



From Food Waste to Biogas: Energy for Small Scale Farms *An Interactive Qualifying Project Report*

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ABSTRACT

Our team faced the challenge of restarting and improving the design and operation of a small scale biodigester constructed by a WPI team the previous year for Nuestro Huerto, an urban farm in Worcester. The overall goal was to use the food and plant waste to produce a useable energy source in the form of methane gas and to serve as an educational example for the community. We developed methods to produce, filter, collect, and store biogas and used the gas as a cooking fuel instead of a heat source for the greenhouse. Our work was influenced by a human centered design framework in which we focused our design and improvements on the needs and capacities of our sponsor to maintain and operate the technology.

ACKNOWLEDGMENTS

The completion of this project and report would not have been possible without a few individuals who we would like to acknowledge. We would like to extend gratitude to our faculty advisors, Professor Robert Hersh and Professor Rosbach. They helped guide us through the project as well as draft and revise the final report for the project. In addition to our faculty advisors, we would like to thank other WPI faculty members Professors Bergendahl and Kmiotek for providing insight on gas testing. We would like to thank Amanda Barker of Nuestro Huerto for the opportunity to work on this project. We all take away numerous lessons learned from the journey.

EXECUTIVE SUMMARY

Sustainability, is “the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance” (Random House, 2015). Using resources sustainably is especially relevant to small scale organizations that farm in cities. Urban farms can improve what are often degraded, compacted urban soils through application of compost and organic fertilizers created from recycling food waste; they can also use food wastes as a feedstock to produce renewable energy (*e.g.*, heat) through anaerobic digestion. This renewable energy source can help urban farmer’s heat greenhouses and extend the growing season to maximize crop yields.

Nuestro Huerto, an urban farm located in Worcester, MA, hopes to use the food and plant waste that it generates to produce a useable energy source in the form of methane gas and to serve as an educational example for the community. Last year, another WPI team was able to construct a biodigester to begin and establish a mesophilic bacteria culture meant to function at a temperature of about 90-100 degrees Fahrenheit without the presence of oxygen. The process of anaerobic digestion consists of bacteria breaking down organic material and producing biogas containing methane, carbon dioxide and trace amounts of other gasses. Because the bacteria are living biological organisms, they require certain conditions to live, such as maintaining a constant temperature, pH level, and a constant supply of food. These conditions can be difficult to maintain, especially in the cold climate of Worcester. Despite the team’s efforts to create a functional small scale biodigester, the prototype built last year did not reliably produce biogas. Procedures for feeding and managing the biodigester, and for capturing biogas were not firmly established, nor were suitable educational documents about operating and troubleshooting the biodigester developed. Our task was to develop a system that provides a productive and maintainable feeding schedule, establish a means to filter and store the biogas, and institute a plan to apply the final methane gas product as an energy source to benefit Nuestro Huerto.

These goals were organized into a design challenge: How can we further develop the biodigester's operation in order to produce a viable product all the while keeping the needs, hopes, and aspirations of Nuestro Huerto in mind?

With a solid design challenge as our focus, we developed four objectives to guide our project.

The first was to gain a better understanding of the needs and capacity of our sponsor to operate and manage the biodigester. In order to do this, the team

utilized a Human Centered Design Toolkit which gave ideas on how to design using three criteria: desirability, feasibility

and viability. These criteria, discussed with the sponsor,

guided our design ideas and improvements. We then

focused on the next objective which was to determine the

drawbacks of the existing design and identify improvement

to make the biodigester more efficient and easier to

operate. After the initial assessment of the biodigester's functionality, we were able to quickly identify

the most pressing issues of the existing biodigester design. First and foremost, the bacteria culture

residing in the biodigester had become dormant due to lack of feeding. To produce biogas, we quickly

developed techniques to feed the biodigester that were specific to the Phase 1 design. By doing this, the

bacteria culture was restarted and biogas began to be produced at a slowly increasing rate.

The initial feeding process was one of trial and error. The Phase 1 design proved to be very inefficient as it led to spills during feeding and because of the difficulty of feeding, increased the amount

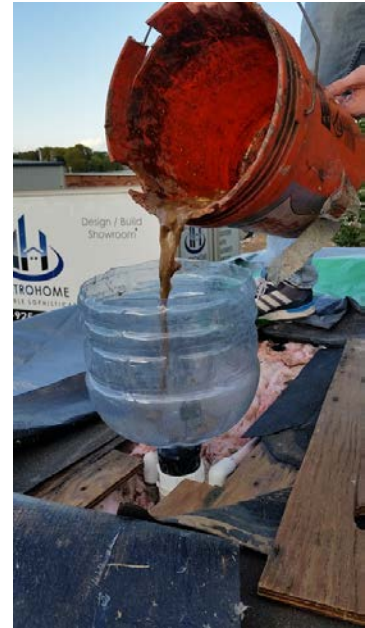
of time needed to feed. In order to solve this, the team decided that improvements to the roof and

physical structure of the biodigester had to be made. The new roof was designed to make it easier to

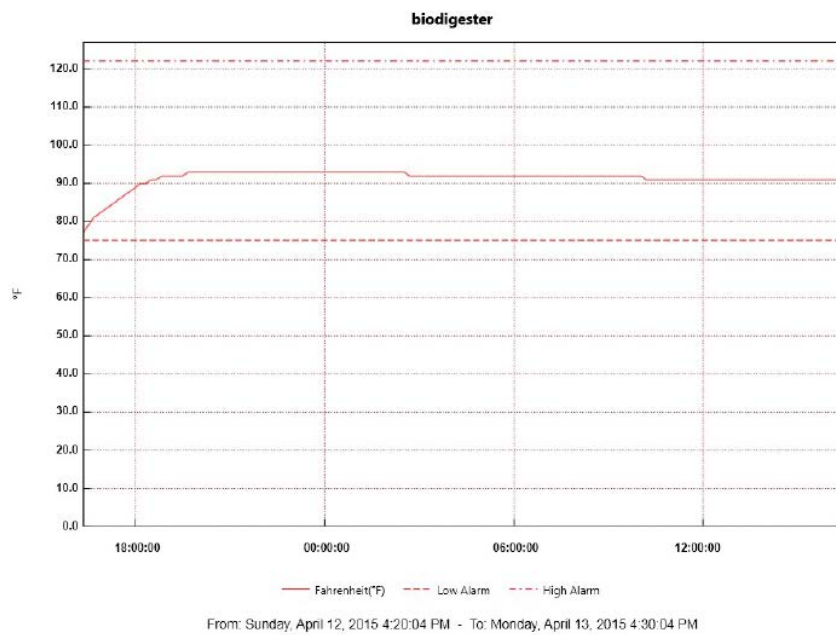
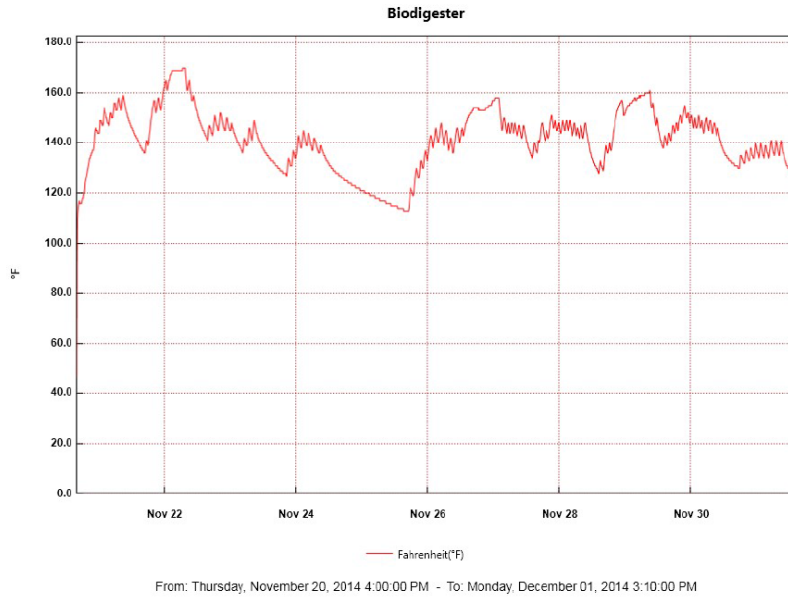


feed the biodigester and to improve the heat retention of the biodigester box. After multiple revisions, for the final design, we decided on an angled roof with a chimney-style feeding tube protruding through the roof.

With a bacteria colony established within the biodigester, the team had to make sure to maintain an environment conducive to biogas production. The mesophilic bacteria, as noted above, rely on a temperature range of 90-100 Fahrenheit. To maintain this temperature we used a heating mat wired to a thermostat. We monitor the system



through a thermometer that was purchased for its ability to record temperatures. The thermometer readings were used to calibrate the thermostat in order to reduce energy required by the heating mat. The first graph below is from the beginning of the project when temperatures varied widely. The graph shows temperature recordings from the thermometer that was inside the biodigester from Thursday, November 20th, to Monday, December 1st. The temperature varied over a large range of temperatures. This was because we did not know how to properly set the thermostat to get the desired temperature. These recordings were significant because it allowed us to predict if the bacteria colonies were still alive and producing gas. The second graph show temperature values from April 12th to 13th when the temperatures had become steadier. At this time, the temperature was in the desired range for mesophilic bacteria to produce gas and was remaining relatively constant.



In addition to calibrating the thermostat and heating mat, the team investigated ways to improve heat retention of the biodigester box. This was done by implementing a new roof design as well as by sealing holes from the existing design that were deemed unnecessary. By sealing the holes, the team not only improved the system’s heat retention, but also eliminated possible oxygen leaks into the

system. This was important because allowing oxygen into the system could kill off any bacteria that were producing gas. This also stopped any biogas from being released into the atmosphere.

Our third and primary objective was to establish a sustainable system that uses food waste to produce biogas and a process to filter and collect the gas. This system is sustainable in that it can be easily managed and uses readily available food waste as source of renewable energy. We developed a filtration process to remove hydrogen sulfide and carbon dioxide from the biogas. The removal of hydrogen sulfide is critical to ensure storage vessels,



potential gas lines, and burners do not erode from the corrosive properties of the gas. To do so, the team utilized the chemical reaction that happens between hydrogen sulfide and iron present in steel wool.



Steel wool was placed inside of a PVC container. The PVC scrubber was then attached to the gas pipe leading out of the biodigester vessel in a location that assured gas would flow through the scrubber before entering any sort of collection bag.

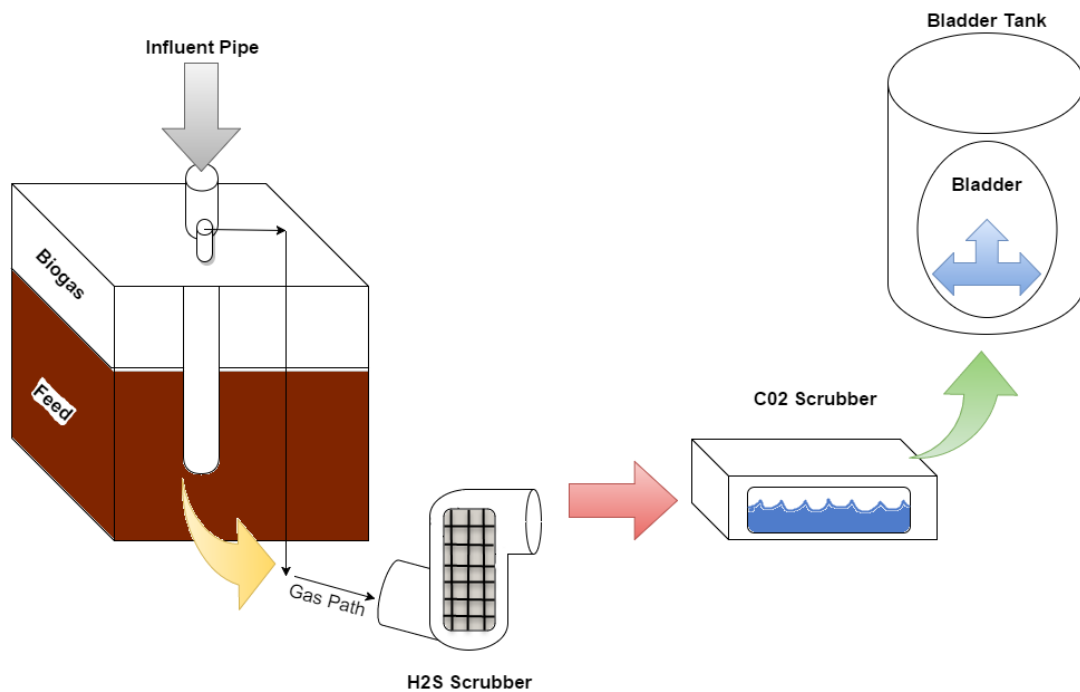
The scrubber to remove carbon dioxide was developed as a possible addition to the biodigester and became a recommendation for future use of the biodigester. In order to separate CO₂ from methane, the biogas is passed through water. The water absorbs a percentage of the CO₂ and has to be changed once it becomes saturated with CO₂. Based on potential gas production calculations and CO₂ saturation data, it was estimated that a CO₂ scrubber that held 10 gallons of water, would need



to be replaced every 3 feeds. Because of the work required to change the water, and the amount of

water that would have been needed to use, the scrubber was not used on the final design. A consequence of not having a scrubber is that between 30 and 40% of the collected gas will be CO₂ and not methane. This means that between 30-40% of the space in a collection vessel will be wasted on gas that cannot be combusted. Pictured below is the full schematic, with the CO₂ scrubber left in, in case it is decided to be used in the future.

Biogas Scrubbing Process



A byproduct of the anaerobic digestion process is unused biomaterial called effluent. This effluent can be utilized as a very effective fertilizer for various crops and plant life as well as a good indicator of the health of the bacteria culture. The biodigester had a pipe built into it that would release the built up effluent once it reached a certain level in the tank. The effluent needs to be drained or else the tank will fill up and overflow causing possible over pressurization. It is important to keep track of the effluent level so that the health of the biodigester is known. Besides testing the chemical properties such as pH, the effectiveness of digestion can also be assessed by analyzing the contents of the effluent.

For example a clear, odorless, liquid would indicate a healthy digestion process. It took a while for the biodigester vessel to reach the correct level of slurry in order to remove effluent, but once it did the team was able to remove about 5 gallons. This collected effluent was not as clear as expected but this was assumed to be because it was the first sample collected. Despite this, the pH level of the collected effluent was tested and found to be within the correct range

With warmer weather came an increase in biogas production. There were many factors that led to the increase in production. One suspected main factor was tightening the gas outlet and effluent pipes. These pipes were inaccessible until the construction and installation of the new roof revealed them. Another factor of the increase in gas production is an increase in regular feedings. During the winter months, access to feed and the biodigester became limited and the feedings decreased. When it became easier to travel to the biodigester and a regular feeding schedule was made, the gas production increased. An average feed consisted of nine to ten pounds of solid food and up to twenty pounds of water. Based on our calculations, we should have produced 24 gallons of biogas per feed. In our actual collections, the amount was around 10 gallons. This lack of production could have been caused by collecting the gas before the feed was fully digested or by not being able to collect all of the produced gas at once because of low pressures not forcing all of the gas out. A third factor in the biogas production was a constant temperature. Once the thermostat and heating mat and been fully calibrated, the internal temperature of the biodigester stopped fluctuating widely like it had before.



With the increasing production of biogas, the team had to quickly develop methods to collect and possibly store the biogas for extended periods of time. The first methods of collection we devised used a plastic grocery bag and a rubber band to create a gas-tight seal. This proved effective initially

when gas production was at low. The grocery bags then evolved into an 8-gallon prototype collection bag created by a trash bag, duct tape and PVC pieces. This prototype proved to be efficient at collecting gas but was not effective at storing the gas over time.

At this time, the gas production rate greatly increased causing pressure issues to arise within the system. While a pressure gauge was installed, it failed to record any readings even when there was noticeable pressure in the system. To deal with the increasing pressures, the team decided to create a larger storage bag using a larger trash bag. The volume chosen was a 55-gallon bag that proved to be somewhat successful at collecting gas for a short amount of time. After a few days the team noticed that the gas was diffusing through the bag membrane and the excessive size of the bag caused it to not fill up as quickly as anticipated because of an over estimation of gas production.

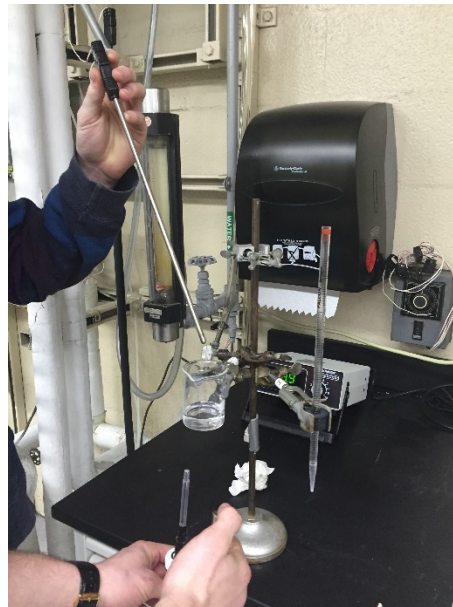


To deal with the leaking bags, the team attempted to pressurize the gas by compressing the bag in order to force the biogas into a metal tank containing a rubber bladder. This attempt failed because insufficient pressure to bypass a regulatory valve within the bladder tank. Although there was a design for a collection system designed by a member of last year's group, it was deemed to complex and did not fit our design challenge of being able to build the biodigester so that it is reproducible and cost effective.



Tests were then conducted on the biogas using an experimental setup that involved heating a known amount of water and measuring the initial and final temperatures of the water. This test consisted of burning the gas and using the heat produced by the combustion to raise the temperature of a beaker of water. The energy typically found in biogas is 80 BTU per gallon of gas. While methane has a BTU value of 133, biogas is only 600 because of the 40% that is CO₂ and does not

combust (Dana, 2010). By heating the water, we hoped to calculate energy of the gas. By knowing how much energy there was in our gas sample, we could figure out the composition of the gas. This was an important aspect to our project because we had not come up with a method to test the composition of the gas that could help determine what application the gas would be best used for. The first time the test was conducted, the results produced estimated the amount of energy produced per gallon of methane to be



about 8 BTU per gallon, which is one tenth of the expected value. This result was found to be very low with the reason being that not enough water was used causing it to boil. Once the water boiled, there was a lot of energy that was lost through the water vapor that evaporated and the phase change of water to gas. Heat loss to the atmosphere was also credited as a source of error in the calculation.

A second test was conducted with the hope to improve upon the first trial. This time the team used a larger quantity of water and a slightly more controlled version of the experiment setup. This second test yielded results that were much better than those of the first test however they were still not to expected levels. The calculated energy value per gallon of gas was now at about 20 BTU. The error in this experiment was again credited to heat loss to the environment and through the heat transfer process involving the container holding the water. Due to the fact that the container was metal, a lot of the heat from the combustion was absorbed into the container before it could heat the water. This led to our results being inaccurate because a lot of the energy could not be determined because it was not used in heating the water.

During the final presentation to the sponsor and a group of interested local community members the team was finally able to successfully use the gas as a fuel for cooking. The team adapted a grill located near the biodigester so that the 8-gallon prototype bag could easily be fitted to the burner. We compressed the bag thus forcing the gas out of the bag and through the burner where it was ignited. Once lit, a cooking pan was placed on the burner and an egg was cooked in the pan.

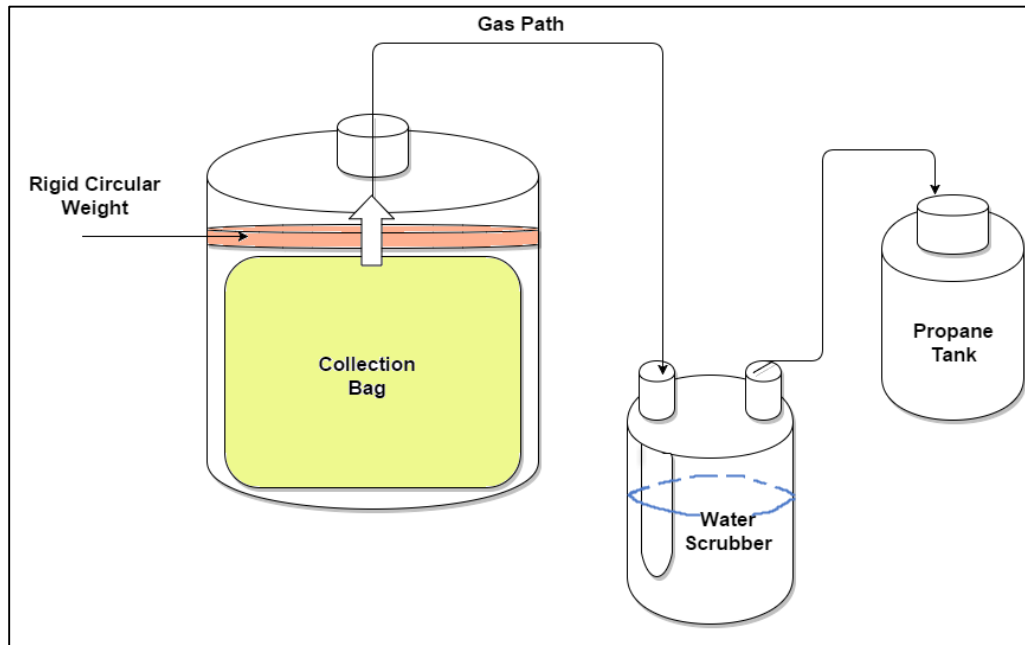


We also achieved the final goal of developing relevant operational and troubleshooting guides so that Nuestro Huerto can successfully manage the biodigester in the future. The team compiled an Operations Guide as well as additional deliverables including a Feed Data Record sheet and Scrubber Check-Up Guides. These accomplished the objective of producing deliverables capable of establishing institutional knowledge for the sponsor to ensure the future success of the project.

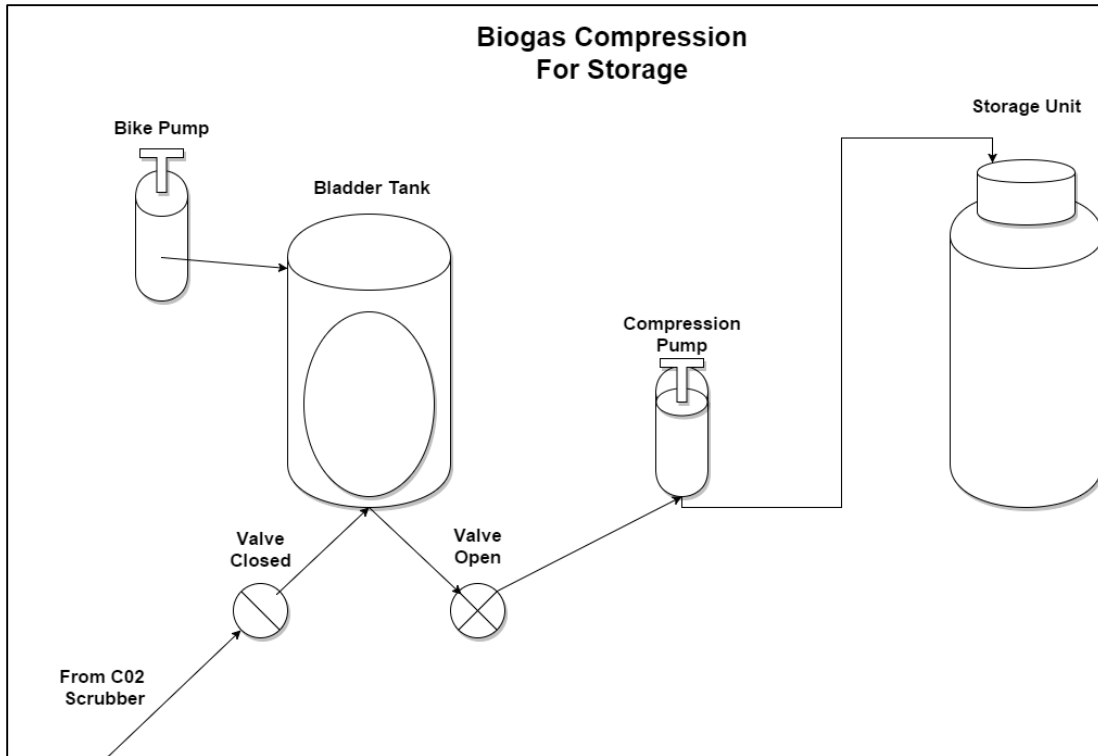
Recommendations:

1. Proposed methane compression techniques

- A. The gas collection bag can be placed inside of a rigid structure, such as a trash can, or another container with vertical sides. A weighted platform placed on top of the bag would compress the gas to levels that can allow us to move the gas into a more permanent storage vessel such as a propane or air tank.



- B. A compression pump can easily be made from a bike pump which would intake gas from the short term gas storage vessel and then compress the gas moving it into a more permanent storage vessel such as a propane tank, via the pump.



2. Nuestro Huerto should establish a feeding schedule that would maximize the production rate of the biodigester. This would be done initially through trial and error by measuring and controlling the amount of feed, number of times fed per week, temperature inside and outside, etc. We made a feeding schedule that fit our needs, but this would have to adapted based on the availability of resources in the future, such as amount of food and peoples availability to feed the biodigester. Additionally, a schedule to remove gas and effluent should be created. A form for these tasks has been made and can be found in the appendix

3. To lessen or eliminate reliance on external electrical and water input, for sustainability and financial benefit, we recommend Nuestro Huerto make use of a solar panel and rain collection system. The current method to power the heating mat uses electricity from a wall outlet. While this is a convenient and relatively cheap method for energy, it reduces the biodigester's sustainability, as it becomes reliant on a nonrenewable source of energy. Although the initial cost of a solar panel might be high, it would pay for itself eventually, as it would eliminate

electricity costs created by the heating mat. Also it is a cleaner, more sustainable source of energy than a wall outlet. This is because the electricity from the solar panel is from a renewable source and produces no emissions while the electricity from the wall comes from traditional power sources such as coal, which produce a lot of greenhouse gases. By including rain barrels, rainwater can be collected to be used for mixing the feed and for a potential CO₂ scrubber. Currently water is taken from a sink to mix the feed. This method is the only possibility for the winter months as the water from a rain barrel would freeze. However, including a barrel would make use of wasted water that would normally just fall on the ground. This method of collecting water also makes the biodigester more sustainable because it reduces water usage from Nuestro Huerto.

AUTHORSHIP

All team members added to the development of the overall outline and revision of the entire report. Justin Marsh contributed to writing and revising of the final submission, and he drew most of the diagrams included. Alex Silk helped format the final submission as well as wrote and edited particular sections. Joe Pizzuto led in outlining sections to be written and helped revise the final version. Natalie Marquardt led primarily in editing and revising the content of this submission. Most of the content was written collaboratively, by dividing each section into four parts for each team member to write. All team members have given feedback on and approved each other's work, and all agree on this final submission.

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1.0 INTRODUCTION

Sustainability, is “the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance” (Random House, 2015). Using resources sustainably is an especially important goal of small-scale organizations that farm in cities. With sustainable operations, these communities can thrive independently despite the potentially harmful impacts of their industrial surroundings. Urban farms can improve what are often degraded, compacted urban soils through application of compost and organic fertilizers created from recycling food waste; they can also use food wastes as feedstock to produce renewable energy (e.g. heat) through anaerobic digestion. This renewable energy source can help urban farmers heat greenhouses and extend the growing season to maximize crop yields. The independence gained from practicing sustainability allows urban farmers to practice and profit from their trade while being environmentally conscious and beneficial.

Nuestro Huerto is an urban farm located in Worcester, MA, founded in 2009. Their mission is “to foster community resilience by making urban food production a viable possibility for Worcester residents (Nuestro Huerto, 2009).” They grow vegetables, flowers, and herbs to sell to Worcester residents, local restaurants, and farmers markets. They hope to use the food and plant waste that they generate to produce a useable energy source in the form of methane gas and to serve as an educational example for the community. Last year, another IQP team built a biodigester for Nuestro Huerto but despite efforts to create a functional small scale biodigester, the prototype built last year did not reliably produce biogas. Nuestro Huerto wants to use food waste to create biogas, both as a means of generating usable energy, and as an educational example for the community.

The biodigester at Nuestro Huerto was built by a previous IQP team, and their design will be referred to as Phase 1. Phase 1 was incomplete, as systems for feeding and managing the biodigester,

and for capturing biogas were not established, nor were suitable educational documents about operating and troubleshooting the biodigester developed. Our task was to implement our own Phase 2 design, the intention of which was to improve the biodigester to a fully functional state, establish a means to filter and store the biogas, and an institute plan to apply the final methane gas product as an energy source to benefit Nuestro Huerto.

The first step was to study the anaerobic digestion process and the functionality of biodigesters. We then analyzed the original state of the Nuestro Huerto biodigester and made improvements to its physical structure, functionality and manageability. As part of a human centered design process, throughout this project, we took into account the resources and capacity of Nuestro Huerto to manage the biodigester far into the future.



Figure 1: Greenhouse at Nuestro Huerto

This project established a solid understanding of how biodigesters function, which will be discussed in the background section, and then applied that knowledge to the Nuestro Huerto biodigester. First we assessed the site needs and needs of the sponsor. It was important to research

similar biogas operations in order to achieve a working knowledge of the system. In addition to this, we implemented useful problem solving techniques in order to improve efficiency of communication within the group as well as with the sponsor. Personal communication and conversations were vital in creating a process that can be sustained by this community, fits their lifestyle, and will provide them with long-term benefits. Finally, we applied appropriate solutions through human centered design, experimentation, assessment, and modification.

2.0 BACKGROUND

2.1 Urban Agriculture

The Food and Agriculture Organization (FAO) of the United Nations defines urban agriculture as “the growing of plants and the raising of animals within and around cities” (FAO, 2014). It is an industry that creates fresh, locally grown produce in an urban setting. The practice generally involves large communities, and greatly impacts these communities and the urban area as a whole (Ringebach, Valcourt, & Wang, 2013). Urban agriculture is practiced in many countries around the world, however it is increasing in popularity in the United States. Urban agriculture in the US is tied to de-industrialization. In the 1970’s, the practice of offshoring factories became very popular among American manufacturers (The Week, 2011). Factories that once used land and provided jobs in American cities began to migrate to Mexico and Asia. This migration produced abandoned lots and unemployed workers. From these abandoned lots a new, community-driven practice emerged, as community gardens took root in these vacant lots. These smaller gardens quickly evolved into larger urban farming initiatives, producing fresh food for local residents to consume or sell for a profit (Philpott, 2010).

Between the 1970’s and today, local and national programs have been established to help promote urban farming, such as Growing Power, the national leader of the “Good Food movement” (Growing Power, n.d.). Existing programs have also expanded their interests to include urban farming, such as the United States Department of Agriculture (USDA, “Urban agriculture” n.d.). Modern urban agriculture in the US has become a multifaceted practice, with various styles and levels of success, including small-scale community gardens for personal consumption, and larger farming initiatives that are run like businesses for profit.

There are several obstacles that make urban farming difficult. Urban farms are much smaller and denser than rural farms, as large open spaces are scarce in cities, and most urban farmers are compelled to grow their food on small plots of land that they do not own (Mougeot, 2000). Land

availability and land tenure are major constraints but urban farmers face additional challenges as well. In highly industrial environments, soil can be prone to contamination, making crops grown in these conditions prone to health risks from contaminant uptake (Ringebach, Valcourt, & Wang, 2013). In temperate climates, especially continental climates (climates with considerable variation in temperature which typically occur in northern Asia and North America), little work can be done during the winter months (A. Barker, personal communication, Sept. 16, 2014). Additionally, in drier climates, watering crops can become difficult, especially in dense arrangements, as plants are forced to compete for resources (Ringebach, Valcourt, & Wang, 2013). Moreover, many cities also have laws and regulations that can inhibit urban agriculture. For example, a 2013 zoning policy in Philadelphia that restricted the use of commercially zoned areas put 20% of Philadelphia's existing urban farms and community gardens at risk due to zoning conflicts of having agricultural plots in commercial areas (McGoran, 2013). All of these challenges work to hinder the growth and practice of urban agriculture, however, there are many other factors that are favorable.

There are several organizations across the country, and even some international organizations, that work to promote urban agriculture in American and international cities. Sharing Backyards is a Canada-based organization that links people who would like to grow food in an urban setting with people who have unused space available for farming. By helping to foster a productive relationship between farmer and land owner, Sharing Backyards achieves their goal of "every single person who wants to garden, can garden." This organization not only operates in Canada, but also in the US and New Zealand as well (Sharing Backyards, n.d.). Another organization that promotes and aids the urban agriculture community is Food Field. Located in Detroit, Food Field promotes urban agriculture by setting environmental, social, and economic goals to strengthen the community and the success of their operations (Food Field, n.d.). In addition to private organizations, governments can also help to promote urban agriculture. The city of Chicago, for instance, specifically amended their zoning laws to allow more

community gardens and urban farms, as well as helping to integrate them with the community by minimizing potential negative impacts on the surrounding neighborhood, such as conflict within industrial and commercial zones (City of Chicago, 2015). Even internationally, the FAO recognizes the importance of, and supports the integration of urban agriculture, with programs in Burundi, Colombia, Guatemala, Namibia, Venezuela, and many other countries (FAO, 2014).

There are many reasons that an urban agriculture initiative may exist in an area, as the practice has many benefits. Urban agriculture increases the availability of access to healthy food, and increases food security (FAO, "Urban agriculture"). It also provides education about agriculture to people who would otherwise have no experience with the process (Ringebach, Valcourt, & Wang, 2013). It not only provides healthy food for the growers, it is also an industry that generates tens of millions of dollars yearly as income for urban farmers (Mougeot, 2000). Farmers' markets are becoming increasingly popular, and are an excellent way to provide income to farmers, and to share locally grown food with the community, increasing their access to fresh and healthy produce (FAO, "Urban agriculture"). Finally, it also promotes the ideals of sustainability within the community, by recycling waste, utilizing otherwise empty space, and distributing food without wasteful packaging or transportation expenses (Ringebach, Valcourt, & Wang, 2013).

One of the less obvious impacts that an urban farming initiative can have on the larger urban community is innovating new ways to be sustainable. One such way of promoting sustainability is the practice of using biogas as an alternative energy source. This process is particularly conducive to farms, as they tend to have access to large quantities of food and plant waste. The use of methane as a means of producing energy can be traced back to 17th century England, but it wasn't until the early 1930's that the technology boomed and researchers rapidly expanded methods of creating biodigesters to safely produce and capture biogas. Many reports of small scale biodigesters have been documented from

developing countries starting from the 1970's. Numerous advancements have been made since then, contributing to the modern practice of biogas production (Sasse, 2013).

2.2 Biogas and Biodigesters:

2.2.1 Biogas:

Biogas is a gas mixture containing roughly 60% methane (CH_4), 40% carbon dioxide (CO_2), and trace amounts of hydrogen sulfide (H_2S) and hydrogen gas (H_2). Biogas is the main product of an anaerobic digestion process, which involves four stages (Dana, 2010). These stages are shown in Figure 2. The first stage, hydrolysis, is where enzymes begin to break down larger polymers and molecules such as proteins, carbohydrates and fats from the feed, into amino acids, sugars, and fatty acids. This leads into the second stage of the process, acidogenesis. During this stage, the products of the hydrolysis stage are converted to volatile fatty acids and alcohols. In the third stage of anaerobic digestion, acetogenesis, bacteria break down these volatile fatty acids into acetic acids. The final stage of the process is methanogenesis, in which acetic acid is converted into the final products of methane and carbon dioxide (Kim, 2012).

One of the most important factors in anaerobic digestion is temperature. The temperature in the digester will determine what type of bacteria will grow and the rate at which they will produce biogas. There are two different types of bacteria that can drive the process of anaerobic digestion. The first type of bacteria is called mesophilic bacteria. These bacteria prefer temperatures around 35 degrees Celsius. The other type of bacteria are thermophilic bacteria. Thermophilic bacteria prefer warmer temperatures nearing 55 degrees Celsius. Thermophilic bacteria are very specialized and can become unstable if the operation conditions are constantly changing. On the other hand, mesophilic bacteria are more resilient to changes in operating conditions (Kim, 2012).

Another major difference between the two types of bacteria is the fact that thermophilic bacteria have a faster reaction rate than mesophilic bacteria. This means that the thermophilic bacteria can digest more influent matter than mesophilic bacteria. Under thermophilic conditions, it takes about four days to generate gas, depending on the feed material. Using mesophilic conditions, it will take about 17 days to generate a similar volume of gas (Kim, 2012).

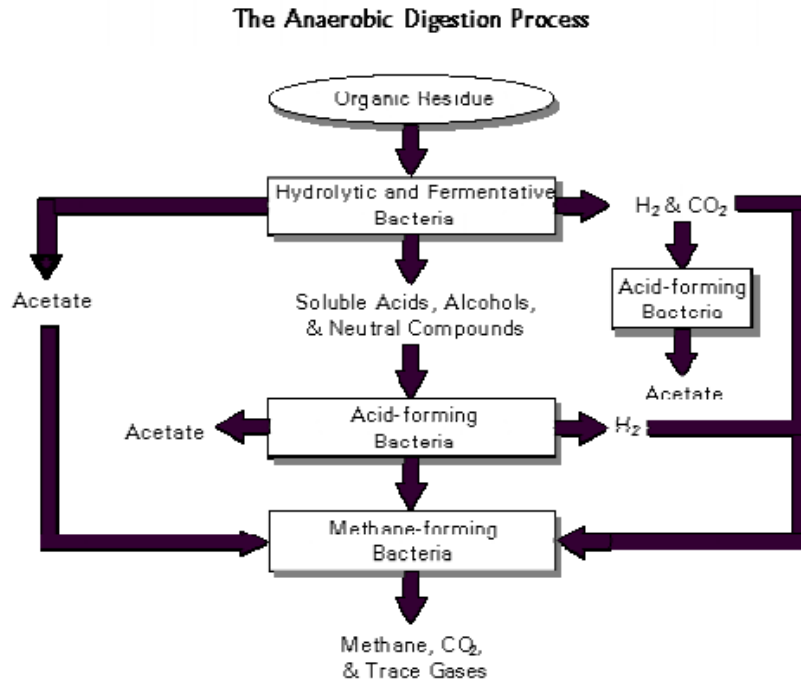


Figure 2: Anaerobic Digestion Process (Gunaseelan, 2004)

Because of the mixed composition of the biogas the methane must be separated from the other gases in order for it to be used effectively. If the hydrogen sulfide is not removed from the biogas, it can lead to the corrosion of tanks and equipment that are used to collect and utilize the gas. Also, burning biogas with hydrogen sulfide will create sulfur dioxide as a byproduct, which is environmentally hazardous. Hydrogen sulfide is commonly removed by using iron oxide. The iron atoms in the iron oxide binds with the sulfur atoms in the hydrogen sulfide, creating iron sulfide on the surface of the iron in addition to water vapor. In small biodigesters, iron oxide is usually used in the form of iron shavings or steel wool that the gas flows through for filtration (Inthapanya, 2013).

Like hydrogen sulfide, carbon dioxide is another gas that needs to be removed in order to have a more pure methane product. Methods of removing carbon dioxide include physical absorption using water, chemical absorption using basic compounds, adsorption on solid surfaces, and membrane filtration (Kapdi, 2005). If carbon dioxide is not removed from the biogas, it will not burn as effectively as it would without the carbon dioxide (Dana, 2010).

2.2.2 Biodigesters:

Small scale biodigesters are used around the world to produce low cost, sustainable energy. They are commonly used in developing areas such as India, Africa, and other countries in Asia and South America where traditional energy sources are expensive or unavailable. Biodigesters can also be useful in urban agriculture, as a potential source of clean, sustainable energy. Biodigesters are also being used more frequently in developed countries where people are trying to live greener lives and be more sustainable because they are less expensive than traditional energy sources and use easily available materials.

One challenge in using biodigesters is collecting the generated gas. Because of methane's physical properties, it would be too costly and not feasible for urban agriculture groups to liquefy the biogas like traditionally done with propane. One method to capture the gas involves using large bags, which take up a lot of room and are prone to leaks (See Figure 3). A benefit to this method is that it is simple and one can see how much gas has been generated. Another way to capture the gas is to store it in a floating water drum (See Figure 4). Some positive aspects of this method are that it is easy to see how much gas has been produced, and it can be easily pressurized by adding weight to the top of the drum. A problem with this method is the water in the drum can freeze at low temperatures and it is possible to spill and lose the collected gas. A third method to contain the gas is to pressurize it in a tank

and then transfer the gas into a propane tank. This process takes more work than the other methods and involves equipment that is not easily accessible.

One important part of the biodigester's operation is the feed used, or the organic material to be broken down by the bacteria culture in the anaerobic digestion process. This organic material can vary from animal manure to ground up fruits and vegetables (Gunaseelan, 2004). Feed can be categorized as either wet or dry, based on its aqueous percentage of the final mixture, also known as slurry. A feed with 15% or more solid organic material is considered "dry" and is only considered an option in small scale biodigesters. Since wet feed exposes more surface area to the bacteria culture, it is the more productive method of feeding a biodigester, but is not always applicable in barren environments (Weiland, 2010). In order for a biodigester to produce the most methane that it can, the feed must have a high concentration of volatile solids. A report from Gunaseelan (2004) reflects on the potential methane yield from differing fruits and vegetables for a large scale biodigester. These numbers can be easily translated to fit our small scale design when calculating our potential yield as well. A reference to the table (Tauseef, 2013) can be found in the appendices. This report shows that citrus matter contains the highest percentage of volatile solids and would allow for the highest methane production. On the other hand, cellulose based organic material such as tree leaves and celery produced the least amount of methane because of their low percentage of volatile solids (Gunaseelan, 2004).

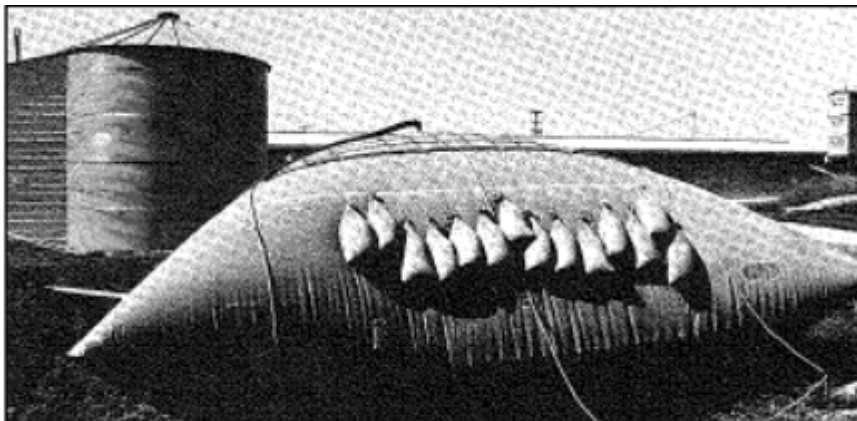


Figure 3: Large Bag Style Digester (Weiland, 2010)

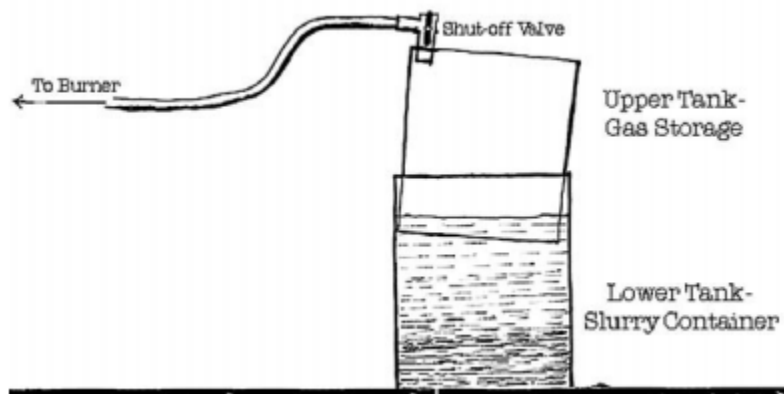


Figure 4: Floating Drum Collection (Dana, 2010)

The amount and type of feed will ultimately determine how much gas can be produced.

Depending on the setup, energy may have to be used to maintain operation, in the form of heaters, feed mixers/grinders, electrical pumps, etc. It is essential that the amount of energy produced by the digester is greater than what is used to produce biogas, otherwise, it results in a net energy loss. In order to make sure a biodigester operates efficiently and maximizes the energy gain, all components of its operation must be assessed and implemented in a cost-effective manner.

2.3 The Nuestro Huerto Biodigester

2.3.1 Potential benefits

The use of a biodigester at Nuestro Huerto provides a number of benefits for the local Worcester urban agriculture community. These benefits include reduction of food waste, renewable energy production, and education opportunities. Resources required to run a biodigester include an abundance of organic material and a means of constant high temperature, two things



Figure 5: Initial state of biodigester at site

Nuestro Huerto can easily produce without any real negative impacts on their operations. In fact, collecting organic waste from the community is a benefit in and of itself, as this waste will not contribute to landfills or greenhouse gas emissions. The biodigester's byproducts can also be used to improve plant growth at Nuestro Huerto. Digested feed from a biodigester will eventually need to be extracted from the mixing tank to make way for new feed to be added and digested. This digested feed, or effluent, retains properties that make it an excellent fertilizer for plant growth. In addition to this, the carbon dioxide scrubber produces a renewable resource as well in the form of CO₂ rich water that can be used to further aid plant growth. With two instances of plant growth acceleration as well as a positive yield of energy, the biodigester benefits suit Nuestro Huerto and their self-sustainability mindset.

By using food waste to generate gas, biodigesters will help keep groups practicing urban agriculture sustainable and efficiently using food scraps and other plant waste as fuel for the digester. This helps limit the contribution to the use of landfills and other waste management sources. Another

advantage of biodigesters used in urban agriculture is that a byproduct of the process is a liquid fertilizer, which helps to reduce reliance on fertilizers produced from unsustainable means. This fertilizer is nearly odorless and does not attract insects and pests, unlike traditional compost fertilizers. A third advantage to using biodigesters is that it limits the amount of methane that would be released to the environment. By using composts, the natural digestion of the food waste creates methane that goes directly into the atmosphere as a greenhouse gas. However, by using a biodigester, that methane is being used and burned, and is not released into the atmosphere as a pollutant. Another byproduct of biodigesters that can be helpful for practitioners of urban agriculture is a carbon dioxide enriched water source. In systems that use a carbon dioxide scrubber, water that has been saturated with CO₂ becomes a byproduct. This enriched water has been shown to improve plant growth compared to watering plants with non-carbonated water (Enoch, 1992).

2.3.2 Adapting the Phase 1 design

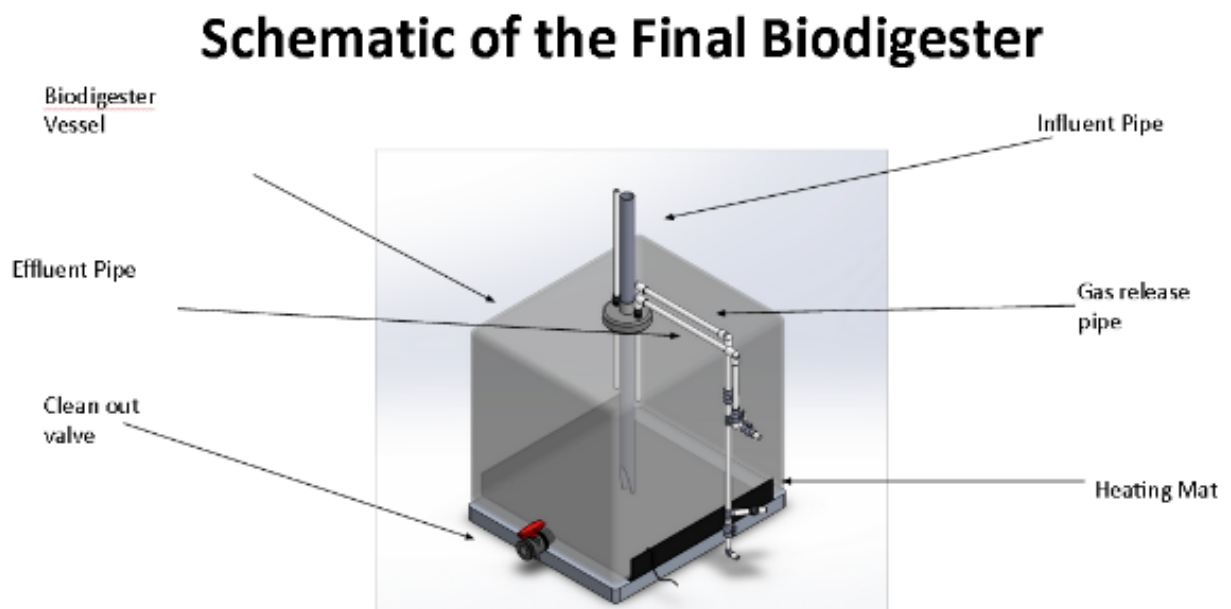


Figure 6: Solidworks rendering of digester piping, Phase 1

The biodigester located at Nuestro Huerto was built to operate as a small scale biodigester and to produce enough methane gas to heat the greenhouse on site at Nuestro Huerto in late March to provide a suitable environment for seedlings, ultimately extending the growing season. The final schematic of the Phase 1 biodigester built by last year's team can be seen in Figure 6.

The biodigester vessel that holds the food waste slurry is just a simple, plastic tank. The influent pipe, or feeding tube, goes all the way to the bottom of the tank to ensure that the slurry is fed from the



Figure 7: Inside the biodigester box, mid Phase 1

bottom which is a key aspect to the design. This is important so that the new, undigested influent is added below the more digested slurry. Eventually when the influent or slurry has become fully digested, it will rise to the top of the tank, where it can be removed through the effluent pipe. Another characteristic of this feed tube design is an easier removal of the methane gas from the digester tank. With the influent being added at the bottom of the digester tank, it will force the methane gas gathering in the space above the slurry out of the tank through the gas release pipe that is labeled on the model above.

Despite these numerous benefits of the design for the influent pipe, there are possible drawbacks to the design as well. The main drawback is that the influent tube may be clogged by larger parts of solid food waste at the very bottom of the tank. This buildup could result in a thick sediment at the bottom of the tank that may be difficult to remove, even if the drain valve is opened, as well as limit the efficiency of the digestion process.

As mentioned previously, temperature is a vital part in the anaerobic digestion process that is taking place inside the digester vessel. In order to ensure easy maintenance of the proper temperature, the Phase 1 biodigester included a heating mat that is located underneath the digester vessel. To control the temperature of the heating mat and thus the tank and its contents, the Phase 1 team installed a thermostat that is wired to the heating mat. Along with the heating mat, another important aspect of temperature control is insulation or heat retention of the box that contains the digestion tank.

To deal with the problem of insulation, the Phase 1 team coated the inside of the box that contains the tank with R19 fiberglass insulation. This provided an insulated base for the box, on all of its sides. In addition to the insulated wall material, the group stuffed the open space between the tank and the sides of the box, including the roof, with fiberglass insulation. On top of the fiberglass insulation the



Figure 8: Insulated collection space, Phase 1

group stapled a thermal-heat shield to add even more heat retention to the insulation system. The insulation inside of the biodigester box can be seen in Figure 8 (K. Gagnon, S. Peoples, C. Bloniasz, personal communication, September 20, 2014).

The Phase 1 team concluded their work on the project by building the biodigester as well as inoculating the anaerobic digestion process inside of the tank, by introducing bacteria to hopefully produce some methane. Although they had no way of collecting any of the gas, the team managed to fill the tank with a slurry composed of 65 pounds of cow manure and 193 gallons of water. This slurry provided the necessary fuel and the live mesophilic and thermophilic bacteria required to digest it. After introduction, either a mesophilic or thermophilic culture would develop from the slurry. In addition, the Phase 1 team was able to compile technical guidelines for how the biodigester should be fed and with what feed. They calculated that the influent should have an approximate composition of about 79% of volatile solids per gallon of water (Gagnon, Peoples, & Bloniasz, 2014). They also presented calculations to find the percentage of volatile solids in a given feed source as well as a table of various feed materials and their volatile solid percentages. All of this information and more on how to restart the digestion process and how and what to manage and monitor in the system at Nuestro Huerto can be found in the Operator's Handbook (Gagnon, Peoples, & Bloniasz, 2014).

The challenge presented to our team on the project was to continue where the Phase 1 team left off. During Phase 1, the sponsor's goal was to produce the methane and use it as an energy source to heat its greenhouse in order to help germinate and grow seedlings in the spring. This goal was revised to first make the biodigester operative and then to focus efforts on capturing and storing methane in a viable, safe, and sustainable way. The sponsor also stated that if it is deemed impossible or unsustainable to properly heat the greenhouse, then the use of the methane could be applied to another task and the biodigester could primarily serve educational purposes as an operating prototype for others in the local area of Worcester.

3.0 DESIGN CHALLENGE

To begin our project, we formulated a design challenge: How can we further develop the biodigester's operation in order to produce a viable product while keeping the needs, hopes, and aspirations of Nuestro Huerto in mind? To answer this question, we looked at several factors that could improve the biogas production, including the type of feed, feeding methods, and advancements that could be made to improve the Phase 1 structure and the internal digestion process, as well as ways to test the products created by the biodigester, to confirm that we have achieved our goal.

3.1 Human Centered Design

To help us focus the project on the end-user and their experience, we used a method known as Human Centered Design. Human Centered Design involves using techniques and strategies to successfully develop solutions, with the human user in mind. This process involves three lenses of focus: desirability, feasibility, and viability. Desirability takes into account what is wanted by listening to the needs of the people. Feasibility organizes what is and what is not technically possible. Viability considers what is financially reasonable for the project. The goal of this Human Centered Design process is to overlap all three lenses and fulfill the design challenge (Human Centered Design Toolkit, IDEO).

At the very beginning, it was important for our group to identify what the sponsor was hoping to achieve as a result of the project. In order to fully understand the challenge presented by Nuestro Huerto, a meeting was held at the site of the biodigester with the sponsor representative, Amanda Barker. During this meeting, Ms. Barker was asked what her vision for this project was. She described how she wanted to see the biodigester fully operational. Her goal was to extend their growing season by heating their greenhouse in late winter months to allow for seedling growth. In order to properly grow seedlings, the greenhouse would have to be around 32°C during the months (late February - early March) when growing begins. However, based on the results of the Phase 1 IQP, it was unclear whether

or not this would be a plausible objective. Regardless, Ms. Barker expressed her wish to create biogas, and to use it in any way that could be helpful to their operations. Other options presented to us, in the event that the greenhouse could not be heated adequately or when the greenhouse does not need to be heated, were to use the gas as fuel for cooking on a grill or to produce electricity with a generator.

Additionally, Ms. Barker expressed her wish that the operation of the biodigester contribute to the sustainability of their farming practices. Because the biodigester requires a constant temperature, a heating source was needed, especially in the winter months. Ms. Barker wanted us to use as little energy as possible while heating the biodigester. Another constraint that results from the cold climate of New England, is the fact that no water outside of the biodigester vessel can be utilized due to freezing conditions, therefore limiting various collection and filtration methods that involve water. An additional request from Ms. Barker was to keep the biodigester as simple as possible to ensure that anyone would be able to operate it. The size of the Phase 1 biodigester box was also to be maintained into Phase 2, prohibiting any possible space additions.

One specific practice taken from the Human Centered Design Toolkit (IDEO 89) was “empathetic design.” This includes the development of a positive relationship to increase the likelihood of a successful project outcome. The idea behind this approach is to obtain a deep understanding of what feelings and ideas the stakeholders have regarding the project, in order to engage them into a co-design process. This allowed us, as the design team, to become straightforward and transparent with the sponsor about our ideas, data, and overall level of success throughout the duration of the project, and get appropriate feedback from them to integrate their ideas. One very important way that we achieved this with our sponsor was with the use of prototypes, in the forms of models and sketches. These prototypes created a tangible medium for us to discuss ideas with the sponsor. Together using the prototypes, we could visualize the ideas, allowing for easy understanding, critique, and adaptations of each idea, before final implementation of the collaborated result.

Our sponsor had expressed a desire for the creation of durable institutional knowledge, so that the project can continue to run and benefit the urban farm community however it may evolve in the future. It is necessary that the knowledge to maintain the project does not rely on one singular person, but rather on the community as a whole, so that as community members come and go, the project can remain as productive and educational as possible. The use of sketches was essential in accomplishing this goal and these were compiled into the operations manual, which aims to educate individuals about the biodigester processes as well as aid the facilitation of its future operations. For the operations manual to be effective, the Human Centered Design approach was instrumental. Ms. Barker relayed to us that she wanted it to be very simply written and easy to follow by someone who may have almost no previous knowledge of the biodigester system. After meeting with our sponsor, we turned our attention towards the biodigester itself.

3.2 Initial Assessment

When our team arrived in early September to see the biodigester, the heating mat had been turned off, the feed cap was open to the atmosphere, and inside of the biodigester vessel was roughly 200 gallons of stagnant slurry used by the Phase 1 team in an attempt to begin a bacteria culture in the spring of 2014. From last year's report, we ascertained that the contents of the slurry were a mixture of about 65 pounds of fresh cow manure and 193 gallons of water (Gagnon, et al, 2014). The gas collection sub-system of the biodigester had not been created and the biogas outlet pipe was closed with a valve. The roof of the biodigester box had been severely damaged from inclement weather over the summer months and was sagging in the middle near the location of the feed tube. The insulation had



Figure 9: Damaged old roof

also suffered serious water damage and needed repairs as well. However, the most pressing task was to reboot the anaerobic digestion process inside of the digester vessel, which had slowed to a stop. This began with feeding the biodigester and making improvements to the feeding process.

3.3 Development of the Biodigester Feeding Process

In order to restart the bacteria colony established in Phase 1, we began feeding the biodigester food scraps that we collected from the compost pile near the biodigester. These included rotten fruits and vegetables, other food scraps, and brewery spent grain (BSG). To begin feeding, a process had to be developed to reduce the food waste to small chunks that would fit down the feed pipe without clogging. Different methods of chopping were considered, including food processors, hand-powered meat grinders, and drill bit attachments. While these options are feasible, none of them were deemed



Figure 10: Initial feedings with funnel

suitable due to their reliance on added electricity and concerns about reproducibility. As an alternative, we experimented with manually chopping with various tools, such as shovels, hoes, and pitchforks. It was found that a flat hoe worked the best, however it still left some larger chunks, mainly orange peels that could not be completely cut or mashed up.

As the fall season came to an end, new problems in the feeding process were revealed. The winter months proved to be difficult for feeding the biodigester because of a couple of issues. Due to intense weather conditions, it was difficult for our team to travel to the biodigester and feed it on a regimented schedule. For part of the winter, the biodigester

could not be reached, due to the amount of snow that had accumulated surrounding it, even when

travel to the site was possible. In addition to not being able to access the biodigester, the amount of food waste available for feeding had decreased. During the warmer farming season, there was a lot of available food waste in the form of rotten fruits, vegetables and fresh compost materials. The cold temperature froze the primary source of biodigester feed in the form of fresh compost, extremely limiting the amount of feed available throughout the majority of the winter. The decrease in the number of feedings and the amount of available feed lead to decreased gas production to the point where essentially no gas was being produced. This caused us to realize how important consistency and size of the feedings are to the biodigester's production.

Once we returned to feeding the digester regularly, the problem of how to estimate gas production potential needed to be addressed. In order to properly estimate how much gas would be produced, the weight of the feed must be known. In the beginning of the project, we did not have access to any sort of scale and just fed the biodigester everything we had without knowing the actual amount, and therefore had no means to calculate gas outputs in relation to food inputs. This restricted our ability to evaluate potential uses of the gas for heating purposes, as we did not know what the production rate would be. This also limited the reproducibility of the biodigester, as we could not make recommendations on how much feed could optimize the system. Eventually we acquired a scale through our sponsor in order to compare theoretical to experimental gas production rates. We determined that on average we would feed the biodigester a 4-gallon mixture comprised of approximately 9-10 pounds of miscellaneous solid food waste and 20 lb. of water each feeding.

Because of the design of the feed tube, it was difficult to lift the 20-30 pound bucket to the top of the tube without spilling or having to climb on top of the roof in order to feed it. Standing on top of the roof presented safety concerns as it did not feel sturdy enough to hold too much weight, and was also slippery when wet. In addition to the feed tube being placed in an awkward position, it did not initially have a cap after Phase 1.

3.4 Improved Roof and Heat Retention

With winter approaching and the roof in bad condition, we decided that a new roof had to be designed and built. The main issue with the Phase 1 roof was its inability to keep water out of the insulation surrounding the vessel and piping. Fiberglass insulation is rendered ineffective when wet, meaning that heat could easily escape through the insulation and roof. Mold had also begun to grow in the insulation directly surrounding the feed tube, which began to smell and further limit the insulation's heat retention ability. We assessed the issues with the roof and concluded that the fact that it was flat allowed water to accumulate in the middle and caused sagging. In addition, the Phase 1 roof was poorly waterproofed. A single sheet of roofing paper with an unreinforced flap for feed pipe access provided no sort of moisture defense.

Before designing and installing a new roof, we needed a temporary fix to protect the biodigester box from further water damage. Phase 1 had left a tarp covering the roof, but it was worn out and ripped at the corners. We purchased a new tarp that was specifically designed for long term outdoor use and screwed it to the sides of the biodigester box to keep it in place. This was not enough to fully fortify the biodigester against the weather, but it was enough to reduce its impact until we could implement a more appropriate, permanent solution.

After researching different designs and styles of roofs, a decision matrix (see Fig.11) was created in order to analyze the most viable roof design option. We weighed each factor with respect to the importance of its impact on the final result of the design. A scale of 1-10 was used to represent the desirability of each factor of each design. The value of 10 represents the ideal situation and the most positive impact, while a 1 represents the least positive impact. Ensuring the digester could be safely and easily fed was the forerunning factor of our roof design decision. With this in mind we set the "Feed Accessibility" factor with the highest weight and chose the "Cost" factor to be the lowest weight since all

three design options would roughly result in the same amount of material used. The factors and their respective weights along with each design's score can be seen below:

		Designs		
		A-Frame	Inclined	Flat
Factors	Factor Weight	Score / 10		
Simplicity	0.25	4	6	9
Feed Accessibility	0.35	5	7	4
Climate Defense	0.25	9	8	2
Cost	0.15	4	8	9
Total	1	5.6	7.15	5.5

Figure 11: Design matrix for roof design

The decision matrix showed that the inclined roof design would be the most feasible option. We began the development of the roof with simple sketches showing size and shape. We then evolved these sketches to show more detail such as support for the roof and materials needed for the construction. With the inclined roof design, there were two possible ways to access the feed tube. The first being a flap cut into the roof and the second being a chimney style feed tube through a hole cut in the roof. We took these ideas and schematics to Ms. Barker, and together we analyzed and evaluated them collaboratively. After discussion, the inclined roof with a chimney style feeding tube was chosen as the final design of the roof. Once the materials were acquired, the roof was constructed using plywood and 2x4s. A plastic waterproof lining was wrapped around the exterior to increase the roof's weather defense. After the lining, corrugated steel was drilled into the top using self-tapping screws. The layers overlapped going up the incline of the roof, to ensure rainwater would flow smoothly off and not seep into the lining or plywood. Creating a hole for the feed tube presented a challenge during the construction. The team decided it would be best to drill the hole using a metal hole-saw bit that was slightly larger in diameter than our feed tube to make sure the chimney would fit. When attempting to

drill the hole, we depleted two drill batteries and over-heated a wired hammer-drill with no success of boring a hole. We finally created the hole by taking metal snips and cutting around the desired outline made by the hole-saw bit. In addition to replacing the roof, we replaced old the ineffective insulation. An image of the Phase 2 roof can be seen with Figure 12.

3.5 Maintaining Mesophilic Conditions



Figure 12: New roof implemented with chimney style feed tube

The bacteria that live inside of the biodigester vessel require a very specific environment, with the most important factor being the temperature. The condition of the open feed tube, left by Phase 1, was concerning because of the amount of heat that was lost through it. In order to fix this problem we installed a removable PVC cap on the open end of the feed tube. This helped with heat retention within the system by limiting heat loss through the open end of the feed tube. The feed tube was located next to two open holes that, in Phase 1, were intended to be used for an internal heat source (heating coil) and a manometer or pressure column to measure pressure inside of the system. We determined that these access holes would not be useful, as the heating coil was redundant with the heating mat, and the planned manometer would be inaccessible in that location, so they were not going to be useful, and

capped them as well. This was to further improve heat retention, as well the elimination of oxygen in the system, another important aspect of the bacteria's environment.

To determine the temperature of the biodigester, we needed to install a thermometer. Initially, we obtained a thermometer that could read temperatures of two separate locations. This was useful because it allowed us to know both the internal temperature of the biodigester vessel as well as the temperature of the outside environment. Knowing this allowed us to see how well the insulation worked to retain the heat as well as whether the temperature was ideal for the bacteria. The thermometer showed us that the biodigester was running at over 150 degrees Fahrenheit, and that the thermostat that controlled the heating mat was not accurate. This thermometer did not last very long due to humidity and orientation issues causing it to break. Being in a horizontal position for too long caused the fluid inside to give inaccurate readings. A better solution was needed, and research efforts were directed to find the thermometer that would best fit our design challenge. A thermometer was found that fit our financial constraints and could record temperatures over extended periods of time.

The new thermometer was attached to a thin metal wire and placed inside the feed tube. The team believed that this was the best spot as we could directly see the temperature of the slurry inside the biodigester vessel. Over a period of a few months, the thermostat was slowly dialed in and the temperature readings stabilized. This was difficult as the winter months began and the outside temperature was continuously dropping. This can be seen in Figure 14.



Figure 13: Final thermometer design attached to feed tube cap

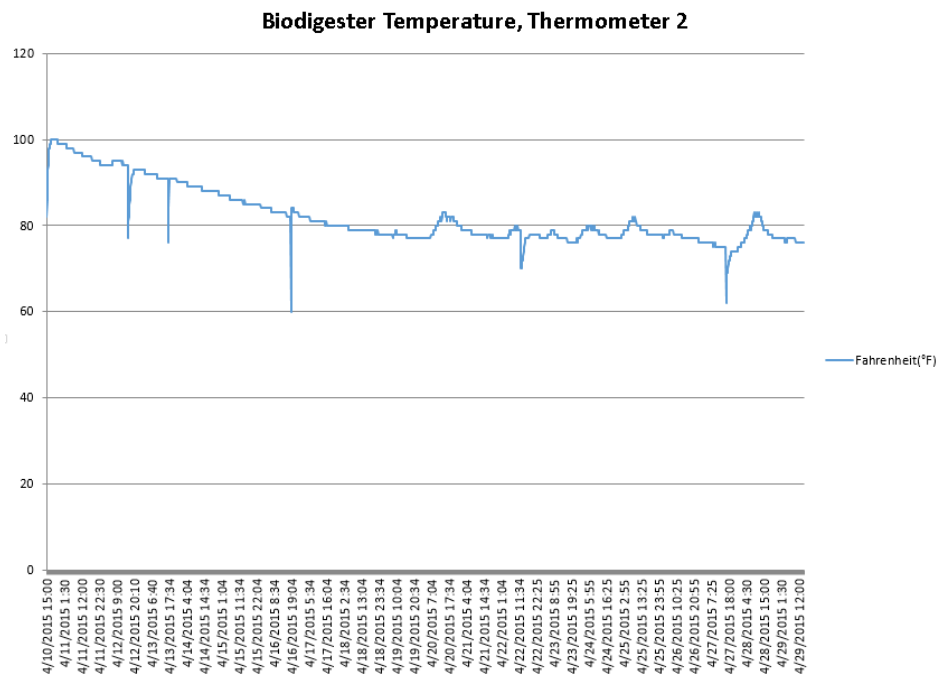
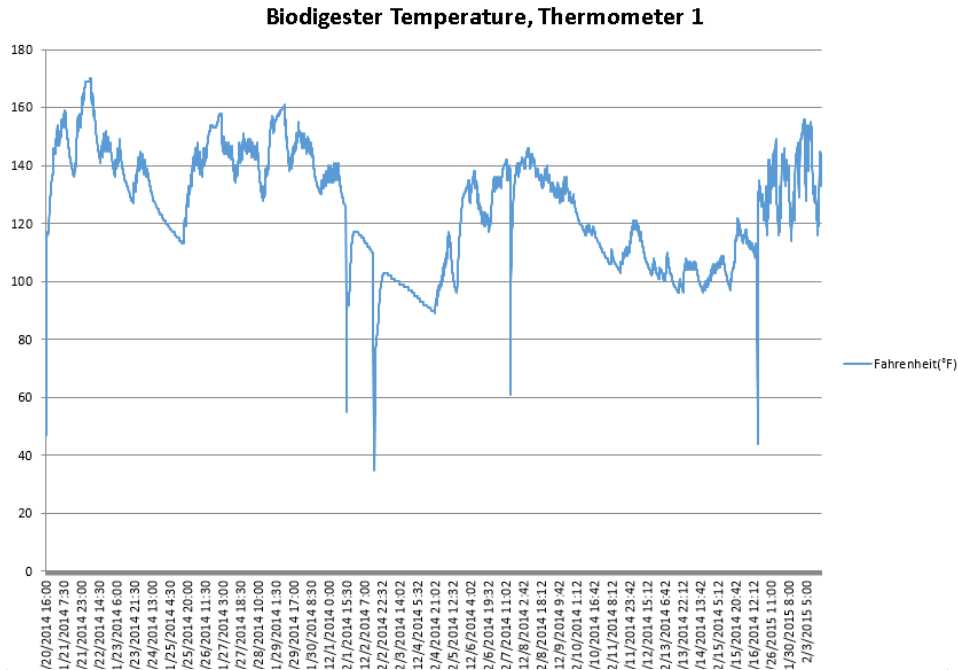


Figure 14: Dated thermometer readings

Also shown in the graph are brief and sudden dips that are caused by the times that the thermometer was removed from the biodigester, while we extracted the data from it. This continued until the battery (which was supposed to last for a year) unexpectedly died, causing a gap in the data. Additionally, shortly after the battery was replaced, the thermometer was accidentally lost inside the biodigester,

causing another gap in the data. During a feeding, the thermometer was not removed beforehand, and ended up being pushed down, irretrievably into the tank, along with the feed.

Once a replacement for the second thermometer was purchased, a new method of putting the thermometer inside the biodigester was needed, so that the same mistake would not be repeated. To keep the thermometer from falling into the biodigester again, it was attached to a PVC pipe, which we permanently fixed to the cap. This way whenever the cap is taken off, the thermometer comes out, and when it is put back on, the thermometer is returned. While the data was steadier once the second thermometer was installed, the temperature began to decline. This could have been caused by the heating mat being unplugged. The thermostat also may have turned off the heating mat since it is reading the temperature of the area around that biodigester tank, which had increased due to warmer spring weather, and not inside the tank, where the thermometer is located.

Another condition that needed to be maintained for a healthy bacteria colony was the pH level. To check the pH level of the biodigester, a pH test strip was used in the effluent from the biodigester. Because effluent was only collected once, the pH was only tested once. The strip showed that the biodigester was at a pH of 8, which is right in the middle of the desired 7.5-8.5 range. Once these conditions were met, the biodigester began producing a reliable source of energy.

3.6 Cleaning Biogas and Maintaining Pressure

Purifying the biogas is an important step that must be completed before it can be stored or used. The two main ways this can be done is by scrubbing, or removing, the hydrogen sulfide (H₂S) and carbon dioxide out from the biogas. The removal of these gases can be done using filters, before the gas is collected for use or storage.

The first filter we focused on implementing was the hydrogen sulfide filter. The reason behind this was because removing hydrogen sulfide is more critical to the collection process due to its corrosive properties. The reduction of carbon dioxide simply allows more gas to be stored in a smaller area, since

its percent methane will be increased. The H₂S filter uses steel wool to remove the H₂S from the biogas, as described earlier in the background section. The removal of this compound serves two main purposes: to reduce the odor of the gas and to reduce its corrosive properties. The two options for the filter casing came down to a glass jar and a PVC casing roughly 8" in diameter. Our weighing of the options can be found below in another decision matrix below where the factors were assigned weights based on the importance of the factor to us and our sponsor. The designs were then scored in each factor based on a



Figure 15: PVC H₂S filter

scale of 1-10, exactly like the decision matrix created for the analysis of roof designs.

		Designs	
		Glass Jar	PVC
Factors	Factor Weight	Score / 10	
Cost	0.1	8	4
Ease of Use	0.3	5	7
Reproducibility	0.1	6	6
Effectiveness	0.2	5	6
Size	0.1	5	7
Design	0.2	6	9
Total	1	5.6	6.8

Figure 16: Design matrix for PVC filter

Seeing that it would fit better into our design and it is more resistant to breaking, we went with the PVC casing.

The second filter, the carbon dioxide scrubber, was then considered. We brainstormed containers that could be used to house such a filter and came up with ideas such as glass or acrylic prisms so the person collecting the gas would be able to see the biogas bubble through the water due to their transparent properties. We calculated that with a 10 gallon filter, the water would need to be changed every 3.4 cubic meters of gas that passed through, which we estimated to happen about every three feeds of 9-10 pounds of miscellaneous solid food waste. Although the carbon rich water is ideal for aiding plant growth at Nuestro Huerto, when we discussed our ideas with Ms. Barker, she expressed concerns. She explained that the high volumes of water required for an effective filter would be unmanageable to keep up with. Our burn tests showed that the biogas burned effectively without having the carbon dioxide scrubbed out, and for these reasons, a carbon dioxide scrubber was not built or implemented.

A point to be made about the use of these filters is that they only work as the biogas travels through them. The only way for the biogas produced in the vessel to travel through them is for pressure to build within the entire system. The anaerobic digestion naturally produces this pressure as food waste digests, and in order to monitor this process we decided it would be useful to measure this pressure. A pressure gauge was purchased and attached to the system's piping just before the H₂S filter. The pressure gauge ranged from 0-100 psi making it less precise at the lower limit. This caused the gauge to never register a reading even though gas passed through the piping it was located on under a noticeable pressure. Knowledge of the value of pressure would have allowed us to directly relate a pressure reading to how much gas is in the system at any given time. This could also be used as a safety measure, by never allowing the system to reach a particular pressure that would cause a breach of the PVC connections or a rupture of the entire system.

Initially, the lack of a pressure reading was thought to be the result of a leak in the system. To ensure that this was not the case we secured and sealed all of the PVC pipe connections located underneath of the roof during the roof replacement process. We also had the pressure gauge tested, confirming that it functioned as it was meant to. After this, there was still no pressure reading, even when it was clear that there was pressure in the system because gas was being forced out when the valve was opened. This allowed us to form the conclusion that the pressures we were dealing with were too small to be registered by the large range pressure gauge.

3.7 Effluent

Once we had fed the digester enough to reach a slurry level above the bottom of the effluent pipe, and there was a sufficient amount of pressure inside, we were ready to remove some effluent. The back pressure inside forces the effluent out through the effluent valve, if opened, until it reaches a pressure equilibrium. The effluent is very useful for two reasons: it can give us an idea of the current conditions inside the digester, and it can be used as a fertilizer for plants.

We were able to collect approximately 5 gallons of effluent in a large bucket, and tested the pH of this collection using pH litmus paper strips. This testing method is easily available to our sponsor for future use to maintain the correct levels. The pH we measured was about an 8, which is perfectly in the middle of the ideal value range



Figure 17: Effluent drainage system

of 7.5-8.5. If the pH level was found to be outside of this range, it can be lowered or increased by adding

more acidic or alkaline foods, as we recommend in our operations manual (Appendix A). After we finished testing, we gave the effluent to Ms. Barker, which she used to fertilize a patch of raspberry bushes growing near the biodigester.

3.8 Gas Collection and Storage

In order to collect the methane, we needed to decide on a method to safely store the biogas. Without having a way to contain the gas, it cannot be used effectively and will end up being wasted. Because of methane's physical properties, unlike propane, it requires extreme pressures to liquefy at room temperature. This means that methane cannot be easily stored in a propane tank in sizeable quantities suited for longer term storage. The initial method we used to collect the biogas was putting plastic grocery bags around the end of the biogas line fixed by a rubber band (Figure 18). Once gas was produced, we opened the valve at the end of the biogas line allowing the stored pressure inside the digester vessel to fill the bag. This



Figure 18: Grocery bag capturing biogas

method was used because only a small amount of gas was being produced at the time, and the bags were cheap, available, and took little pressure to fill. They also allowed us to quickly test the contents due to their portable and disposable nature.

Different designs for gas collection were researched until one was found that fit the design requirements set by the team and Ms. Barker. A design was selected that incorporated a sealed trash bag as a collection device. The benefits of the bag are a low cost, portability, availability, and ease of construction and use. A prototype methane storage bag was made using a white, thin trash bag that held eight gallons of gas. This bag was used to temporarily store the gas we collected so the system

could safely generate more. The construction of the bag was simple and easily reproducible using a PVC connection consisting of two parts that screwed into each other. We fixed the connection on opposing sides of one wall of the trash bag and poked a small hole for gas to travel through. We then duct taped the open side of the trash bag shut and attached a valve to the external PVC piece to create a closed system. An image of our prototype collection bag can be found in Figure 20.

As the spring season approached and climate temperatures began to rise, more feed became available strengthening the bacteria culture and reinvigorating gas production. After each feeding, roughly 6-7 gallons of gas was collected, which our 8 gallon storage bag could not fully contain for successive days. This increased amount of gas production began to cause issues when gas was not released for extended periods of more than 24-48 hours. One of these issues was the metal roofing surrounding the feed tube would pop



Figure 19: Popped roof from excessive pressure



Figure 20: 8 gallon collection bag

up due to the feed tube under so much pressure as seen in Figure 19. Another major issue was the increased back pressure of the system which was caused by the gas pushing slurry back up the feed tube. One instance of this resulted in slurry shooting up and out of the feed tube causing an overflow of effluent. In order to stop this from occurring, the team discovered that if gas is released prior to taking the feed cap off, the back pressure will be reduced. Because of the increase in gas production, the team built a larger bag of around 55 gallons using the same PVC connections and method. The larger bag proved to be successful in capturing gas, but not for very long. The gas would diffuse out of the bag, as it was noticeably less full before every

feeding. After further inspection we realized the bag began to tear which led to a complete loss of all collected gas. For this reason, the larger collection bag was discarded.

A more permanent storage solution was designed using a bladder tank that was present from the project last year. After collecting a fairly large sample of gas in the 55-gallon bag, we attempted to compress the methane and transfer it into the vacated bladder tank. This test was done by attaching the gas bag to the tank via PVC piping with a pressure gauge and a valve to secure the system. After the bag was attached to the bladder tank, we compressed the gas bag by hand and then opened the valve to allow transfer between the bag and bladder tank. When the valve was opened, no pressure was measured on the pressure gauge and no flow from the bag into the bladder tank appeared evident. This solidified the test as a failure, however much was learned from this attempt at compression.

Through this test, the team found out that there may be some sort of regulatory valve in the bottom of the bladder tank that could require a certain amount of pressure to overcome thus opening the bladder. This theory can be supported by the fact that there was no pressure registered on the gauge during the attempt.

3.9 Biogas Testing and Application

The gas that was collected was tested in different ways, to determine the gas's chemical energy. In the initial grocery bags, a hole was punctured into the bag and the gas that escaped was ignited with a lighter. The first bag that was filled did not produce a very large flame and did not stay lit long. This shows that the bag did not contain a sufficient concentration of methane, as it did not ignite fully. This was to be expected, however, as low concentrations of methane are common when a bacteria culture is first being established. After more time had passed, another bag was filled and tested. This bag quickly ignited with a large blue flame, indicating an appropriate concentration of methane in the biogas.

Once the biodigester was consistently producing gas, we wanted to do a more accurate test to determine its composition. This would allow us to give an accurate estimate of how much energy per unit volume could be released from burning the gas. One way that we tried to test the gas was using a gas chromatography, which would let us know the percentage of each substance present in the gas. We contacted various professors at WPI to see about using a gas chromatograph on campus, unfortunately, it can only be used on liquids that have been evaporated into a gaseous state which is impossible to do with methane since it is naturally gaseous at room temperature.

Another method that we considered was the use of colorimetric gas detection tubes. By passing a set volume of gas through these tubes, they would measure how much carbon dioxide is present, changing color accordingly to show the percentage of carbon dioxide in the gas. Because of the composition of biogas, it can be assumed that remaining percentage is almost all methane, with only trace amounts of other gases. However, after discussing this method as a team and with our sponsor, we concluded that this method would be too expensive.

The simplest way that we found to test the gas's energy output was by burning it. Gas samples were collected using the 8 gallon prototype collection bag, and an experiment was set up in Goddard Hall to boil a 25 mL sample of water at room temperature (22 degrees Celsius) to test for energy potential. A glass beaker containing the water was mounted using a clamp with a thermometer placed in the beaker. The bag with an added makeshift nozzle was then placed beneath it. Once the valve was opened we lightly compressed the bag to force a steady stream of biogas out of the nozzle and lit the end using a lighter. Right away, the gas began to burn a



Figure 21: Water boil test in Goddard Hall

shade of blue and the temperature of the water sample began to increase rapidly. In under a minute, the sample was boiling and an estimated one gallon of gas was burned during the process. With a quick calculation involving the temperature difference and the standard BTU consumption of heating water, we estimated that one gallon of the biogas yielded 8 BTU (Appendix E).

With this number seeming extremely inefficient, we decided to refine our experiment and run it again using a full 8-gallons of gas. We decided to heat 3 liters of water in an aluminum bowl using the same method as before, which turned out to be a success. We chose a larger amount to prevent the water from reaching its boiling point and having a more finite temperature gradient when calculating the estimated BTU/gallon of biogas. The initial temperature of the water was 21.8 degrees C and the final temperature was 34.1 degrees C. After similar calculations (Appendix F) this experiment resulted in one gallon of the biogas yielding roughly 24 BTU. Although this is more than double our previous experiment, it is still well below being an energy efficient system with respect to the amount of energy added through the heating mat. This low estimate was likely caused by heat being absorbed by the metal test bowl that held the water and heat loss to the air surrounding the experiment, as well as an overestimation of the amount of gas contained in the bag.

However, at a presentation to demonstrate our final results and educate people from the local Worcester community about the potential for biogas production, we were able to successfully cook an egg as an example of an application for the biogas. In order to accomplish this, we adapted a grill that was located near the biodigester to connect to an eight gallon collection bag. Pressure was manually applied to the bag to push the gas out and into a burner that had a baking pan on it and an egg in the pan. This test showed that the gas can be used as a viable cooking fuel at Nuestro Huerto.

In this final presentation, we demonstrated every aspect of our overall goal. We fed the digester to produce gas, we filtered and collected gas, we used the gas in a beneficial way, and we educated the community on its operations and benefits, by demonstrating the whole process.

4.0 CONCLUSION

In the beginning of this project, the team set out to improve a biodigester to an operational condition, so that the energy it produced could be used to heat a greenhouse in the late winter months to assist early seedling growth for a local urban farm. After researching similar operations around the world, our team was able to create solutions to productively create, filter, and store the biogas. In addition to this, we wrote a user manual to aid in the future use and sustainability of the Nuestro Huerto biodigester. A presentation was given to the local urban agricultural community with the intention of educating about biodigesters and how they can be used as a means to increase sustainability in a community. The biogas produced proved to be of a high enough quality to ignite and create heat. Using the energy from the biogas, the team was able to boil water and cook food. This fell short of the sponsor's ultimate goal of heating a greenhouse, however, the biodigester can still be a useful tool to Nuestro Huerto. Until a long term storage method can be found the biodigester would best be used for cooking fuel and as an educational model for a sustainable system. The future of the biodigester project at Nuestro Huerto relies on the creation of a feasible heating system for the greenhouse.

5.0 RECOMMENDATIONS

After working on this project over the course of the past academic year, the biodigester has gone through numerous improvements and changes. With this being said, there are a few recommendations that may be beneficial to the advancement of not only the biodigester, but also the project as a whole. These recommendations have been compiled into the following: deliverables, biodigester improvement plans, and project ideas.

Our first recommendation comes in the form of a proposed methane compression process. The process is an adaptation of a method using a floating drum collection system. With the floating drum system, weights can easily be placed on top of the floating drum to increase the pressure of the methane that has collected inside. We took this idea and adapted it to eliminate the water aspect in the drum of the system and included the storage bag that we have implemented thus far. A diagram of the suggested compression process can be seen below.

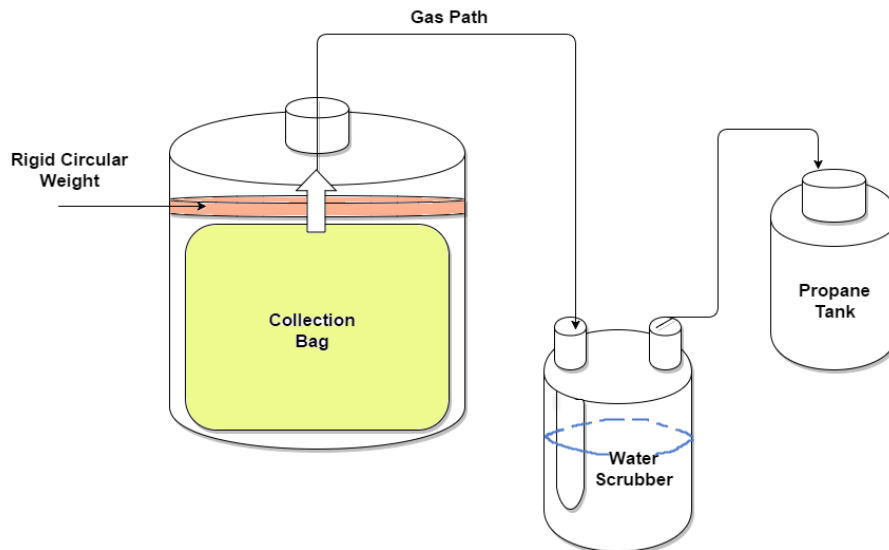


Figure 22: Recommended drawing for carbon dioxide scrubber

Another recommendation is to set forth a definite feeding schedule that would maximize the production rate of the biodigester. This can be done through trial and error by measuring the amount of feed, number of times fed per week, temperature inside and outside, etc. These variables can all be controlled and changed in order measure the waste to methane conversion rates, ultimately yielding information that can be used to optimize the system. In addition to this, it is necessary to establish an efficient schedule for removing effluent and methane from the biodigester. Because the pressure in the system is dependent on both of these levels, they must be balanced properly. A procedure must be established that takes this into account to ensure proper slurry and gas levels in the tank to avoid over pressurizing the biodigester vessel.

A third recommendation is to install a solar panel on the biodigester to power the heating mat to make the whole system more sustainable. While the heating mat currently uses roughly 3 kWh/day, adding a solar panel would make it completely independent of electricity added from outside the system. In addition to a solar panel, a rain barrel can be used to collect water for the feed mix. This would eliminate the need to use tap water and would make the biodigester more sustainable. One challenge that we faced this year was preparing the food waste for feeding the biodigester. Our method to chop the food waste was to use a hoe to manually break apart the food. This is a tedious, inefficient, method that leaves behind large chunks of food. By using a food disposal system, this task would be much easier and quicker, while only using a small amount of electricity.

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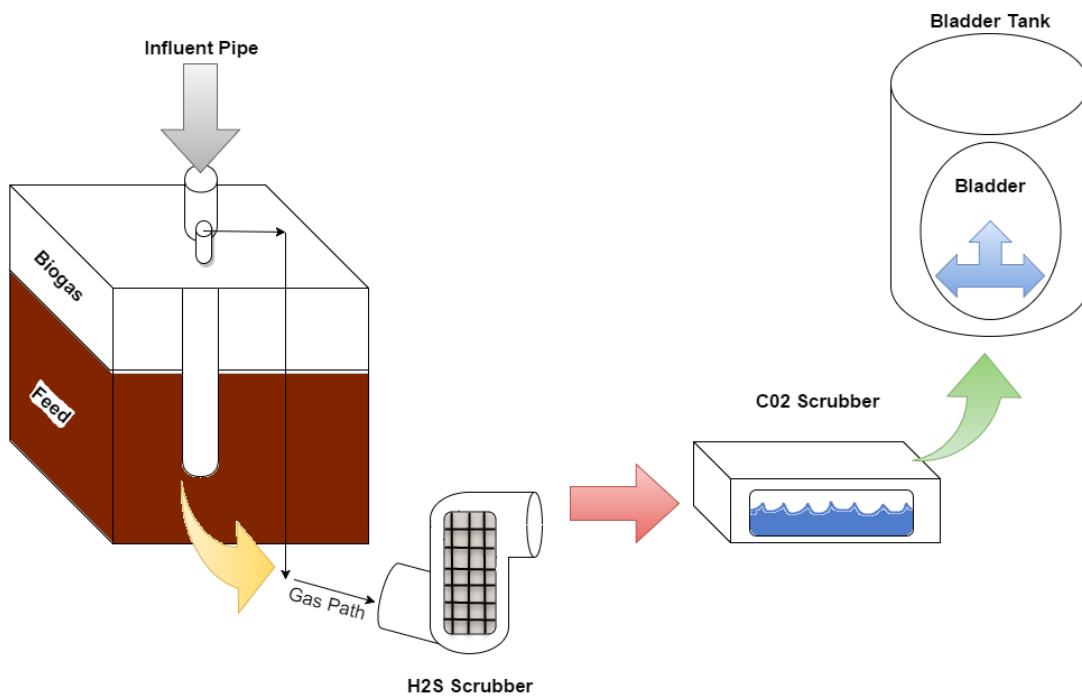
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NUESTRO HUERTO BIODIGESTER OPERATIONS MANUAL

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Biogas Scrubbing Process



Full schematic of biodigester system. The arrows represent the direction of biogas flow through the system.

How It Works

- Inside of the biodigester box, there is a plastic “biodigester vessel” with an influent (feeding) tube, and two additional pipes for gas and effluent exit.
- The feed tube is designed so that when the food exits the tube it is at the bottom of the slurry. It also has an angled opening to help avoid clogging.
 - As the solids in the slurry are digested and become liquid, they become less dense and float to the top of the slurry for removal. Removal of effluent is necessary so that the tank does not overflow. This process is covered in the maintenance section of the operation guide.
- Above the slurry is an empty space in between the slurry and the top of the tank. The biogas fills this space after it is created, before it is collected.
- This biogas will exit the tank through the gas pipe which takes the gas through the scrubbers and then into the bladder tank/bag for storage.
 - The biogas enters the Hydrogen Sulfide scrubber first, this scrubber removes a corrosive component of the biogas (H_2S) by passing the gas through steel wool. The iron in the wool binds with the sulfur in the H_2S and removes it from the gas.
 - The second scrubber is the CO_2 scrubber. This scrubber involves passing the gas through water, where the CO_2 is partially absorbed by the water. This scrubber has not been installed on our biodigester, as it is not a necessary component. The advantage of removing the CO_2 is to maximize storage volume for methane gas, as it removes some of the CO_2 from the gas that cannot be burned.
- One option is to use the CO_2 scrubber as a seasonal filter. In the spring and summer months, more gas will be produced, as there is more available feed material, meaning that maximizing storage is more important. Also when the water from the filter is warmer, more CO_2 can be absorbed, making it more efficient.
- If the filter is installed, but the water is not changed, it will not harm the biogas, nor will it help the biogas.
- After the gas has been scrubbed, it is now mainly methane gas and is ready to be stored in a storage vessel.
- A two way valve will be used to regulate the flow in and out of the storage vessel. This can be seen in the full schematic of the biodigester.
- When filling the storage vessel, the valve will be opened so that the filtered methane can enter the storage vessel.

- After the storage vessel is full, and no more gas is going inside of it, the valve will be closed off completely ensuring that the gas collected remains in the storage vessel. At this point the storage vessel can be completely removed from the system and taken to wherever it is needed.



- The above picture on the left shows the effluent pipe and valve located on the left of the picture and the gas pipe located on the right.
- In the picture on the right, the hydrogen sulfide filter is shown attached to a gas collection bag by a $\frac{1}{2}$ " 2 way PVC valve. The valve will be detached from the scrubber and then attached to a burner or heating apparatus that has a $\frac{1}{2}$ " opening. The heating source or burner may have to be adjusted to fit the valve, as the burner on the grill was by adding tape to the burner so that it was thicker and fit more snug in the bag's valve. Additionally different PVC fittings can be added to change the size of the opening to fit different appliances.
- In order for gas to come out of the bag and into a burning apparatus, pressure needs to be applied to the bag. This can be done by squeezing the bag at a pressure that forces the gas out at a desired rate or by placing a weight on the bag that forces it out. An advantage of doing it manually is that you can adjust the force as needed. A disadvantage is that it requires constant work by the user. An advantage to using a weight is that it requires no effort from the user. A disadvantage is that it may be too much or too little force if the size of the weight is not right, causing the gas flow rate to either come out too fast and burn too quickly or not come out fast enough and not provide as much heat or power.

Feeding Guide

Feeding is a critical component to creating biogas. Without feeding the biodigester, the bacteria that create the biogas will die, and no gas will be produced. Any organic matter can be fed to the biodigester to produce gas.

1. Mix together food scraps, grains, and other organic compounds in 5 gallon bucket.
 - a. Fresher waste is better than waste that has been rotting for a long time
2. Make sure to chop up food as small as possible as seen in the picture on the left.
 - a. The feed hole is less than two inches wide, so chunks should be smaller than that if possible
 - i. methods to do this can be using a shovel or hoe to mix and chop
 - ii. large chunks of food can get caught in the feed tube and take longer time to break down because smaller pieces provide more surface area allowing bacteria to work more efficiently
 - b. During and after food has been chopped up, add approximately 2-4 gallons of water to bucket so that the mixture is roughly half water
 - i. This ensures the feed is mixed, seen in the picture on the right



3. Unscrew cap and remove thermometer. (See maintenance guide on how to withdraw thermometer data.)



4. Insert funnel and make sure it is secure by pressing down hard on it and checking to see if it moves.



5. Begin to pour feed mix into funnel, making sure not to spill.



6. If the feed becomes clogged, use a PVC pipe to gently mix the feed, creating a flushing motion. If this does not work, use the pipe to press the feed down into the feed hole, dislodging anything that has become caught.



7. If feed is too dry, or if not all of the feed came out of the bucket when you went to pour it, bucket, add water and pour it again to get it all inside the biodigester.

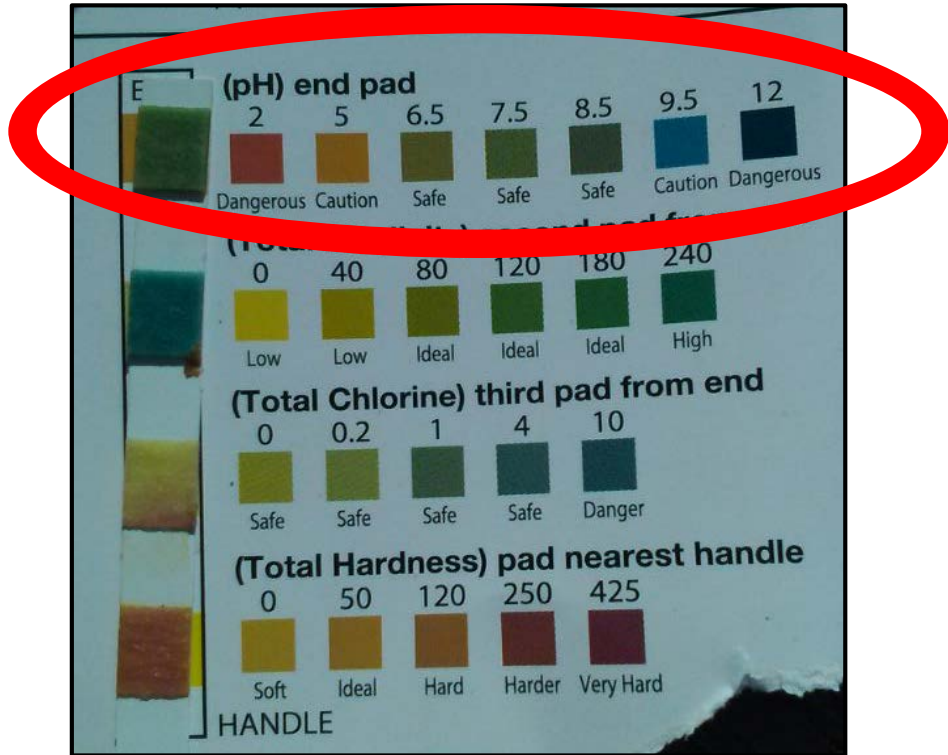
Maintenance Guide

1. To withdraw the thermometer data.
 - a. Remove the thermometer from its metal casing attached to the feed cap.
 - b. Plug the thermometer into the USB port of your computer.
 - c. You will need the EasyLog software, available at:
<http://www.lascarelectronics.com/data-logger/easylogger-software.php>
Download the one called "EL-WIN-USB Windows Control Software." This software is currently only available for Windows computers.
 - d. Open the EasyLog software and click on "Set up and start the USB data logger," and follow the instructions. You may choose the intervals at which the temperature is taken. Shorter intervals will use up more storage space, so keep in mind how long the thermometer will be inside the tank before it will be checked again.
 - e. Place the thermometer back in its case, and twist tightly to close.
2. Once a month check to see if the steel wool needs to be replaced.
 - a. If more than 75% of it has blackened take it out and put fresh steel wool into the filter and screw the cap back on tight.
 - b. An exact calculation for this reaction is about 0.001kg steel wool / m3 of gas.
3. ONLY IF CO₂ SCRUBBER IS BEING USED.
 - a. Replace water after every 3.5 cubic feet of gas has been produced.
 - b. This should be about every three feeds or so.
4. To remove the effluent:
 - a. Check to see the effluent level. This is the level of the digested food inside the tank. This can be done by trying to empty effluent from the mixing tank which can only be done when the level is high enough.

- b. First place a container, such as a bucket, beneath the valve. Open the effluent valve located next to the gas valve. If the level was too high, effluent will drain out, as pictured below.



- c. Make sure to have a large enough container when emptying the effluent, as it can come out pretty quickly. The valve can always be closed if there is too much coming out and the collection container needs to be replaced.
 - d. The collected effluent can now be used as a liquid fertilizer once it is collected.
 - e. This needs to be done or else the biodigester will fill up with unusable waste and will not be able to take in any new food to produce gas.
5. To take pH of effluent:
- a. Check by putting pH strip in effluent.
 - b. It should be between 6.5 and 8.5.
 - c. If it is too low, add baking soda or ammonia (which are basic) to the feed.
 - d. If it is too high, add acidic foods such as oranges or lemons.
 - e. The pH will take some time to correct itself after something acidic or basic has been added, so wait a week before adding more if it is still outside of the acceptable range, so as not to shock the system.
 - f. If the effluent level is not high enough to be collected, use the PVC pipe to stick a pH strip down the feed tube to test it that way.



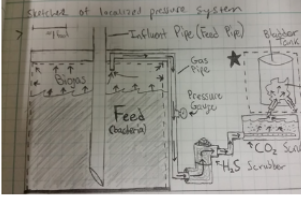






Troubleshooting Guide

1. If the feeding pipe is clogged from feed chunks being too large:
 - a. Pour warm water into the feed pipe until it begins to fill all the way up the feed tube or unclogs it.
 - b. Take a long, thin pipe and push down the feed.
 - c. If still clogged, let it sit for a couple hours and then try again. This can allow feed to work its way down the pipe.
 - d. If no gas is coming out.
 - e. Check pH. If not in the correct range of 6.5 to 8.5, refer to part 5 of maintenance section. PH is one of the vital conditions for the bacteria to produce gas. The pH must be within 7.5 - 8, or the system will decrease in gas production.

2. How to check for pressure leaks:
 - a. Uncover the piping on top of the tank. This can be done by unscrewing the roof and taking it off. Then remove the insulation and the pipes will then be visible leaving the tank. This should only be done if a pressure leak is suspected.
 - b. Use a soapy water mixture to apply around joints or suspected leaking areas.
 - i. If bubbles appear there is a leak that needs to be patched. A patch can be made with a silicone gel. Or, by heating the spot with the leak, the plastic can be melted together. In the case of a large hole, a patch can be made by melting in a new piece of plastic.

3. If the biodigester and its surrounding area begin to smell very strongly:
 - a. Place a cup of citronella or vegetable oil down the feed tube every few weeks to help combat smell.
 - b. Ensure all necessary locations are sealed to maintain the anaerobic atmosphere of the system. (see 2 on checking for leaks)

Appendix C: Brochure

<p style="text-align: center;">How It Works</p> <p>Anaerobic Digestion: This is the process that is taking place inside of the biodigester vessel. This process relies on mesophilic, methane producing bacteria cultures that live feeding off of organic waste. This process requires a temperature within the range of 90-100°F.</p>  <ul style="list-style-type: none"> • Inside of the biodigester box, there is a plastic "biodigester vessel" with an influent (feeding) tube, and two additional pipes for gas and effluent exit • The feed tube is designed to feed the bacteria culture in the biodigester box from the bottom, with an angled opening to help avoid cloggage • As the volatile solids in the slurry are digested, the digested liquid becomes less dense and floats to the top of the slurry for removal • The vacated space in the tank at the top is left to temporarily hold the biogas that is produced from the digestion process • This biogas will exit the biodigester vessel through the gas pipe which takes the gas through the hydrogen sulfide scrubber which removes a corrosive component of the biogas (H2S) • A two way valve will be used to regulate the flow in and out of the storage vessel • When filling the storage vessel, the valve will be opened so that the filtered methane can enter the storage vessel • The storage vessel can then be attached to the heating apparatus of choice 	<p style="text-align: center;">Collection Methods</p> <p>Currently, We are using trash bags to collect the gas until a long term system of collection can be installed.</p>  <p style="text-align: center;">55 gallon trash bag attached to H2S scrubber</p>  <p style="text-align: center;">8 gallon prototype bag</p>	<p style="text-align: center;">From Food Waste to Biogas Interactive Qualifying Project at WPI</p> <p>Using the biodigester built by the project group last year, our team was able to produce biogas through the process of anaerobic digestion taking place within the internal environment of the biodigester. We researched and developed improvements and advancements in the functionality of the biodigester, and implemented a hydrogen sulfide filter, as well as a new roof design for the biodigester box.</p> <p style="text-align: center;">Biodigester located at The Shop</p>  <p>Team Members: Justin Marsh, Joe Pizzuto, Alex Silk and Natalie Marquardt</p> <p>Advisors: Professor Robert Hersh and Professor Derren Rosbach</p> <p>Sponsor: Amanda Barker, Nuestro Huerto</p> 
<p style="text-align: center;">Why a biodigester?</p>  <p>The use of a biodigester comes with a number of benefits much of which are due to its sustainability characteristics. The energy input needed to maintain bacteria living conditions is much less than the amount of energy that is produced in the form of methane gas. This gas can be used for a burner on a stove top, or possibly some type of heating system.</p> <p>A byproduct of the digestion process is effluent that is drained from the biodigester vessel periodically. This effluent can be used as a rich fertilizer that is more potent than regular compost.</p>	<p style="text-align: center;">Feeding the biodigester in Fall 2014 (before new roof)</p> <p style="text-align: center;">Types of Possible Feeds</p> <ul style="list-style-type: none"> • Food waste • Cow or pig manure • Any organic matter or material <p style="text-align: center;">Applications of Gas</p> <ul style="list-style-type: none"> • Cooking (stove top, grill) • Water heater • Heating 	<p style="text-align: center;">Application of Effluent</p> <p>A natural byproduct of the anaerobic digestion process is the effluent that is left over after the digestion of the volatile solids in the slurry. The effluent is drained out of the tank using pressure caused by a difference in the level of the slurry in the feed tube and the slurry in the biodigester vessel. The effluent can be used as a fertilizer for any kind of plant.</p> 

Appendix D: Feeding chart

Feeding Outline:

1. Find food waste/organic material, fill 5 gallon bucket slightly less than halfway recording the “dry” weight of just food waste with no water.
 - Record what the feed is comprised of. If you add anything to correct a pH imbalance, be sure to specifically record those ingredients.
2. Add 2-3 Gallons of water to the food waste and record the “wet” weight of the food.
3. Remove cap from feeding tube with attached thermometer probe that extends down the feed tube.
4. Ensure that the level of the feed tube is not high enough to hinder feeding.
 - If level is too high, open either the gas or effluent valve to relieve pressure of the system.
5. Once feed level is at appropriate height, attach funnel to top of feed tube securely
6. Pour feed into funnel, making sure not to pour too fast so that funnel becomes too full.
 - If draining of the funnel becomes clogged use PVC “plunger” to clear the tube.
7. Wash down any necessary leftover food scraps.
8. Replace feed tube cap with thermometer attachment.

<u>Date</u>	<u>Time</u>	<u>“Dry” Weight</u>	<u>“Wet” Weight</u>	<u>Ingredients</u>

Appendix G: Calculations

CO₂ scrubber capacity:

$$\frac{2.5 \text{ g CO}_2}{1 \text{ Kg H}_2\text{O}} * \frac{1 \text{ mol CO}_2}{12 \text{ g CO}_2} * \frac{22\text{L CO}_2}{1 \text{ mol CO}_2} * \frac{0.264 \text{ gal}}{1 \text{ L}} = 1.21 \frac{\text{gal}}{\text{Kg H}_2\text{O}}$$

$$1.21 \text{ gal CO}_2 * 10 \frac{\text{gal}}{\text{feed}} * 0.4\% \text{ CO}_2 = 4.84 \frac{\text{gal}}{\text{feed}}$$

$$\frac{4.48 \text{ gal}}{1.21 \frac{\text{gal}}{\text{Kg H}_2\text{O}}} * 4 \text{ Kg H}_2\text{O required per feed}$$

$$4 \text{ Kg} * \text{H}_2\text{O} * \frac{1\text{L}}{1\text{Kg}} * \frac{0.264\text{gal}}{1\text{L}} = 1.05 \frac{\text{gal}}{\text{feed}}$$

A three gallon scrubber would require the water to be changed roughly every three feeds

BTU Calculation:

$$\frac{1\text{lb}}{\text{H}_2\text{O}} * (T_2 - T_1)F = \frac{\text{BTU}}{\text{gallon}}$$

$$6.6 \text{ lb H}_2\text{O} * 22.4 \text{ degrees F} = 24.64 \frac{\text{BTU}}{\text{gallon}}$$

This yield is roughly 1/3 the amount of BTU we should expect from a gallon of biogas

Potential Methane yield

$$20 \frac{\text{m}^3 \text{ gas}}{1 \text{ Tonne}} * \frac{1 \text{ Tonne}}{2204.62 \text{ lbs}} * \frac{10 \text{ lbs}}{\text{feed}} * \frac{1 \text{ gal}}{0.0379 \text{ m}^3} = \frac{24 \text{ gal}}{\text{feed}}$$