitchen, and common area. Outside is a hoop-house that Nuestro Huerto built to grow the seedlings for the start of their growing season. Our sponsor would prefer to utilize the hoop-house located at the shop to begin germination in March. This would increase both the amount of food Nuestro Huerto could produce over the year.  By implementing a biodigester, Nuestro Huerto hopes to create a site for organic waste recycling in Worcester, and heat their hoop-house when necessary.

# 3 METHODOLOGY

Our project explored the possibilities of an anaerobic food waste digester in small urban farms and gardens. The goal of our project was to design and build a safe, reliable, low-cost, and replicable biodigester in collaboration with Nuestro Huerto. The design required extensive collaboration with our sponsors, and multiple iterations of the design process before building a complete digester. The objectives of this project were the following:

1. Identify relevant design criteria with Nuestro Huerto for building an anaerobic digester.
2. Determine the feasibility of installing a digester with the intent to heat the hoop-house during the month of March.
3. Build a small prototype digester in order to establish a hands-on model to allow research into digester maintenance and performance.
4. Develop designs for a biodigester design based on the agreed criteria, and construct an operational digester.
5. Educate our sponsors so they may operate a digester autonomously.

## 3.1 IDENTIFYING RELEVANT DESIGN CRITERIA

In order to build a purposeful collaboration with the Nuestro Huerto, we had to first identify, discuss, and negotiate feasible objectives. Early meetings showed difficulties for both parties to communicate effectively. Our sponsor shared her understanding of digesters and why they wanted to construct one. The WPI team shared its literature review, tried to identify misconceptions, and explained existing examples of digesters. This enabled the sponsor to understand how our proposed designs functioned, and led to more cooperation. While we understood the basics of building a biodigester, many important aspects of the project depended on the needs of the sponsor for heating and space requirements.

## 3.2 HEATING FEASIBILITY

Questions for our sponsor:

- What organic waste is available? Would they use manure?
- How was the greenhouse insulated?
- What temperature did they want to maintain in the hoop-house?

The revised plan for the biodigester was to heat the hoop-house during the month of March, and permit Nuestro Huerto shareholders to begin the growing season a month early. We examined the heating duty required to meet this objective, and how a biodigester could feasibly fulfill it. In an urban environment, access to manure to feed a biodigester can be difficult. The sponsors had previously been collecting different types of food waste to compost, so we met with the sponsors to ask what resources they had been collecting. This included juiced fruit, egg scraps, coffee grounds, and assorted vegetables. We inspected the available resources that Nuestro Huerto could obtain to fuel our digester, and how they would affect the output of methane gas. Using this data we analyzed if the goal could be met, and the volume required if applicable. The WPI team then researched the volume of methane produced per mass of these feeds using information from our literature review. Using a number of different iterations, in appendix A, we calculated the amount of volume required to heat the hoop-house during the month of March.

### 3.3 DESIGN PROCESS

Questions for our sponsor:

- At what locations did we have to permission to build?
- Do we have permission to rearrange the inside of the hoop-house?
- What materials at The Shop are available for use in the design?
- What were the safety concerns?
- What were limits on electricity and water usage for digester operation?
- How much time per day would they have to maintain the digester?
- How much fertilizer could they utilize from the digester?
- If the design cannot heat the greenhouse, how would the gas be used?

The team proposed a number of designs in order to gain building approval. The digester could not be constructed without our sponsor's consent, so constant updates and meetings allowed us to work through design constraints with Nuestro Huerto.

Each member of the team developed designs we thought would fit the criteria specified by Nuestro Huerto. Common features were the use of the large digester vessel, feeding under the waterline, and use of a water displacement gas capture. Using this we discussed and defended design choices. Then for each different function of the digester we constructed a decision matrix in appendix B. The matrix had different parts, performing the same function, rated in relation to effectiveness, cost, reliability, and simplicity of the part. An exception to the subjective rating was cost which could be objectively rated based on the relative prices. These different criteria were weighted by their importance to the design using subjective criteria.

Using the Decision Matrix the team constructed a CAD model of our preliminary design, and proposed the design Nuestro Huerto.  Our sponsors declined the original design, so the team returned to the design matrix approach to generate four different iterations. Nuestro Huerto selected a design out of the second set of options, but asked us to modify the digester's gas capture and tank heating method. In the following weeks all parties involved on the project met weekly to discuss how to modify the digester.

## 3.4 CONSTRUCTION OF A PROTOTYPE MODEL

We built a 5 gallon bucket digester which was much easier to operate than a full scale 275 gallon tote and easier to transport. This digester used a design very similar to those seen in section 2.4. This allowed us to operate it and test at home, but also show it to our sponsor. The small model helped the team understand how to operate a digester.

*Figure 8: The 1/50th scale Prototype used to educate the team and sponsors on digester operation*

One of these tested design constraints was Nuestro Huerto's lack of interest in using large amounts of fertilizer. One of these ideas was feeding the digester dry mass to reduce effluent being produced. By showing how the operator had some control on the amount of fertilizer required we were able to move the project design forward. We also tested the floating drum system which bubbled the gas into the inverted barrel. This method had been seen before, but as gas collection is a critical component we wanted to show this to the sponsors.

# 4 RESULTS

## 4.1 DESIGN CRITERIA

From discussions with out sponsors, we learned that the four main parameters to consider when building a digester were size, heat, safety and cost. The need to keep costs to a minimum was a primary consideration, and using recycled resources helped to do so. In addition safety played a role in justifying design choices to our sponsor and impacted our rate of progress. The WPI team members had the technical background to perform the construction, but Nuestro Huerto would have to learn how to operate the digester over the long term

Safety precautions made an impact on most stages of the design. The team worked with Nuestro Huerto to identify main objectives and then proceeded to incorporate these criteria into each aspect of the design. The biggest safety factors included gas storage and pressurization.

The size of the digester determined the amount of gas produced and the space that our sponsors would lose. A smaller vessel was preferred because Nuestro Huerto wanted to maximize the space to grow seedlings in its hoop-house. Many discussions involved which locations at the project site could be used to house the digester, and how to best optimize the space available.

Efficient use of available resources impacted our design more than most of the other factors. Many of the expensive items used had been recycled from team members or The Shop. As the digester phase transitioned from a concept to construction the team located resources available for free, and began redesign to reduce the cost of the digester. A decision of financial feasibility was a primary consideration to make our design reproducible and fit the team's budget. The following sections explain the design choices for different parts of the digester.

Figure 9: Schematic of final design

The final digester utilized a new 275-gallon vessel supported by a steel cage. This vessel was the largest single stage volume available at The Shop that the team could implement into the design. The vessel owned by The Shop had a large gash in the vessel that had been plastic welded, but its ability to store gas in the vessel had been compromised. We traded used tools for another 275-gallon tote in better condition and a steel cage that provided needed support for the vessel walls. In order to meet the heating requirements for the hoop-house during the winter a large quantity of gas needs to be produced, and even with 275 gallons, the digester would not produce enough fuel to heat the greenhouse.

## 4.2 ONE VESSEL VS. MULTIPLE VESSELS

The 275-gallon tote was the least complex solution as a vessel. Consideration was given to using flow between multiple vessels. This would allow us to fit the digesters along the entire length of the hoop-house using numerous barrels, and optimize the space for growing seedlings on pallets at waist level. The shop had many 50-gallon containers at hand, but unfortunately they could not be laid on their side while full making it difficult to fit underneath the pallets. To equate to the 275 gallons of the tote would require 6 barrels, but would require more space in the greenhouse due to their circular geometry. Using multiple vessels could provide more challenges during construction as each vessel would require their own gas collection lines and insulation. This complexity would make the design more expensive and less replicable to others looking to construct their own digester. A large plug flow bag would have fit along the length of the hoop-house at a low height, but could not get placed on the premise since it might experience puncturing forces from nearby work. Thus, the team decided to use the largest free vessel available since it was an industrial strength container that would maximize our gas production.

*Figure 10: Location of the digester before construction.*

The team constructed the digester outside the hoop-house at the shop to allow maximum usage of the greenhouse. The inside of the hoop-house gets busy in the early months of the year where Nuestro Huerto grows seedlings on 3 ft. high shelves. We planned to build the digester inside the greenhouse since it would receive additional protection against the weather and require less heating for methanogenesis but Nuestro Huerto needed growing space, and growing on top of the digester would become challenging with a total height of 4.5 feet. With the curvature of the space inside, and the limited width of the aisle, a biodigester located inside the hoop house would hinder effective operations. Thus, the digester site moved outside of the hoop-house to optimize space for seedlings. As the digester moved outside additional measures had to be taken to insulate and protect the digester from the elements such as snow and rain.

*Figure 11: Insulated tank inside the box*

## 4.3 INSULATION & HEATING

The design team used reflective insulation, fiberglass insulation, a submergible heating coil, a heating matt, and a waterproof plywood box to protect and heat the vessel. The group designed a prototype without a box, but as heating the larger digester became an issue, proper insulation became necessary for success. The box needed to protect the digestion tank and prevent heat loss. The team considered using readily available polyethylene vinyl to cover insulation and protect the digester, but plywood provided a reliable and permanent structure. In addition, moving the digester outside made it a requirement to use plywood to properly protect the vessel from snow and heavy rain. The inside of the box had R-15 fiberglass surrounding the vessel to improve the thermal resistance of the system, as well as thinner R-2 thermal bubble wrap. This drastically improved the heating efficiency of the system.

In order to maintain the temperature between 80-90F, a 100W 120VAC submersible heating coil and a 300W 120VAC piezoelectric heating mat were implemented into the design. The heating coil will provide direct heating inside the vessel while the mat would radiate heat vertically through the cross sectional area of the vessel and the total volume of solution. These devices were attached to a thermostat that monitors the temperature of the system, and turns the heating on and off to maintain a steady state temperature for the system. A heating probe is inserted inside the vessel through the feed line to take an accurate temperature for the system. The most important decision factor was the wattage of the heating device used. A small heating coil was purchased for $35 that provided 100 watts, but concern arose about the ability to keep up with the heat loss of the vessel. A test run was done on a few gallons of warm water, and it could not support a temperature above $70^0$ F when placed in a room at $60^0$F. Later on in the design process our sponsor gave us a heating mat.

### 4.4 GAS COLLECTION:

Unfortunately methane cannot be liquefied at standard temperature like propane, and the biogas is corrosive due to water and sulfuric acid content. Thus, storing methane proves a difficult challenge. As will be further mentioned in the conclusion, until additional research has been done gas collection should only occur using low pressures.

The most reliable method we identified would use a floating drum system that bubbled the gas into an inverted barrel. This would cause the barrel to rise as gas. Some challenges to this method include the possibility of the barrel tipping over. The rising barrel would also have to fit within the height of the hoop-house, and not freeze during winter operation.

### 4.5 HEATING THE GREENHOUSE VS SPACE CONSTRAINTS

After discussions with Nuestro Huerto it was understood that given the size of the vessel, we could not heat the entire greenhouse but only a portion of it. A previous assessment of biodigester viability suggested that an average of 168 kg of food waste per day would be required to produce enough methane to heat the greenhouse all year long. In an aqueous solution this would result in a 1775 gallons/day minimum, or operating a digester at six times the current volume at maximum residence time efficiency. While attempting to fit this heating requirement for the hoop-house the space required conflicted with the space allotted (appendix A). The hoop house did not have the necessary space to digest such a large volume of aqueous food waste, and it would require the purchase and construction of addition vessels.

We constructed a small prototype vessel to experiment with yield amounts from feeds. In order to attempt to minimize the amount of water volume necessary to operate the small-scale digester tests were run using dry feed. The prototype showed successful methane production using this method, and suggested that using very fine dry mass could help reduce the amount of water required to dilute the influent feed.

# 5 CONCLUSION

Nuestro Huertos initial goal was to find ways to turn local food waste into energy by operating a digester and they now have a tool to continue their research.

A biodigester can transform food waste into gas for various purposes: heating, cooking, etc.  In the course of the project, we came to understand the trade-offs between optimizing methane production and competing concerns of Nuestro Huerto related to safety, space, and cost. The biodigester we constructed is not sized to heat the entire hoop house, which was an initial goal of our project.

## 5.1 FUTURE WORK ON THE DIGESTER

The team has successfully constructed a digester, but work to improve the digester still exists. Safety and efficiency of the gas capture system has delayed start up, and thus data collection has not been done on our deliverable. This could include testing a variety of feed sources, and determining the most effective feed to increase production and provide stability to the bacteria culture.

Future work could also include improvement of the design. Since the digester has not been tested, issues will arise that would need answering. While the team will make themselves available beyond the timespan of the project, future groups might work on design improvements to the mechanical restriction of production. This might include: determining an efficient way to store the gas, and help the sponsors find ways to utilize the gas produced.

If a gas production and storage can be optimized, they could manage to heat the greenhouse next winter, and extend the growing season. With a constructed digester, the next step is learning how to fulfill the requested heating duty for the shop. After looking at methane production, steps can be taken to section off a small section of the greenhouse to heat seedlings during the winter.

# APPENDIX A

## HEATING REQUIREMENT

The calculations use the independent variables of production of gas per volume, the thermal insulation of the greenhouse, average temperature, and 100% efficiency. Gas production has been measured for different food wastes in lab scale experiments, but these measured vessels have tightly regulated temperature and different bacteria cultures. To calculate the thermal requirements of heating the greenhouse we used the greenhouse calculator as an estimate to base our calculations. However, while we used the corresponding thermal resistance of the material for the greenhouse the ground and one side of the greenhouse are concrete. The driving force of heat loss out of the greenhouse is the temperature difference. The temperature outdoors fluctuates wildly during the winter months, and the average temperature could inaccurately represent the most crucial part of this calculation.

### BASED ON FINDINGS FROM PREDECESSOR REPORT:

**Mass of Food Waste (Given)** = Total Mass Required (Unknown) x Dilution in Water (specified)

Assumption: Density of food waste and water mixture equal to 1 kg per Liter.

$$\frac{168\,\frac{kg}{day}}{(\frac{10}{100})} = 1680\,\frac{kg}{day} * \frac{L}{kg} * \frac{1\ gal}{3.785\ L} = 444\,\frac{Gal}{day}$$

Total Reactor Volume = Residence Time x Flow Rate

$$4\ days_{Thermophilic} * 444\,\frac{Gal}{day} = \mathbf{1775\ Gal}$$

$$17\ days_{Mesophilic} * 444\,\frac{Gal}{day} = \mathbf{7766\ Gal}$$

Result: To meet specifications would require total digester volume of 1775, or 7766 Gallons in volume. Next approach will use a commercial greenhouse calculator to determine the Volume needed for our digester.

### LITTLE GREENHOUSE HEATING CALCULATOR:

*Table 1: Inputs and outputs from littlegreenhouse.com calculator*

| **Height** | **Length** | **Width** | **Arc Length** | **Exposed Area** |
|---|---|---|---|---|
| **7.41 ft.** | 34.67 ft. | 14.33 ft. | 23.30 ft. | 1013 ft.$^2$ |
| **Temp. Outside** | Temp. Inside | Thermal Resistance | Heater Strength Required | |
| **$27^0$F** | $60^0$F | 0.7 | 23400 BTU / day | |

Assumptions: Outside temperature is equal to the average of temperature from the month of March, which is the month of interest. Hoop-house walls consist of 6 mm inflated double-layered polyethylene with no damage, and they will inflate the walls during early winter. No snow cover over the hoop-house.

*Table 2: Biomass Potential*

| **Energy (Monthly)** | **Energy (Daily)** | **Daily Heat (BTU)** | **Total Biomass** |
|---|---|---|---|
| **2665 kWh** | 86.00 kWh | 293334 BTU/ Day | 1725 kg / Day |

Assumptions: One kg of Feed produces 170 BTU of energy. One kWh is equal in conversion to 3412 BTU.

Result: Considering that a digester of 200-500 gallons typically produces a maximum of an hour of cook fuel, it seems more likely that the commercial calculator has more accurate results (Purdue University, 2008). This information was presented to the sponsors to alert them of the limits of the gas production of this vessel.

# APPENDIX B

## DECISION MATRIX & INITIAL DESIGN

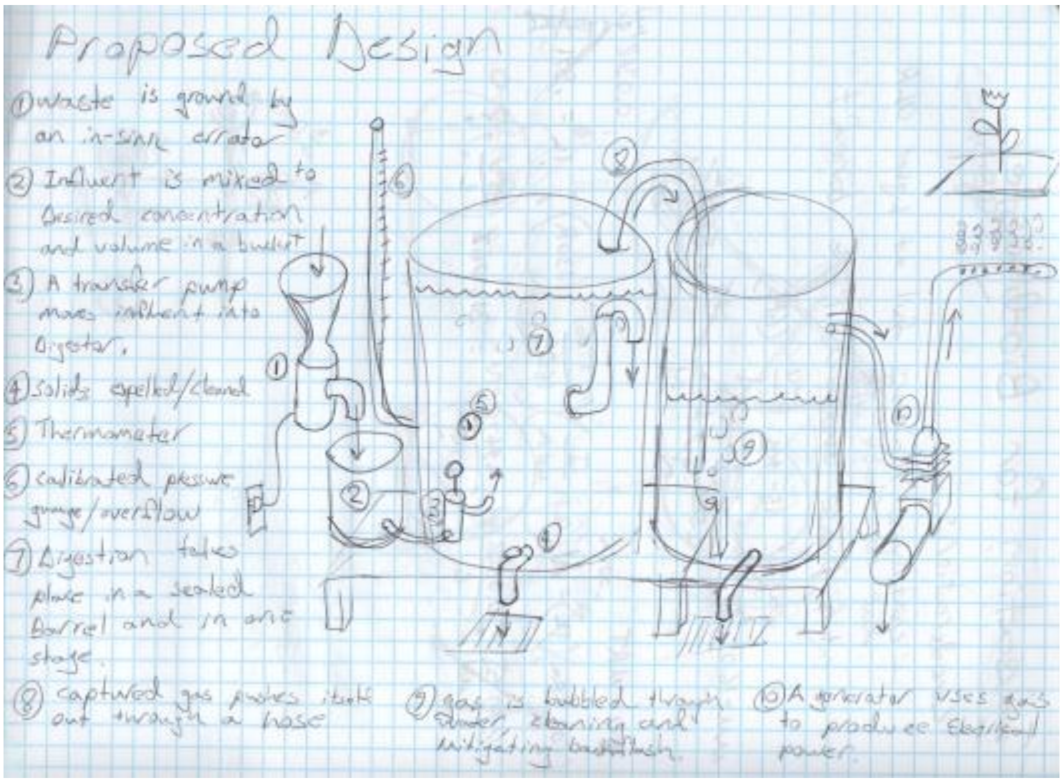



*Figure 12: Initial Design Concept.*

Each member individually picked designs we thought would fit the constraints of our sponsor. Using this we discussed and defended design choices. Then for each different function of the digester we constructed a decision matrix. The matrix had different part options rated based on the prior discussion and literature review on the effectiveness, cost, reliability, and simplicity of the part. An exception to the subjective rating was cost which could be objectively rated based on the relative prices. These different criteria were weighted by their importance to the design using subjective criteria. Below is the matrix used to decide on the original design:

*Table 3: Key parameters were rated objectively by the group, and then multiplied by their relative weight in the decision for the design. Highest total is deemed best option.*

| Influent Grinding | Effectiveness | Cost | Reliability | Ease of | Totals |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| | | | | use | |
| Weighting Factor | 0.3 | 0.2 | 0.2 | 0.3 | 1 |
| in sink Aerator | 9 | 6 | 7 | 6 | 7.1 |
| hand crank grinder | 8 | 8 | 7 | 5 | 6.9 |
| Manually | 5 | 9 | 9 | 4 | 6.3 |
| unground | 3 | 9 | 9 | 6 | 6.3 |
| | | | | | |
| Influent Injection | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.3 | 0.2 | 0.3 | 0.2 | 1 |
| angled pipe | 5 | 5 | 5 | 5 | 5 |
| vertical pipe | 6 | 7 | 7 | 6 | 6.5 |
| top opening | 1 | 7 | 7 | 6 | 5 |
| electric pump | 8 | 3 | 5 | 7 | 5.9 |
| hand pump | 7 | 7 | 6 | 2 | 5.7 |
| | | | | | |
| Digester Vessel | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.3 | 0.4 | 0.2 | 0.1 | 1 |
| 55gal barrel | 6 | 8 | 6 | 7 | 6.6 |
| 275 gallon tote | 9 | 7 | 6 | 6 | 7.1 |
| Metal Drum | 4 | 4 | 5 | 4 | 4.3 |
| Steel Oil Tank | 7 | 3 | 4 | 3 | 4.5 |

| | | | | | |
|---|---|---|---|---|---|
| Horizontal Bag | 7 | 5 | 3 | 5 | 5 |
| | | | | | |
| Solids Out | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.3 | 0.1 | 0.4 | 0.2 | 1 |
| Bottom spigot | 7 | 5 | 8 | 6 | 6.7 |
| manual cleaning | 4 | 8 | 7 | 2 | 5.3 |
| threaded cap | 3 | 5 | 5 | 6 | 4.6 |
| | | | | | |
| Liquids Out | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.3 | 0.2 | 0.3 | 0.2 | 1 |
| displacement flow | 7 | 6 | 6 | 8 | 6.7 |
| center tap | 5 | 5 | 5 | 5 | 5 |
| Spigot | 6 | 5 | 7 | 5 | 5.9 |
| | | | | | |
| Gas Isolation | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.4 | 0.1 | 0.3 | 0.2 | 1 |
| 55 gal bubbler | 6 | 8 | 8 | 6 | 7 |
| 5 gal bubbler | 6 | 8 | 6 | 6 | 6.4 |
| custom bubbler | 5 | 2 | 5 | 4 | 4.2 |
| scrubber | 8 | 2 | 4 | 3 | 4.6 |
| | | | | | |

| Gas Collection | Effectiveness | Cost | Reliability | Ease of use | Totals |
|---|---|---|---|---|---|
| Weighting Factor | 0.2 | 0.3 | 0.4 | 0.1 | 1 |
| water displacement | 4 | 4 | 6 | 4 | 4.6 |
| floating hood | 7 | 5 | 8 | 6 | 6.7 |
| floating bag | 6 | 7 | 4 | 7 | 5.8 |
| Immediate use | 4 | 7 | 8 | 7 | 6.4 |
| | | | | | |
| Gas Utilization | Effectiveness | Cost | Reliability | Ease of use | Totals |
| Weighting Factor | 0.3 | 0.3 | 0.2 | 0.2 | 1 |
| generator | 9 | 3 | 5 | 7 | 6.2 |
| Burner | 8 | 5 | 6 | 5 | 6.2 |
| water heater | 6 | 1 | 4 | 5 | 4.2 |

In the original proposed model the following design selections were chosen, and can be seen below.

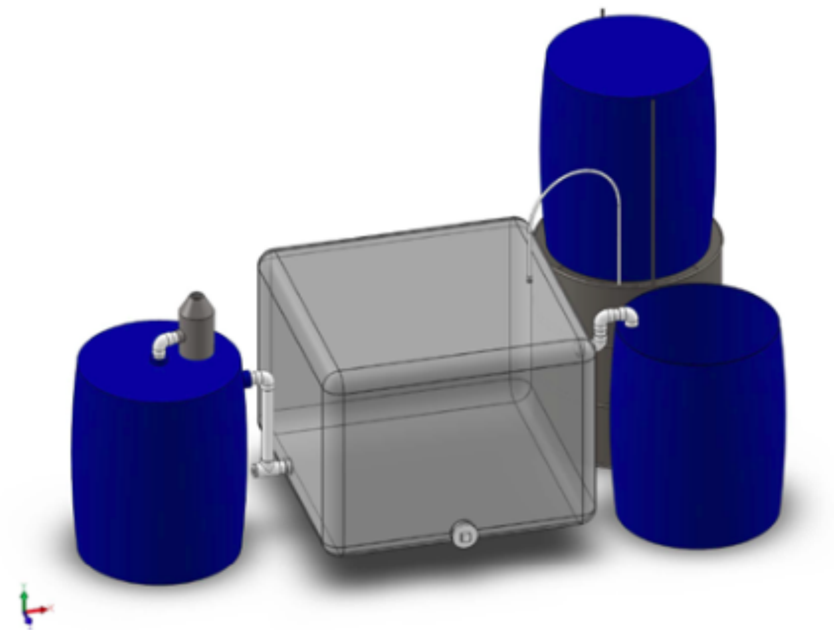


*Figure 13: View of a pre-digestion design of a digester done on SolidWorks with a floating barrel capture.*

**Influent Grinding: in sink Aerator** – This would allow our sponsor to easily grind any food waste they needed using an electrical aerator. This could reduce the time spent preparing the feed and make the process much easier with little additional cost of electricity. Alden was able to find one for under $10 for purchase.

**Influent Injection: Vertical Pipe** – The vertical pipe was the easiest and cheapest solution. While a pump would ensure less exposure to the outside air it unnecessarily complicated the feeding process. The vertical pipe was the most common influent method seen in other designs.

**Digester Vessel: 275 gallon tote** – Using the largest volume available allowed us to produce as much gas as possible. In addition, all of these options were available at The Shop, so the largest vessel became the most efficient.

**Solids Out: Bottom Spigot** – The spigot on the tote could drain effluent from the bottom of the vessel, and provided a cheap method. Cleaning to remove solids at the bottom of the vessel should not be required unless improper digester operation. The most reliable way would be to disassemble and clean the entire digester.

**Gas Isolation: 55 gallon bubbler & Gas Collection: Floating Hood** – The original design included a 55 gallon barrel of water used to isolate the gas from the main digester which would get collected. The gas would get bubbled through this membrane to the floating barrel.

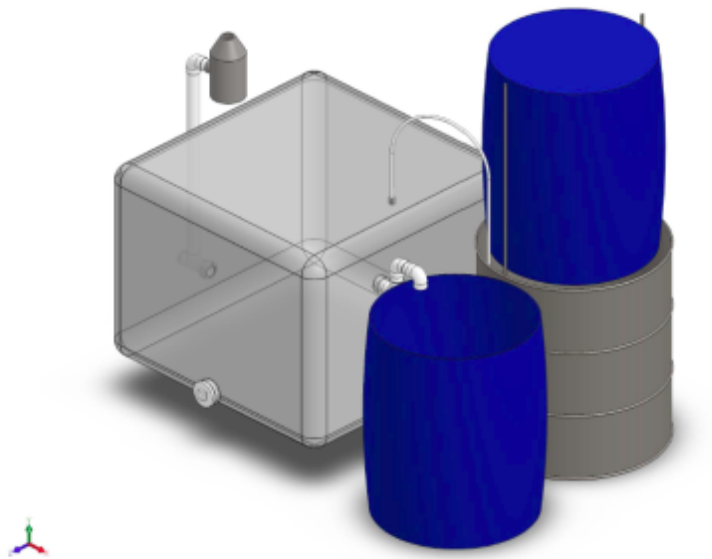


*Figure 14: View of a design of a digester done on SolidWorks with a floating barrel capture. Other barrel is effluent collection.*

# APPENDIX C

## CONSTRUCTION MANUAL

Below is a series of simple steps to construct a digester:

**Step 1**: Obtain the necessary parts, and tools. The total amount that we spent on this project can be seen in (Appendix E). However, we bartered and donated many of the most expensive items.

**Step 2**: Create an enclosure for the digester vessel leaving excess space for insulation. If the digester is under a roof and in a safe area lighter material can be used. The main functions of the enclosure is to protect the insulation from moisture, and the digester from any outside forces. Do not fully assemble walls until digester is placed inside.

**Step 3**: Create doors and access panels for access to the top of the vessel for feeding, and the side to access any wiring. For our digester we placed two doors on hinges that opened up an entire side of the box.

*Figure 15: View of Access Panels*

**Step 4**: Using a hole-saw or pre-existing holes, create openings for influent, effluent, and gas on the digester vessel.

**Step 5**: Create the necessary holes for the other end of these pipe lines on the gas container and effluent container.

**Step 6**: Place multiple valves on gas lines, and if possible pressure gauges.

**Step 7**: Place heating mat underneath the vessel. Wrap up the sides of the walls if excess space exists.

*Figure 16: Heating Mat*

**Step 8**: Move the enclosure to desired location and place digester inside. Finish assembly of walls. Do not place on roof.

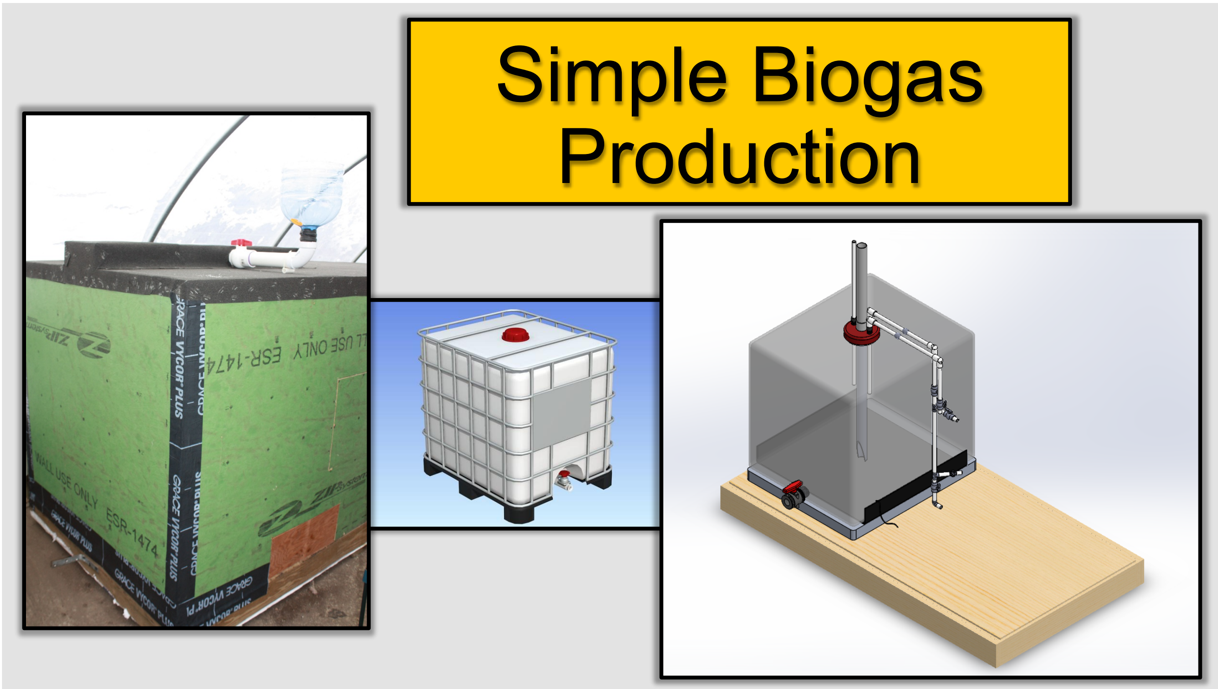
**Step 9**: Place the influent pipe down into the digester vessel, and seal. If you have a heating cable thread it through the influent pipe before attaching the pipe.

**Step 10**: Construct the other lines using sealant and cement to permanently hold them in place. Ensure that the type of sealant used is for PVC to PVC, or for the correct two surfaces in contact.

**Step 11**: Connect thermostat to the heating matt and heating coil. Ensure that the wiring is safe from any water sources.

**Step 12**: Place insulation inside of the vessel, and seal.

**Step 13**: Fill up biodigester




1. **Mix a solution of cow manure and water containing a minimum of 10 lb fresh manure and 193 gallons of water.**
   Cow slurry is a preferred inoculant because of its buffering capacity and stable concentrations of both volatile acid-forming bacteria (saprophytic bacteria) that feed on decaying organic matter and methane producing bacteria that feed on volatile acids. Each available vessel should be filled between 60-70% of its total volume. *We are arbitrarily choosing %70 of our 275-gallon drum as our solution volume.* Less volume is less expensive to heat but more volume allows for increased solution stability. The operator must take into consideration the fact that bacteria need an initial supply of oxygen from the atmosphere followed by an internally produced supply of

*Mixing Manure Inoculant*

carbon dioxide in order to produce methane. Therefore, there must be an optimum condition for the solution: airspace ratio within the tank but it will not be discussed any further in this paper. **The initial solution should contain at least 20x *Volatile Solids (VS)* than the intended daily feed rate VS.** This ensures a high concentration of alkaline buffer components to neutralize the addition of acidic food waste.

### *Calculations:*

***To determine the minimum amount of manure inoculant to use, the following calculations may be helpful. This does not have to be an exact science, particularly because the make-up of cow manure and food waste will always vary. However these numbers are determined from scientific experiment and represent an accurate consensus found in current literature. From our literature review, we know that,***

*I.* **Average %TS of Fresh Cow Manure** = 5-13% of *Total Mass (TM)*

*II.* **Average %VS of Fresh Cow Manure** = 75-80% of *Total Solids (TS)*

*III.* **Total Solution Volume (Water and manure)** $= 275gal * 70\% = 192.5gal$

*IV.* **Maximum Daily Feed Rate** $\approx \frac{0.757\ g \cdot VS}{gal \cdot Day}$

$$\approx \frac{0.757\ g \cdot VS}{gal \cdot Day} \cdot 192.5gal \approx 145.7 \frac{\text{g} \cdot \text{VS}}{\text{Day}} \approx 0.146 \frac{kg \cdot VS}{Day} \approx 0.32 \frac{lbs \cdot VS}{Day} \approx 5.12 \frac{oz \cdot VS}{Day}$$

- **Minimum Initial VS Content** $= 20 * 0.32\ lb \approx \mathbf{6.4\ lbs\ VS}$

  Fresh Cow manure commonly consists of ***5-13% Total Solids (TS) and 75-85% of the TS are VS.***

  Therefore,

$$0.13 \cdot TM = TS$$

$$0.85 \cdot TS = VS_{Required}$$

$$VS_{Required} = 6.4 \text{ lb}$$

$$0.85 \cdot 0.13 \cdot TM = 6.4\ lb$$

**TM=8.8 lbs**

$$\textit{Total mass of manure required to mix with } 192.5 \textit{ gal } H_2O \approx 9 \textit{ lb}$$

2. **Allow solution to ferment for 20-30 days.**
   A constant temperature between 85°F and 100°F and airtight container are critical for stable methane production. Increasing the temperature can reduce retention time and speed methane production. However, fluctuations in temperature can inhibit methane producers. A consistently stable environment is vital for the growth and proliferation of methane producing bacteria inside the digester. If the temperature rises or falls suddenly, methane production will slow and it may take a day to a few weeks for cultures to restore methane production.

3. **Food waste solution is added to the digester after fermentation period.**
   ***To determine the amount of food waste to weigh for feeding depends on the volatile solids concentration and the carbon: nitrogen ratio.***

   A feed rate of a maximum $\frac{0.757gVS}{gal}$ is recommended to ensure that the methane-producing bacteria are able to keep pace with the volatile acid production and maintain healthy buffer levels. A digester maintained at a constant temperature in the presence of minimal oxygen increases the buffering capacity due to the methane production process (carbon fixation) and therefore results in a more stable solution that is capable of handling a higher feed rate. A recommended carbon: nitrogen of 20:1 - 30:1 is also recommended to help maintain digester alkalinity and provide sufficient soluble carbon for bacteria to turnover to methane. C: N ratios of some common digester feedstock's can be found in *(Ileleji, K. E. (2008))*. The average carbon: nitrogen ratio of dairy manure is 9:1 *(United State Environmental Protection Agency (2013)).* Activated carbon may be explored as an option to increase the soluble carbon content. High carbon content food or yard waste can also be used but these also introduce small amounts of other compounds such as nitrogen and sulfur. The methane-producing bacteria break down acetic acid into methane and nitrogen rich ammonia. It is therefore critical that the feedstock introduce sufficient carbon along with the volatile solids in order to maintain the 20-30:1 carbon: nitrogen ratio necessary for methane production.

Total Solids and Volatile Solids content of common food wastes can be determined using previous research journals that contain data similar to what can be found in table 1 *(Gunaseelan, V. N. (2004))*. To take a slightly more scientific approach, solids content can be found more accurately by the procedures outlined below according to (*Wisconsin Department of Natural Resources (1992))*

***More Calculations;***

To determine the **Total Solids content** of a particular food waste sample,

***I.*** Collect a representative sample
***II.*** Weigh empty dry crucible
***III.*** Add sample to crucible and weigh *(Dry Weight)*
***IV.*** Dry sample by heating in an oven at 103° C. to 105° C.
   a. Centigrade and Fahrenheit conversion
      **i.** $\boldsymbol{C = \frac{5}{9}(F - 32)}$
      **ii.** $\boldsymbol{F = \frac{9}{5}C + 32}$
***V.*** Cool in desiccator or moisture free environment
***VI.*** Repeat drying until a constant weight is achieved

$$\frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight} * 100 = \%\ \boldsymbol{Total\ Solids_{by\ weight}}$$

To determine the **Volatile Solids content** of a food waste sample,

***I.*** Heat sample in muffle furnace at 550°C.
***II.*** Cool sample in desiccator or moisture free environment and weigh *(ash weight)*

$$\frac{Dry\ Weight - Ash\ Weight}{Dry\ Weight} * 100 = \%\ \boldsymbol{Volatile\ Solids_{by\ weight}}$$

*Table 4: Volatile solids content of some common food wastes taken from (Gunaseelan, V. N. (2004)).*

| Biochemical Methane Potential | | | |
|---|---|---|---|
| **Food waste** | **Percent V.S.** | **Food waste** | **Percent V.S.** |
| ***Microcrystalline Cellulose (Control)*** | *99.4* | ***Loose Skin Mandarin (Whole rotten fruit)*** | *89* |
| ***Tight Skinned Orange (Peels)*** | *94.7* | ***Loose Skin Mandarin (Seeds)*** | *94.7* |
| ***Tight Skinned Orange (Pressings)*** | *92.3* | ***Lemon (Pressings)*** | *96.8* |
| ***Loose Skin Mandarin (Peels)*** | *97.3* | ***Rotten Tomato (Whole fruit)*** | *92.5* |
| ***Loose skin Mandarin (Pressings)*** | *97.4* | ***Onion (Exterior peels)*** | *88.2* |

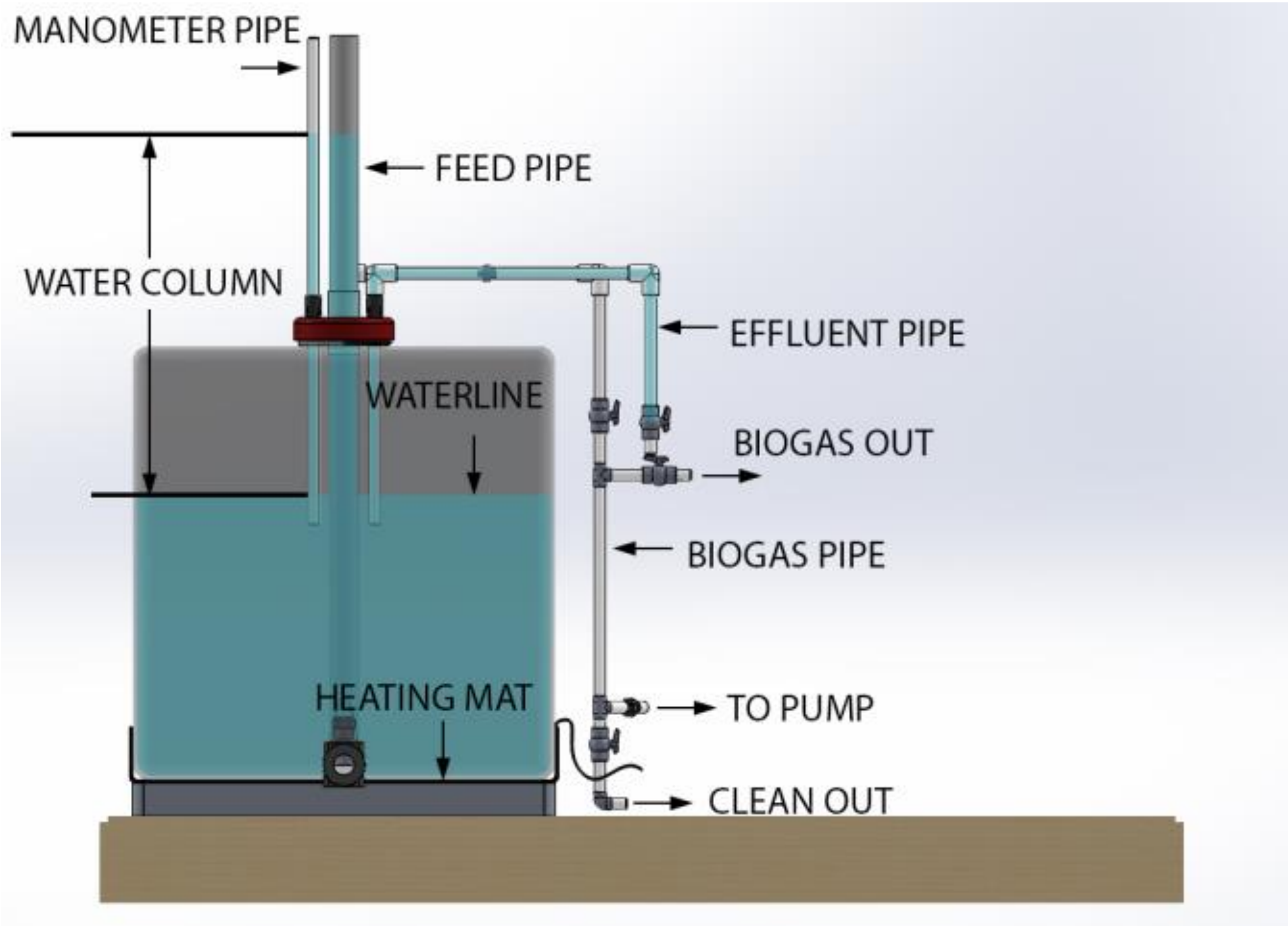
4. **Monitor Volatile Acid concentration, Buffer Capacity, and pH**

   Slowed methane production can be a sign of decreased buffer capacity. If temperature is maintained constant and methane production slows, it is likely due to low volatile acid concentration, which would require feeding, or a high volatile acid concentration in which solution should be allowed to ferment at constant temperature until methane producers increase production and restore the buffering capacity. A solution of cow manure and water that is of the similar concentration as the initial solution should be used to reestablish buffer capacity if methane production is slow to pick up or if pH drops. A drastic pH change occurs after digester upset and is difficult to reverse without flushing the system with new inoculant solution.

   *Effluent samples will be necessary to monitor neutral to slightly basic pH using any standard technique. A drop in pH merely provides reassurance of a digester upset.* ***In order to monitor digester stability one must monitor the volatile acid to alkalinity ratio.*** *Alkalinity is the buffer capacity of a solution or the ability to resist massive changes in pH (Management, Volatile Waste). This process is slightly more complicated because it requires titration techniques, which are* *outlined in (Management, V.W.). Overfeeding with food waste will cause a decrease in buffer capacity due to increase in volatile acid to alkalinity ratio.* ***When the ratio exceeds 0.8, the pH will fall rapidly.*** *Action should be taken when this ratio exceeds 0.5. Buffer capacity should be monitored as often as is reasonable for the operator, particularly after experimenting with unfamiliar feedstock.*

5. **Semi-decomposed effluent mixture will be drained to the effluent vessel where it can be stored and potentially analyzed and separated into organic components.**
   Effluent can be separated into solid and liquid components. Liquid is predominantly ammonium hydroxide (or household ammonia) while the solid portion consists of fibrous plant material that was unable to be hydrolyzed by the saprophytes. Both products have potential organic benefits to the gardener or farmer. The liquid portion can be diluted and applied to soil as a high nitrogen fertilizer. Fibrous plant material can be used as a soil or compost amendment.
6. **Pressure changes inside the vessel will be used to ensure safe operation as well as monitor rate of gas production.**
   The likely option is to add another pipe to act as a manometer to measure water column and also serve as a potential access for our heating cable. The manometer also serves as a safety mechanism ensuring excessive pressure doesn't build up in the tank.
7. **One of the most important components of biogas production is temperature.** The bacteria require a consistent temperature in order to maximize biogas production. A minimum temperature of 80-85° F is a recommended temperature because it is affordable and results in a consistent digestion rate. A 300W heating mat was implemented as a heating mechanism on our 275 gallon digester which wired to a thermostat that can be set to 90° F. This means that the heating mat will shut off when the ambient temperature inside the box reaches 90°F. A more efficient and controllable approach would be to have a submersible thermostat wired to the heating mechanism.

8. **Effluent Removal.** The effluent pipe sits just below the water line inside the digestion tank. This is because the less dense digested effluent will float to the surface. When the pressure builds up inside the vessel due to methane production, this pressure can be used to move effluent out of the drainpipe.
9. **Gas Removal.** Our design did not incorporate a gas capture mechanism due to the complications associated with volatile gas handling. However, we did provide an outlet for a pump mechanism to be connected to the gas pipe. Some important parameters to consider for gas storage and utilization are;
    - **Gas contaminants and corrosiveness.** Biogas contains corrosive compounds such as water and sulfur. Both of these components can be filtered. Desiccant or paper filters can be implemented to remove moisture from the gas lines; we also incorporated a water trap and cleanout. An in-line sight glass can also be implemented in order to visualize the moisture content of the biogas. A homemade steel wool filter can be implemented to remove sulfur from the gas line. Sulfur hydroxide is a very corrosive compound and although it is only present in trace amounts in the biogas, it is important that it be removed if one is planning on storing gas under pressure for any length of time. Both filtering mechanisms require frequent monitoring and must be changed out regularly to ensure efficacy.
    - **Temperature and storage.** An increase in gas temperature is accompanied by an increase in pressure if held at a constant volume. Methane, which is the main component of biogas, does not liquefy under moderate pressures in the same way that gases such as propane do. This means that in order to store a significant amount of methane in a safe container, the container should be isothermal (very well insulated) and also have a large volume. This of course is interferes with any space constraints. Finally, a storage tank that is filled with activated carbon may allow for more methane gas to be stored in a given volume due to the porous nature of carbon and its affinity for methane.




*Digester Schematic*

## Safety

In order to ensure proper function and to maintain safe and responsible methane production, it is important that only those who understand the digestion mechanism attempt to feed or capture methane from the digester.

The operator is responsible for inspecting and maintaining equipment regularly. Frequent inspections for gas leaks are required to ensure safety and efficiency. Gas leaks can be detected using soapy water, commercial gas leak detectors, or electronic natural gas leak detectors. The entire digestion unit is assembled in a way that it can be readily disassembled for maintenance or fabrication. The operator is required to understand safety measures and ensure spark proof tools are used or open flames are not allowed in enclosed areas exposed to fugitive methane emissions. Any spills should be contained and diluted/cleaned to maintain a clean and safe environment.

***Strict attention should be paid to these three variables in order to maintain a stable digester***

- **Temperature**
  - Fluctuations in solution temperature can inhibit methane production by disrupting the biological processes taking place within the vessel. Stable temperatures allow for stable bacterial cultures.
  - Loss of heat during colder months can lead to digester slowed methane production and eventually ceased production.
- **Pressure**
  - Pressure in the digestion vessel should be monitored daily to ensure safe conditions as well as rate of gas production
- **Rate of Methane Production**
  - Monitoring the rate of methane production is achieved by recording the time it takes for the manometer to reach a determined height. Change in the rate of gas production allows us to monitor the effects of different feedstock's on digester performance. It can also be used as an indication of overfeeding and reduced buffer capacity. It is therefore of great value for the operator to understand and record the performance of the digester.References

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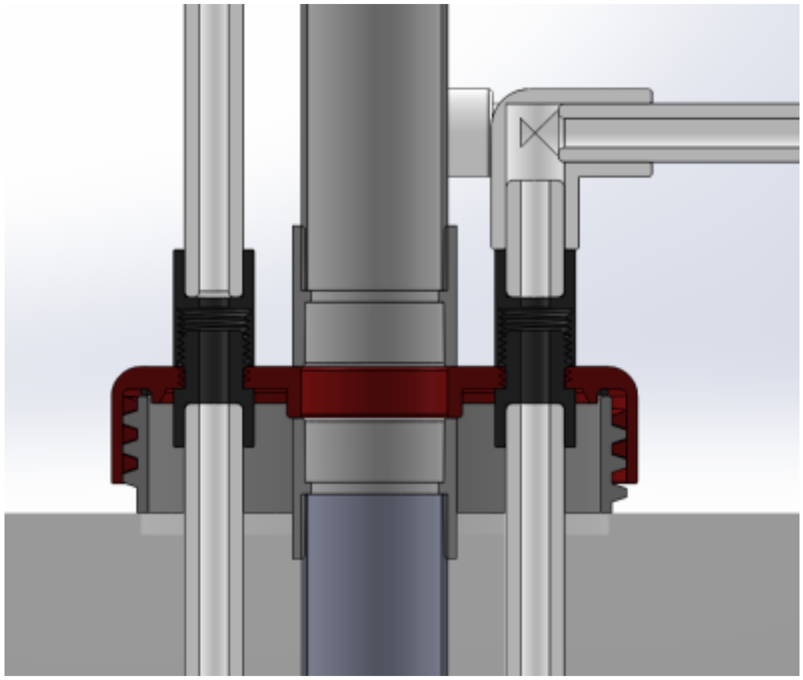
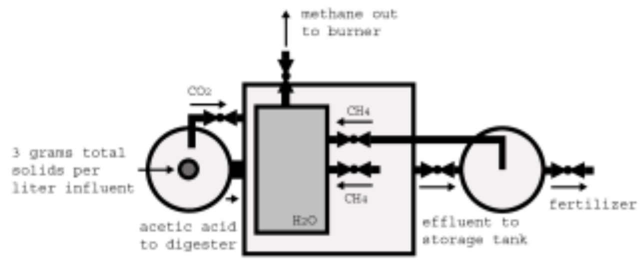
Culhane, Thomas H., Ph.D., co-founder of Solar CITIES. *Visiting researcher and Professor at Mercy College*

# EXTRA FIGURES



*Representative cross-section of our cap design adopted from (Culhane, Thomas H.)*

Digester A13: Corey Bloniasz
10-01-2013




Assumptions:
0.32-0.42 Liters Methane produced per gram Volatile Solids.

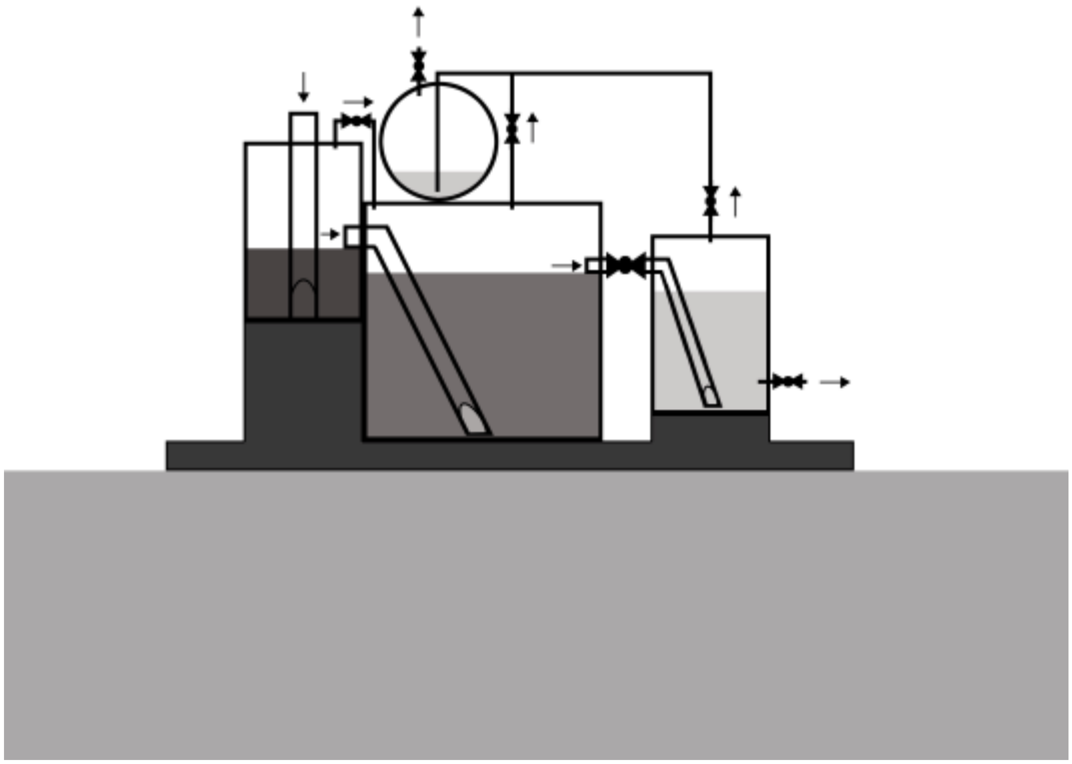
Feed Rate:0.18 grams Acetic Acid per Liter digestate.

275 gallon tote X 3.78541 Liter per gallon = 1041 liter total digester space

1041 X 75% = 781 liters of digestate volume

0.18 grams VS per liter X 781 Liters X 0.42 Liters per gram = 59 L Biogas per day

*Top View of a multiple unit digestion system design that allows for more controlled and stable, monitoring and breakdown of food waste feed stock.*



*Side view of multiple unit design.*

# BUDGET

*Table 5: Out of pocket expense*

| Design Cost | | | | |
|---|---|---|---|---|
| **Item Number** | **Material** | **Cost per Item** | **Quantity** | **Cost** |
| 1 | Weatherproof tape | $19.29 | 1 | $19.29 |
| 2 | Leak Detector | $4.47 | 1 | $4.47 |
| 3 | .5 inch union | $2.44 | 4 | $9.76 |
| 4 | LCD Digital Thermometer | $2.49 | 2 | $4.98 |
| 5 | 3/8 inch female coupling | $1.99 | 2 | $3.98 |
| 6 | 3/8 inch barb fitting | $2.29 | 2 | $4.58 |
| 7 | air filter | $2.99 | 1 | $2.99 |
| 8 | ph test kit | $7.50 | 1 | $7.50 |
| 9 | 1.25 inch pvc slip cap | $0.86 | 1 | $0.86 |
| 10 | 3/8 x 1/2 inch brass barb adapter | $3.12 | 5 | $15.60 |
| 11 | .5 inch ball valve | $8.97 | 1 | $8.97 |
| 12 | 1.25in x 2ft pvc pipe | $2.83 | 1 | $2.83 |
| 13 | .5 inch gas ball valve | $8.67 | 3 | $26.01 |
| 14 | 1x3x8ft furring | $1.15 | 40 | $46.00 |
| 15 | .5inch x 10 ft pvc pipe | $7.12 | 4 | $28.48 |
| 26 | 2" male adapter | $1.38 | 6 | $8.28 |
| 17 | 2" female adapter | $2.32 | 6 | $13.92 |
| 18 | .5 inch pvc 45 elbow | $0.67 | 2 | $1.34 |
| 19 | .5 inch pvc 90 elbow | $0.26 | 8 | $2.08 |
| 20 | 8 oz all purpose cement | $6.40 | 2 | $12.80 |
| 21 | .5 inch pvc male adapter | $0.37 | 6 | $2.22 |
| 22 | 8 oz thread sealant dope | $3.34 | 1 | $3.34 |
| 23 | female pvc adapter | $0.30 | 12 | $3.60 |
| 24 | male terminal adapter | $0.29 | 14 | $4.06 |
| 25 | .5 inch pvc ball valve | $2.52 | 6 | $15.12 |
| 26 | 2 inch x 10 ft pvc pipe | $5.99 | 1 | $5.99 |
| 27 | r30 14"x25' fiberglass | $12.79 | 2 | $25.58 |
| | | | | |
| | | | Net Total | $284.63 |
| | | | Tax | $17.79 |
| | | | Gross Total | $302.42 |

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