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ANAEROBIC DIGESTION FACILITY IN RHODE ISLAND

An Interactive Qualifying Project Report

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Abstract

The construction, operation, and feasibility of an Anaerobic Digestion plant are studied. All aspects of the Anaerobic Digestion process are examined and its ability to produce and sell fertilizer and various forms of energy evaluated. It has been determined that the facility can generate revenues of around 10 million dollars annually from fertilizer sales, with a two percent market capture. Energy sales will surpass that of fertilizer sales, although the regulations and methods for delivery have yet to be studied.

Authorship

This section provides notations as to which group members wrote specific portions of the paper.

Table of Contents

1 Introduction

The process of Anaerobic Digestion to create methane gas has been in existence since Egyptian times. By digesting the waste products of cows, farmers have used the methane gas that is produced from this process to heat their homes and barns. As technology progressed the use of specific anaerobic bacteria was found to produce a greater concentration of methane gas when added to the decomposing material, instead of relying simply on the intestinal bacteria of the cow. By applying this idea on a much larger scale to human waste, waste water treatment facilities have been able to create electricity from the decomposing material, enough to power the remaining portions of the Waste Water Treatment Facility. By designing a heating system for an Anaerobic Digestion chamber, New England may be able to benefit from the use of Anaerobic Digestion to create useable methane gas, which can in turn be used to create electricity, power vehicles, and heat buildings. This Interdisciplinary Qualifying Project will research the best methods of methane gas extraction from sewage, manure, and other digestible materials, their uses in the creation of electricity, and heating systems which allow for year round operation, in addition to the legal, and the economic feasibility of the construction of such a plant.

2 Literature Review and Background

2.1 Anaerobic Digestion History

The very first recorded use of the Anaerobic Digestion process was by the Assyrians around 1000 BC. They used simple batch loading type "reactors" which were nothing more than tanks they put waste in and covered, then harvested the methane that came off the digesting waste through a series of pipelines and used it to heat the bathwater of the richer citizens. While the digester itself was incredibly rudimentary, and the Assyrians obviously had no idea what was going on, they are still credited with the invention of the process. The next time the process was seen was in Persia in the 1600s where it was used for the same purpose. The first scientific breakthrough in the process, though it was not regarded as such, was made by the great Belgian chemist/biochemist Jan Baptista Van Helmont. His main field of research was in the minute working of plants, such as what they gained their mass from, how they produced energy and other such ideas. He studied plant biology by using his chemical background. He is therefore known as the father of biochemistry. In one of his projects he was trying to figure out where the mass of plan matter went when it was decomposed. Thus the first scientific study of the byproduct of the decomposition of waste products was conducted in 1774. He noted that not only did the plant matter give off water vapor, it also gave off two other gasses. Since the concept of separate gasses did not yet exist, he called one of them "inflammable air." Inflammable air turned out to be methane. Two years later, in 1776, Count Alessandro Volta, for whom the term volt was coined, was doing some experiments on the ability of organic matter to carry electric current. One of his experiments lead him to investigate the rate at which certain samples gave off byproducts during decomposition and allowed him to show that there was a direct correlation between the amount of a given substance being decomposed and the amount of "inflammable air" being produced. He later used these findings and the findings of many of his other experiments to produce the Voltaic Pile, the world's first battery. For this, the emperor of France, Napoleon, gave him the title of Count. After creating the Voltaic pile and going back over some of his earlier research, Count Volta tried applying the Anaerobic Digestion process to create energy, using his electronic devices as ignition sources. He even saw the potential for military uses and attempted to build cannons that ran on this mystical "inflammable air" that seemed to come off of rotting material everywhere. Unfortunately for Count Volta, the electronic technologies and the harvesting abilities of the time prevented him from coming up with anything more than hot bathwater. This is the first time that someone starts making serious steps in developing the Anaerobic Digestion process for municipal usage, though the lack of biochemical research to identify and replicate the most efficient bacteria was not present. The next major breakthrough in Anaerobic Digestion research was made in 1808 by Sir Humphry Davy, though like Van Helmont, his research had nothing to do with advancing Anaerobic Digestion technology and its use. The breakthrough therefore was ignored for a long time. At the time, Sir Davy was trying to develop a lantern for miners that would be less likely to set off the incredibly explosive and dangerous mine gas pockets that miners sometimes encountered. He determined that the best way to do this was to build a lantern with a cloth surrounded flame to dissipate the flames heat more slowly into the atmosphere, effectively causing a lower surface temperature. To test his device, since the idea of getting blown up if he was wrong was unappealing, he decided he needed to produce mine gas in his laboratory. Through his analysis of samples of mine gas that his assistants got him he determined it was methane. His breakthrough for Anaerobic Digestion was in synthesizing this gas. He looked to past research and found that Van Helmont had determined that the flammable marsh gas was created from decaying organic material. He thought there might be a correlation and built a digester with cow manure as its feedstock because it was rich in the vitamins and nutrients that plants needed to survive. After much experimentation he determined that the gas produced by the Anaerobic Digestion of cow manure was in fact methane and used it for his testing. He did not realize what a revolution in Anaerobic Digestion technology he had caused. Just 32 years later a digestion plant was constructed in Otago, New Zealand. It was used to treat the sewage the townspeople and their animals produced to provide hot water and heat for all of the houses in the town. It was only possible to achieve total coverage of the town's heat and hot water needs because it was a very small town with several cow farms that produced much manure to feed the plant. After the concept of diseases and germs were discovered, people became uneasy about coming in contact with any of the bodily produced fluids, gasses or solids of the sick, so in 1859 a digester plant was built at a leper colony near Bombay India. This plant was built mainly to break down the sewage of the colonies inhabitants to create less of a danger to society but also served as an energy source for the colony itself. Finally, in 1895, the first "advanced municipal use" of this process occurred in England when some of London's civil engineers decided to test out the viability of the process as an energy source. They designed and built a few small digester units that would siphon off a very small portion of the sewage in Exeter. When they found that the digesters produced a fairly consistent amount of methane gas, they hooked up a harvesting system for the gas and used it to light the streetlights in Exeter. They did not further pursue the idea due to a low yield of methane and not being able to justify a larger scale operation. This was mainly due to the lack of specialized bacteria for the process, and the consistent digester temperature of well below 95 degrees Fahrenheit, both of which inhibit the rate of the process severely. Two years later in 1897 another Indian leper colony, The Matunga Homeless Lepers Asylum, was given an Anaerobic Digestion plant to make sure their sewage waste was broken down and would not leak into the neighboring city of Mumbai. The digester broke down all of the sewage from the colony and the leftover remnants of the sewage were burned in larger fires. In the 1900s there was another large push for anaerobic digestion in 1930s with the first large scale MSW digester reactor plant was built in 1934 in Colorado. This plant ran until 1973, when it was shut down. Also during the 1900s there was a large upsurge in use in Asia's farmlands, turning their extra manure, and plant products into heat and electricity for their homes. While these plants were widely used, the technological advances were not in making the process more efficient, but rather making the systems cheaper to build. Since the 1970s, larger amounts of research have been done into refining the processes of the digestion plant in order to start considering large scale use. The first thermally efficient technologies are now surfacing today.

3 Methodology

3.1 Project Goal

The goal that this project team is attempting to accomplish is to minimize the dumping of "biosolids", or the solid material removed during the waste water treatment process, into our planet's land fills. In accomplishing this, the facility will create useable resources such as methane gas and nitrogen rich fertilizer. Our research has shown that the burning and dumping of these biosolids can be avoided if the material is put through a process called Anaerobic Digestion. A general description of this process is to digest the biosolids using specific bacteria to create methane gas, leaving behind only fertilizer and water. By harvesting the methane gas produced during the process, it can be used to fuel the truck fleet, heat the facility, and provide it's electricity. One of the goals is to overcome the drawback to the process, which is the temperature at which the bacteria perform the best. This optimal temperature differs between different types of bacteria, although roughly all types require significantly greater temperatures than are available naturally in Rhode Island, where the facility will be located. By researching different types of bacteria we will determine the best combination or single type bacteria for the design and location of the facility.

3.2 Methods

In order to determine the feasibility of this Anaerobic Digestion Plant in this area, the team will be using the following methodology to assess the state of Rhode Island's current situation. To determine the design of the facility, the team will be looking into different processes of Anaerobic Digestion as well as different designs for the structure of the digestion tanks. Following the completion of these, the economic feasibility will be determined given the costs of the previously mentioned activities.

To determine a location for the facility, research has been done into the legal issues surround the placement of a waste water treatment facility. Through information sources like the Department of Water Resources of Rhode Island web site, all of the documentation for constructing and operating one of these facilities can be found. Before beginning construction of the facility, a collection of potential sites will be evaluated on their physical characteristics, for example access to transportation routes and the cost of the land, to determine the best possible choice.

The economic operation of the facility requires the use of the most advanced form of Anaerobic Digestion bacteria. After researching the Anaerobic Digestion process state of the art, we determined which form of bacteria works best in our specific application. This was an integral part of the process because the design of the plant's systems could not be completed until the physical requirements had been obtained from the process we will be using. Research on this topic was done using the databases and indexes at the W.P.I. library, mainly the scientific citation index known as Web of Science. Also, the project team contacted already existing waste water treatment facilities which used the process to determine the type of anaerobic bacteria that they used, and why. Once this is completed the process of designing the power plant structure itself can began as well as the determination of the operation costs and revenue generating ability of the facility.

The design of the power plant structure was based on the current Anaerobic Digestion tanks at various waste water treatment facilities, with some changes to the design, and on a much larger scale. First, the current Anaerobic Digestion tanks designs were analyzed to determine if they were applicable to our application. This was another critical phase of the project, because the design and construction of a previously un-constructed tank of this nature will be far more difficult and time consuming. Also, until that portion of the project was completed, the team was unable to determine the return on investment for the financers of this facility.

Finally, the economic feasibility of this project was determined following the completion of the fore mentioned steps. The funding for waste water treatment generally comes from the state in which the treatment facility is located. Therefore the economic feasibility of this project was determined by the return of the investment to the state or other investors, specifically the amount of time it will take to recuperate the required funds. The costs for this facility that were determined are the cost of the location, the cost of operation, the cost of the facility construction, and the cost of hired labor. These costs were offset by researching different ways of revenue generation for the power plant. The primary source of revenue for the initial years of operation of the facility was found to be its ability to provide fertilizer in different quantities of nutrients to farmland throughout New England. Other sources of revenue include the removal of manure from local farms to be used in the same Anaerobic Digestion process as the biosolids, and the sale of electricity into the grid provided by our facility. The sale of electricity has been determined to provide the largest soured of revenue to the facility, although not until it has been fully operational for some time. Also the sale of the fertilizer produced, to either the consumer or local farmers, had been found to be the easiest market to enter upon the construction of the facility. Upon completion of this portion of the project, the team determined the cost of the entire structure including operation until the original investment is returned, and the return on the investment once that is complete.

4 Anaerobic Digestion Chamber Design

4.1 Anaerobic Digestion State of the Art

4.1.1 Introduction to the Process

Anaerobic digestion started with the Assyrians just using human and animal waste to produce flammable gasses to heat their bathwater. Today it is a highly developed and complex process with sets of bacterium so advanced they can consume almost any matter that was produced biologically. There are digesters that can digest anything from corn stalks to chicken feathers. This process now has the capability to take every biodegradable waste we produce and turn it into electricity to power homes, fuel to power cars, heated air for forced hot air heating system in smaller cities and towns and more. It is not simply a process but it is an opportunity to start cleaning up the planet in a big way. The latest revolution in Anaerobic Digestion technology started in 1981 and continues today with the Gas Research Institute. This was a response to the energy crisis of the late 70s. Scientists at the Gas Research Institute first looked at how we produced biogas from biosolids at the time and the state of the art then was thermal conversion, where the material is heated up until it breaks down into combustible gasses. The problem with thermal systems is they take more energy to run than they create in useable energy gasses, and the gasses they produce are a mixture of methane, oxygen and carbon monoxide. In addition, these were only in a total concentration of 10-30%. Creating pipeable methane out of such a gas mixture is a very expensive and long process. Anaerobic digestion however produces a gas that is almost pure methane and carbon dioxide with a concentration of methane between 50 and 80%. The biogas, after it is produced, can be cheaply improved to pipeable methane which is a mixture of approximately 95% CH_4, 4% CO_2, and 1% semi to non corrosive gasses. When this methane is burned in electric generators and cars, the byproducts are simply carbon dioxide and water. The following is a description of the state of the art technology we employ and are researching today broken down by sub-processes in the whole process.

4.1.2 Hydrolysis Stage

a. Actual Process

The Hydrolysis Stage must occur first in the total Anaerobic Digestion process because before the biological material is hydrolyzed, it is too large and of the wrong electrical orientation to be absorbed by the bacterial cells. This step is limited to the more complex of the biosolids entering the system, called lignocellulosics, as the lipids animal wastes and other such feedstock do not contain long chain polymers that need to be broken down for acetogenic bacteria digestion. Lignocellulosics are woody materials like wood, branches, leaves, and corn stalks. Many more lignocellulosic wastes exist, but those are a few common examples. The hydrolysis bacteria excrete an enzyme that hydrolyzez the biological waste and feeds off of some of the byproducts of this process. The rest of the byproducts are absorbed by bacterial cells called acetogenic bacteria, which is the bacteria used in the Transitional Stage. In any process the slowest step is called the limiting step and in Anaerobic Digestion, the limiting step is definitely the hydrolization of the long chain polymers present in cellulose rich biosolids into monomers.

All lignocellulosic materials, stalky plant material, contain cellulose, hemicellulose, and lignin just in different ratios from sample to sample based on different factors of the plant that produced it. (These factors include which plant it came from, the growing conditions it was growing in, its current stage in the life cycle, etc..) In order to digest these three components they must be separated so that the hydrolyzing enzymes can come into contact with the cellulose and the hemicellulose. The lignin provides little energy and is most commonly a digester waste product which can be readily turned into nutrient rich fertilizer. The reason that the three need to be separated is based on the structure of a plant cell wall. Cellulose fibrils are held together tightly by a lignin hemicellulose matrix. The lignin binds with all of the cellulose and hemcellulose hydrogen bonds and creates a near perfectly protected cell wall. In addition to these three basic molecules (which comprise between 70 and 90% of cellular mass) there are various components to fill in pits and holes in the cellular walls such as nucleic acids, proteins, lipids and fatty acids. These chemicals are readily absorbed by the acetogenic bacteria and do not need to be broken down or hydrolyzed. Wood contains about 10% of these while grass contains about 30%. The strong cellulose fibers and hemicellulose transportation and insulation are protected from chemical and water damage by the lignin. To separate the cellulose and hemicellulose from the lignin a ketone based separation is performed where the material is pulverized, heated to a temperature of 100-135 degrees Fahrenheit and then the water concentration of the pulverized pulp mixture is changed to induce a three phase mixture instead of the one phase pulp mixture. The top phase contains lignin suspended in a ketone solvent while the bottom and middle phase contain water based hemicellulose and cellulose mixtures. The later of the two mixtures are perfect food for an anaerobic digester producing methane concentrations of up to 65% by mass of the solids in solution. The ketone can then be cleaned of its lignin, recovered and used again. In this process it is not considered a consumed material though the ketone level in the tank will drop gradually over time even with the most advanced vapor collection processes.

Cellulose is the complex polymer created by plants to give their cell walls strength. They form long fibril shaped polymers of varying orders of organization, comprised of glucose molecules bonded together with hydrogen bonds. They range from being organized enough to be called crystalline to be disorganized enough to be called amorphous. Van Der Waal's forces of induced dipole interaction are thought to have something to do with the final shape of a cellulose molecule. When considering the strength of a cellulose chain, it is important to realize that they depend entirely on their hydrogen bonds, which are modified by Van Der Waals forces. The highly organized crystalline molecules have many of these hydrogen bonds lined up perfectly so they are more difficult to hydrolyze while the more random of the cellulose molecules can easily be "weakened" by the force of the bipole water molecules that they are in solution of. This means that amorphous cellulose molecules are much more easily hydrolyzed for Anaerobic Digestion than crystalline ones. This difference in hydrolization difficulty is what makes the hydrolyzing step in the Anaerobic Digestion process the limiting one. The process by which cellulose is hydrolyzed into glucose is a well studied well understood area. This process is shown in Figure 1.

As can be seen from the Figure 1, four separate enzymes are needed for this process, endo beta one-4-glucanases, exo-beta-1-4glucanases, exo-B-1-4glucosidases and beta-1-4-glucosidases, which together are called cellulase. Many different bacteria produce these chemicals, and the decision of which bacteria, or bacteria set to use is based on feedstock composition, temperature, p.H. balance required for the other steps of digestion, reproducibility, longevity, and resistance to change in their environment. The process starts when endo-glucanases start to scission, or cut, the cellulose chains at random. In addition to this, four other enzyme groups function to break cellulose down to glucose which can be absorbed by the acetogenic bacteria. These four groups have been proven to have a synergistic effect where they work together and hydrolyze more cellulose faster than if the individual groups acted on the same amount of cellulose in distinctly separate areas. Cellulose is a long string polymer with anhydroglucose as its basic mer, but in cellulose they are specifically oriented 180 degrees apart with relation to their adjacent neighbors as shown in Figure 1.

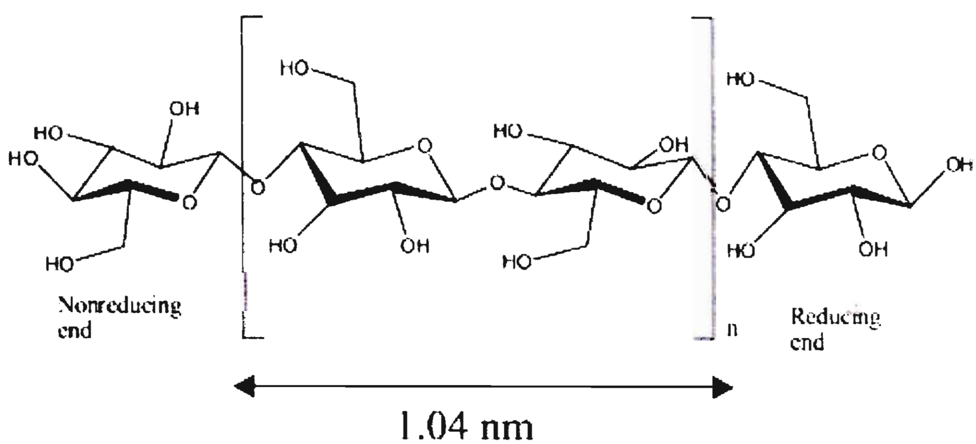


Figure 1– Section of a Cellulose Chain [8]

Due to this celluloses monomer is known as anhydrocellobiose. There are two main forms of cellulose, type Ia and type Ib. Ia is dominant in algae and bacteria, and Ib is dominant in organisms of a higher degree of evolution. The interaction between cellulose, cellulase, and cellulosome are not yet completely understood, however it is known that the crystallinity index, degree of polymerization and accessible areas are the limiting factors in the rate of this process. In addition to these three properties of the cellulose, basically the same three measures of the lignin present in the holocellulose matrix is one of the limiting factors in hydrolysis. There are two ways of making this step faster. The process can either decrease the amount of lignin in the material to process or it can depolymerize the lignin in the material. Studies have shown that vibration ball and hammer milling actually does both of these very well so that is what we will use for this project. Even though the three factors of lignin, called the lignification collectively, are the limiting step in hydrolysis, we will devote no more time to this particular section of hydrolysis since the only efficient methods known for delignification are hammer ball milling, acid explosion, and alcohol reduction. Acid explosion and alcohol reduction are both unfeasible for large scale use due to the difficulty of catalyst recovery so that leaves only leave vibration hammer ball milling. This brings us to a very important point: since the hydrolysis of cellulose is the remaining limiting factor in the entire Anaerobic Digestion waste plant, these three components of the input materials are in fact the limiting factor for the whole process. Based on these being the limiting factors, and the fact that the enzymes should consume the amorphous cellulose more quickly than the more crystalline molecules, this idea suggests that as time went on the crystallinity would change and get higher thus throwing off the balance of the entire reaction. However, it has been shown in 1999 that this is not the case and in fact many samples kept almost exactly the same crystallinity through the entire process. In 2002 Fierobe compared the hydrolysis rates on various sources of cellulosic substrates and found that accessibility is more important than the crystallinity in determining the time for the step. The degree of polymerization is a representation of the number of bonds within the molecule of cellulose as compared to the actual number of mers that are present. Quite obviously, the higher the degree of polymerization the lower the solubility in water and the lower the accessibility will be. Figure 2 below shows several different types of cellulose and cellulosic substrates.

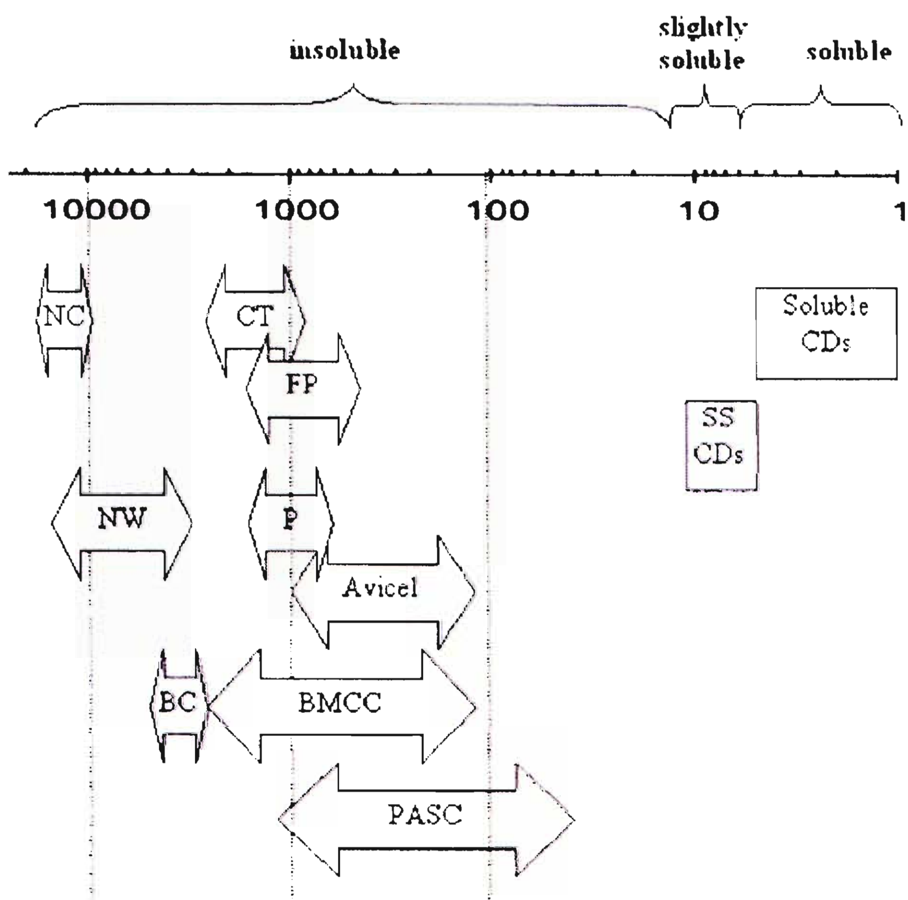


Figure 2 – Chart of cellulose and cellulosic substrates. [8]

Based upon this, the degree of polymerization is all that is needed to be known in order to figure out through biochemical models the approximate system of bacterias and the growing environment required to sustain them. Based upon several studies conducted worldwide, we know that most simple life based cellulose useable for hydrolysis has a DP of about 2-3,000. Wood and cotton can have dps of as high as 15,000 but when they are milled to go into the digester their dp is usually reduced to 500-1500. Naturally, as the enzymes digest the cellulose strands the dp will steadily drop, causing the reaction to speed up. Simply by choosing a bacterially based enzymatic approach to hydrolysis, we have already defined some of the things that slow the process. First and foremost is the presence of lignin. It had been suggested that the lignin polymers would bind to the cellulose making the cellulose encased and not allowing enzymes to break it down. Another theory on the retardation of process efficiency and reaction rate is that non active enzymes bind to the cellulose polymer chains and micropores and block the active ones. Both of these theories have been disproved and though it is not definitive yet, it is strongly suspected that the way the lignin slows the hydrolysis process is by "eating up" the active enzymes needed to break down holocellulose by sticking them to its chain. (The percentage makeup of holocellulose, the combination of cellulose, hemicellulose and lignin, is approximately 35-50% cellulose; 20-35% hemicellulose; and 5-30% lignin with the most amount of lignin being present in soft white woods.) Once the enzyme is stuck to a lignin chain it will never come unstuck except as an inactive enzyme in the holocellulose hydrolysis process. The depolymerization, or delignification of the lignin in the material through the milling pretreatment process greatly reduces this, causing the process to be able to occur at an economical rate.

Cellulase absorption by the cellulose and hemicellulose chains is a rather rapid process as compared to the whole hydrolysis process, often sustaining steady state conditions after merely half an hour, whereas the hydrolysis reaction can take days to ramp up. Cellulase absorption can be described using the Langmuir isotherm which is shown below:

$$E_a = \frac{W_{max} K_p E_f}{1 + K_p E_f} \quad (1)$$

In this equation one, E_a is the total absorbed cellulose, W_{max} is the maximum cellulose absorbable, E_f is free cellulose and K_p is the dissociation constant. The distribution of the cellulose/cellulose matrix can be described by the distribution coefficient, R shown below:

$$R = K_p W_{max} \quad (2)$$

where K_p and W_{max} are already defined. These equations, though implicitly flawed, have shown themselves to be very good approximators and are widely used to predict hydrolysis rates and monomer production. They are flawed due to the fact that not all of the governing variables of the process are represented, however these variables have been shown to either balance out to one, or be so small to have almost no effect on the outcome. Almost no effect meaning that they still produce a finite measurable source of error, but in most calculations they can be ignored. In the appendices there are tables of a few different bacteria and substrate combinations along with their experimental yields which shows these equations to be closely approximately true. The exact mechanisms by which holocellulose is hydrolyzed are not precisely known, nor is it known why the rate of hydrolysis decreases with time faster than the equations approximate. Many theories have been presented but none have been proven yet.

b. Bringing it all together

According to the most modern research, based upon all of the previously mentioned variables and considerations, the plant will employ the Trichoderma reesei, named after the microbiology pioneer Elwin Reese. This bacteria set produces a plethora of hydrolyzing enzymes that efficiently break down holocellulose in any of its configureations whether it be high lignin content, high crystalinity or whatever other limiting factors are present. The bacteria is so effective because the enzyme groups it produces work synergistically very well. This means that the enzymes "work together" to produce a hydrolyzing rate much higher than that of the sum of the individual enzymes combined. This is because the enzymes created by it are specialized and each one only attacks the polymer bonds it is best at breaking leaving the other situations to other enzymes more fit to break the bond apart. Trichoderma reesei is not the MOST efficient bacterial set for many situations, in fact this bacteria rated a close second to the Clostridium thermocellum bacterial set. This set can produce synergistic returns of up to 350% of the stand alone production rates when its enzymes work together, however the feedstocks need to be very precise in correlation to the other conditions of the digester (E.G. p.H. level, solid content, temperature, lignification etc…). Trichoderma reesei, while less efficient, can handle a much broader spectrum of feedstocks and tank conditions without major losses in production rates. One final note on the hydrolysis stage is about starches. Starches are also long chain polymers that need to be hydrolyzed and are often found in abundance, sometimes exceeding the amount by mass percentage of holocellulose in the feedstock, before they can be anaerobically digested, however, in the presence of the enzymes from most hydrolyzing bacteria sets the process is much faster. Most often all of the starch is hydrolyzed before the holocellulose hydralyzation has even reached steady state conditions. In fact with the bacterial set Trichoderma reesei starch is hydrolyzed at approximately 100 times the rate as that of holocellulose.

c. Needs and poisons

Based on the fact that we will be using the Trichoderma reesei set, we can clearly define the needs of the system as well as those things that threaten it. This particular bacterial set thrives best at a temperature between 102 and 122 degrees Fahrenheit. This is beneficial because it is almost 25 degrees cooler than the temperature we will need to run the digesters at and since this particular set produces a slightly exothermic reaction we will need to expend less of our total energy production on heating the feedstock, which can drop to temperatures as low as 50 degrees during the winter. Another great effect of using this bacterial set is that it is self adjusting. Since the feedstock we will be using will have a constantly varying composition as far as all of the limiting variables of the hydrolysis process, this bacteria set will automatically adjust its enzyme output to make the requirements of the feedstock. It is so efficient at this that there will probably be stark gradients of enzyme concentration within the tank itself!

Generally, when during the operation of a biological digester, there there is a possibility that some form of pathogen getting inside the digester and killing your bacteria base, catalyzing a reduction in production rates, or causing other operational. Luckily, this bacteria set is extremely resistant to almost all of the pathogens that will be present in our feedstock, and if something does get into the tank that kills it, a simple culture from another one of the tanks can be used to repopulate the damaged system with Trichoderma reesei rather quickly. Of course the down time of cleaning the tank out and sterilizing it to make sure it is cleansed of the intruding material or life forms is rather costly, but again, this bacteria set is highly resistant to needing such a purging.

4.1.3 Transitional Stage

a. Actual Process

The transitional stage, also known as the acetogenic stage, is carried out by acetogenic bacterial cells which take in organic acids and nuetral compounds, and output an H_2 and CO_2 gas mixture as well as one-carbon compounds. Some of this product gets turned into acetic acid, though not much of it, and the rest of it is "sent" to the methanogenic bacteria in the next step. This step "processes" much of the actual material, between 85 and 95%, into smaller molecules whereas the hydrolysis phase only "processes" roughly 40% of its input as it only dismantles long chain organic polymers such as holocellulose. During this phase it is vital to exclude as much oxygen as possible for a variety of reasons. First, if there is molecular oxygen present it could sustain aerobic bacteria which could digest part of the feedstock into A) unuseable gasses that will just need to be removed later B) pathogens which can harm the anaerobic bacterial stock or C) produce wastes that "stick" to the bacterial cells clogging them and blocking them from taking in the organic acids and nuetral compounds. Second, molecular oxygen will react with the methane in the water, before it can be harvested and turn it into water wasting valuable gas. Third, oxygen itself is a poison to the bacteria we are trying to sustain. Because this stage has allready been developed to a point where it digests material and produces its essential waste products at a rate far faster than the hydrolysis stage can keep up with, we will not delve as deeply into the intricate workings of the system. For our factory, which is designed for an area in northern Rhode Island, we will use the same acetogenic bacteria that the Massachusetts Anaerobic Digestion Reactor.

b. Needs and poisons

As stated earlier, the greatest need and poison to this system is oxygen. This part of the system needs to be as free of dissolved oxygen as possible in order to sustain its high rate of output, and we will enhance upon the Massachusetts digester style in several ways to reduce this. First, a much larger part of the feedstock put into the digester is going to be dry, with the plant itself adding the water to it for digestion. This allows far greater control over the dissolved oxygen content of the feedstock because dissolved oxygen can be easily removed from the water and never put in the reactor in the first place. Secondly, we will use a much higher solids content reactor than the Deer Island Treatment Plant (the Massachusetts plant). This decreases the amount of water substrate that oxygen can be carried into the reactor. Thirdly, we will use a control mechanism for the process, which will be described later, that will modify the inputs to the main reactors in real time to adjust for p.H., higher oxygen levels, and a variety of other factors. This will be described in greater detail later.

c. Bacterial Developments

As stated before, we will be using the same bacterial sets for the acetogenic and the methanogenic stages as the Massachusetts Anaerobic Digestion Reactor.

4.1.4 Methanogenic Stage

a. Actual Process

Once again, since the methanogenic process can digest at rates far faster than the hydrolysis phase, the currently established and used bacterial set will be used though in a radically different reactor. The actual process that the methanogenic bacteria performs is converting the dissolved hydrogen, carbon dioxide, and single carbon molecules into a mixture of pure methane and carbon dioxide. When digesting larger amounts of cow manure a small percentage of HS_4 is produced which must be removed in order for the fuel to not eat away at the interiors of the piping lines and storage tanks as it is very reactive with metals. This process is a simple one and is needed to be done on such a small scale as to be considered "costless" in relation to the amount of energy and money required to keep the tanks of the Anaerobic Digestion and Hydrolysis reactors at the correct temperature.

b. Needs and Poisons

Methanogenic bacteria is very sensitive to the p.H. of the system, much more so than its acetogenic brethren. It is most comfortable and efficient when the p.H. is maintained at a level 7.0, where if the p.H. reaches 6.6 or below, methanogenic bacteria production rates drop radically. Most often, there are two causes of lowered p.H. in a digester, (a) the feedstock is extraordinarily rich in compounds that form alkalinity (for example proteins that break down to form ammonium bicarbonate) or (b) The feedstock has a disproportionately large amount of carbon to hydrogen, producing a higher percentage of carbon dioxide in the harvested gas (up to 50%) which can depress the p.H. of the system by its presence. The system in practice now is to check the p.H. of the tanks every couple of days and use lime to adjust the alkalinity if it gets too low. The system we propose to use will constantly check the p.H. in real time and adjust the balance of the lignocelluloses feedstock introduction and the animal produced wastes feedstock. By doing so the system completely eliminates the need for adding lime which can be a major cost in the running of the plant. This system will be described in detail later. Another thing that methanogenic bacteria are extremely sensitive to is nutrient levels, and most importantly the nitrogen sulfur ratio. Again, the real time control system will use the high nitrogen content of animal wastes and the high sulfur contents of plant wastes and MSW to balance the nutrient levels in the reactor.

c. Bacterial Developments

As stated before, we will be using the same bacterial sets for the acetogenic and the methanogenic stages as the Deer Island Facility, which utilizes the same bacteria set that they have used since the 1970s with very reliable, predictable results.

4.1.5 Producing End Useable Products after Digestion

There are three main sources of income for an Anaerobic Digestion plant, two of which are end user products, or products that the customer directly consumes without reselling. The first, and less profitable, is in fertilizer which comprises most of the solid or liquid output of the plant that is harvested after digestion. The sewage and MSW's come out of the reactor legally acceptably clear of bacteria, pathogens, and other such non desirables for fertilizers of food crops. Unfortunately, these valuable "wastes" of the process leaves the plant dissolved in a 90% aqueous solution. To produce the end useable fertilizer most plants have an offsite dewatering facility which uses one of many methods know to exist for extracting the water from the sewage down to a solution containing only 20% percent water to removing water until the sewage is completely dry and can be palletized into dry fertilizer. The second end useable product produced is energy. Energy itself is not an end useable product, but this project did not cover what the best, most efficient use of the energy produced would be, but we did know that when that use was determined, the plant would process the energy (which leaves the reactor in the form of an 85% methane, 14.5% CO_2, and approximately .5%~0% Hydrogen sulfide) into the products that the end user would buy.

4.2 Technical Design

4.2.1 High Solids Real Time Self Adjusting Reactor Design

Until January of 2005, all Anaerobic Digestion reactors had been controlled by being measured weekly to make sure the p.H. and nutrient balances were in check, and if the p.H. was too low, below 6.9, lime was added to increase it. This is very cost ineffective due to the large costs of buying lime and the manpower needed to apply it. In January of 2005 Dr. J. Liu, Dr. G. Olsson and Dr. B. Mattiasson of the Dept. of Biotechnology, Lund University in Sweden made the first real time controlled Anaerobic Digestion reactor. They used Lab View to program the reactor to instantly change the inflow rate of feedstock to control the p.H. and methane production of their plant. What they found is that they could run the plant at a higher rate of solids and a MUCH higher rate of efficiency without having to use costly lime to keep those values in check. The inputs to the program was the tanks p.H., methane to carbon dioxide ratio, and total methane produced, (the program derived the amount of carbon dioxide from those numbers to predict CO_2 p.H. depressions). The actual unit itself was a revolutionary unmixed reactor bed with polyethylene substrate base. It was laid out as shown in figure 3.

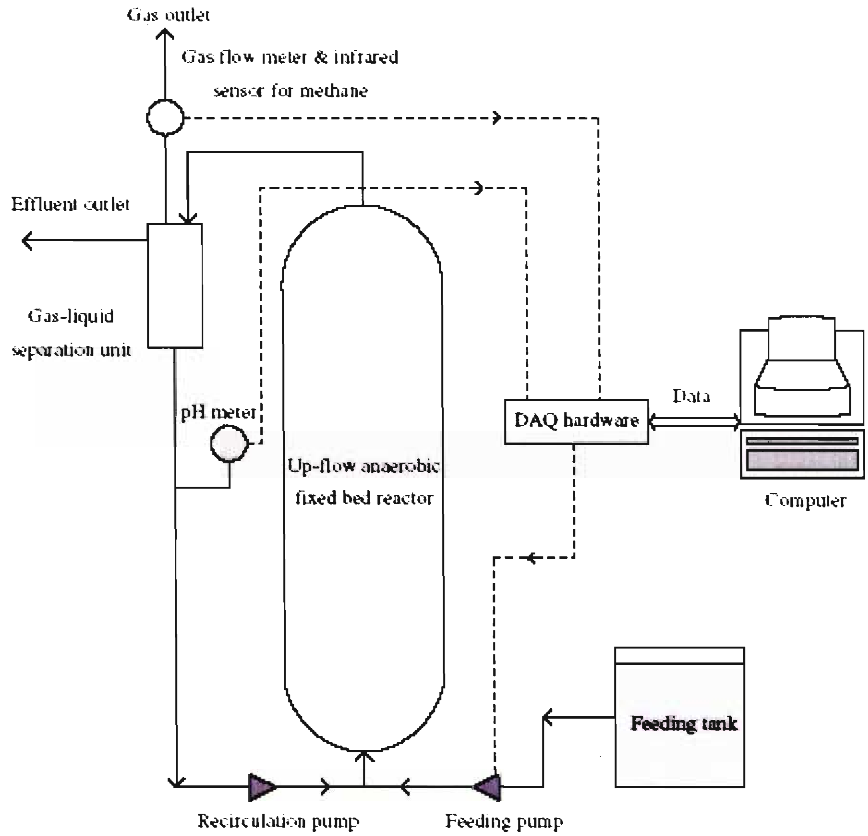


Figure 3 – Material Process Flow Diagram for Self Adjusting Reactor. [8]

As shown, the p.H. meter and the gas flow meter with a modified infrared sensor, (to detect the methane carbon dioxide ratio) are connected to the computer via a DAQ unit. The computer in turn controls the feeding pump rate. In addition to the computer controlled feeding pump there is a recirculation pump which pumps the effluent back into the chamber from the gas liquid separator. This system, though it had only one control, functioned on the following principles:

1) The computer is a rule based system which makes changes based on the goal gas production rate, which the computer constantly adjusts to be approximately the maximum gas output of the system given its feed supply and conditions.

2) Three main variables and one constant determine the rules which need to be applied:

   a) GF_{real} is the actual amount of methane produced.

   b) $GF_{setpoint}$ is the target amount of methane to be produced

   c) p.H. is self explanatory

   d) e_1 is the p.H. set point which is always seven

As shown below in diagram 4, the p.H. is checked every 2.5 minutes and small adjustments are made by the system. Every 30 minutes the methane production rate is checked and larger adjustments are made to bring the GF_{real} closer to the $GF_{setpoint}$. Every hour, the $GF_{setpoint}$ is reset to make the digester run at maximum efficiency for the feedstock being given to it.

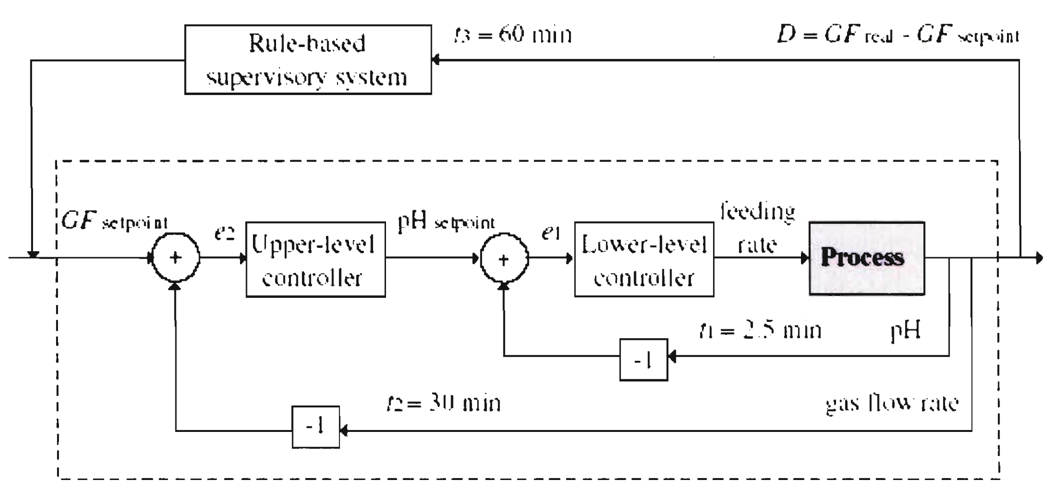


Figure 4 – Electronic Process Flow Diagram for Self Adjusting Reactor. [8]

When this system was run it only took 110 hours to reach its first steady state, as compared to the weeks or months required by all other reactors. All other reactor feeding designs picked a steady state to run at. By doing this, too much non-feedstock material was supplied and the process suffered seriously retarded efficiency ranges when the fuel was lean. The adjustment time for these systems is too long for them to be run at a constantly changing target gas production rate, but with this computerized rule based system, the digester can be run at maximum capacity almost all the time with very little adjustment time. The rules for the system are as follows:

i) If the real methane output is higher than the set point:

This is an indication that the reactor is running at under capacity and thus the $GF_{setpoint}$ is then raised.

ii) If the real methane output is close to the methane output set point:

This is an indication that the digester is running at capacity, and a small increase is made to the feed supply to make sure the system cant handle more. This is done by bumping the $GF_{setpoint}$ a half step as compared to the last condition.

iii) If methane production is lower than the set point:

The computer checks to make sure that the p.H. is not out of balance. If it is, it makes the adjustments in the feed pump speed to balance this out, if it is not then the feedstock supply is sped up to meet the set point demand.

iv) If methane production is lower than expected AND the previous state from the previous time period was NOT in state 1):

The computer then assumes that the $GF_{setpoint}$ is too high for the microbial population and decreases it one step.

As can clearly be seen by Figure 5, the reactor was incredibly efficient and amazingly adaptable.

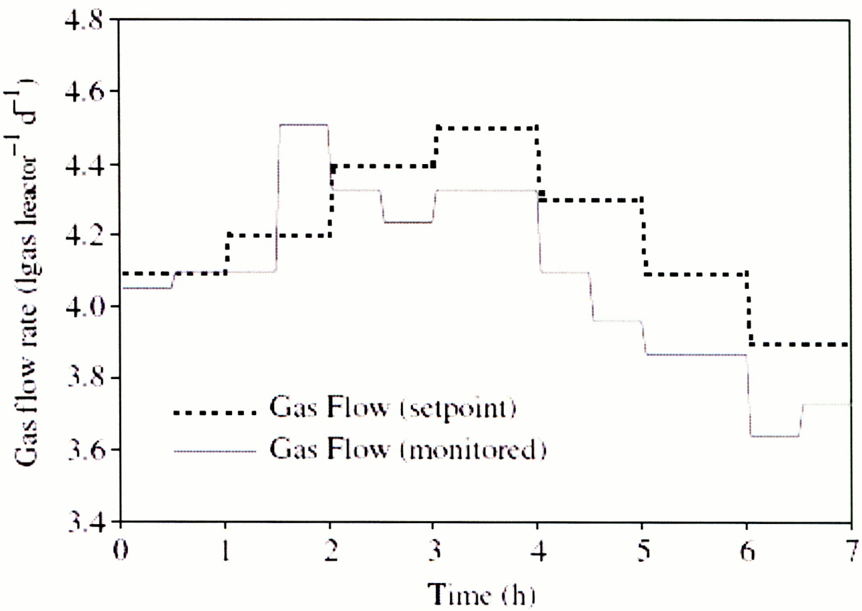


Figure 5 – Actual Gas Flow versus Target Gas Flow. [8]

This technology is truly wonderful, but because of the already unique nature of our digestion plant, we can have even more control over the process than other Anaerobic Digestion facilities did, giving us even better results. This is because we have two completely separate main fuels, MSWs and sewage. Since the things that the Swedish researchers were trying to control was p.H., nutrient levels, and nutrient ratios (specifically the nitrogen sulfur ratio), and MSWs are always high in sulfur while sewage is high in nitrogen, we can exact even more precise control and swift reaction times. We can do this by not only adjusting the feed system speed, but by adjusting the ratios of MSW waste to sewage waste input. The ability to adjust the ratio of the two wastes alone gives us the same control that the Sweedish system gained by changing the feedstock. Since we can change both simultaneously, we can change the reactor efficiency at much higher speeds and keep reactor production rates high. In addition to this, with the unstirred stable bed system, we can use a high solid content greatly reducing the amount of input water we need to heat to keep the system running, which greatly increases its sellable methane output.

4.2.2 Seasonal Considerations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	-0.2	-0.5	2.6	7.1	12	17.1	20.7	20.6	17.6	12.7	7.6	2.2	9.9
°F	31.6	31.1	36.7	44.8	53.6	62.8	69.3	69.1	63.7	54.9	45.7	36	49.8

Table 1

The above data in Table 1 is the average temperature in Rhode Island, as seen from a very centrally located sensor, specifically at 41.1 degrees North, and 71.58 degrees West. For the bacteria to perform optimally, the minimum temperature required in the reactors to maintain a sustainable maximum yield per amount of fuel minimal operating temperature is around 68 degrees Fahrenheit. Using heat balance equations modeling a slurry with the percentage solids that we want to run the plant at, we found out that the threshold for when the process is no longer thermally efficient is the triple point of water where we have to begin thawing ice. As is known, it takes far more energy to turn ice into liquid as it does to raise the same volume of water to the same temperature (using a super cooled water state). As can be seen from last years temperature history, there are only three months where the temperature averaged below freezing. We can use the monthly average due to the fact that there is so much mass in the tanks that they will take a long time to change temperature, especially since the tanks will be insulated. This tells us that from the beginning of December, until the end of February will be the cold season. Since the monthly averages are so close to zero, even though they are below zero, this leads us to believe that we could use some of the methane produced to add more heat to the tanks and still operate successfully as a sewage treatment facility. Also, ramping down intake during these months would be economically beneficial to the plant due to the fact that farmers tend not to buy fertilizer when it's freezing. The overall temperature average of 49.8 degrees Fahrenheit is encouraging because it is only slightly below the optimal operating temperature. With the extensive amounts of very high performance insulation, it will take on average very little heat to maintain the reactors.

4.3 Plant Construction

Anaerobic digestion is a sensitive process such that it has to be efficient enough to not require substantial amounts of energy, but at the same time have the ability to produce enough energy in order to alleviate or even compensate for the energy used to complete the anaerobic process. The reason for this is the bacteria require a minimal temperature be sustained to live. Obviously, due to the fact that Anaerobic Digestion is not used all around the world, this temperature is much higher than the incoming sewage. To accommodate for this severe incongruity, energy must be supplied in the form of heat and used to raise the temperature of the incoming fuel. The lower the required temperature for the bacteria to thrive, the less heat that must be added to the fuel, and the more energy from the process that can be applied to making profits, running equipment, or just plain lowering the cost of running the facility in general. Until February of 2005, making an anaerobic plant that would break even was nothing but a dream, but now that Dr. Zhang has published his work, there is a hope for a financially thriving Anaerobic Digestion plant. For this reason, if we strive to design a very well insulated plant where the heat energy we lose is completely under control, we can harness the power of this new process. These factors all revolve around two main parts of the anaerobic process, how much energy is needed to heat the incoming sewage up to an appropriate level conducive to the bacteria, and how much energy results from actual digestion. When analyzed, these variables combine on a whole to dictate the feasibility of running and maintaining the anaerobic facility.

Beginning a design of an Anaerobic Digestion plant, is to first assess the size of population you want to tender to. To define this variable, an analysis of what we are trying to accomplish with the plant leads us to the population that the plant is intended to tender to. This is due to the fact that the heat analysis cannot be determined until the total amount of heat energy required to run the plant at any given time can be expressed, and compared to the projected energy output of the facility. If the projected energy output of the plant is larger than the required input, based on a certain percentage inefficiency calculated, then the process is self sustaining during that projected time interval. To decide this, a projection based on Bucklin Fields Waste Management Facility will be used in order to produce a more accurate representation of the first variable, Projected Capacity. The population that Bucklin Fields supports produces 65 million gallons a day (mgd). At this projected capacity, prototype digester tanks will have a volume of 16.5 liters, and produce methane at a rate of 7.61 liters of methane per liter of digester space. These characteristics will result in a Hydraulic Retention time of 3 hours, but for the purposes of design projection a 100% safety factor will be used to compensate for any unseen influences, bringing the Hydraulic Retention Time (or HRT), up to be considered as 6 hours instead of 3. With these numbers a projected capacity is established that will aid in determining the energy input needed to heat the sewage. The projected capacity variable also aids in calculating how large the reactor banks have to actually be. This is accomplished by reducing the projected capacity of 65 mgd into how many millions of gallons of sewage are treated during one HRT by converting the hours in a day to the number of HRTs in a day, then dividing the projected capacity by the number of HRTs. Even though the goal capacity of a 65 MGD plant is really only 45 MGD and is designed for 65 to handle overflow, the reactors should be oversized by 10-20%. We chose to oversize the reactors by 20%, because it provides simpler calculations to carry through all of the equations and if we design it too large the worst that will happen is we will have extra space. The projected capacity variable is now determined, which also gives us the total reactor volume (when coupled with the hydraulic retention time), and is an important base number to work out the other two main variables in the heat balance and energy economy equation.

Since the daily capacity has been established, we can now derive the other variables and constants required to eventually determine the big two variables: required daily heat energy, and produced daily chemical energy. These two values, and their ratio to each other are the sole two variables that determine the economic veracity of the plant. The net amount of heat in is based upon the difference in reactor temperature and sewage input temperature. This needed heat is directly related to the conditions the bacteria sets need to be maintained at to sustain life. Most Anaerobic Digestion system require a high temperature reactor, almost always between 35 and 58 degrees Celcius, however this particular reactor does not. This is due to two highly advanced factors of the machine: the reactor is computer controlled in real time so that it runs at nearly maximum efficiency all the time by monitoring and changing the nutrient and temperature levels, and the bacteria set used will be of the species Thermocellum Reesie which only requires an average temperature of 20 degrees Celsius, or 68 degrees Fahrenheight. With this constant, the temperature of the sewage coming into the plant must be determined. To do this, the monthly average temperature must be combined with the average input temperature change for water, which is 7.22 degrees Celsius to 29.4 degrees Celsius.

From this data can be gathered a linear interpellation graph, showing a range in the temperature per month in which a data point can be developed to produce the average pipe temperatures, based on how hot or cold the climate is outside the sewage pipe.

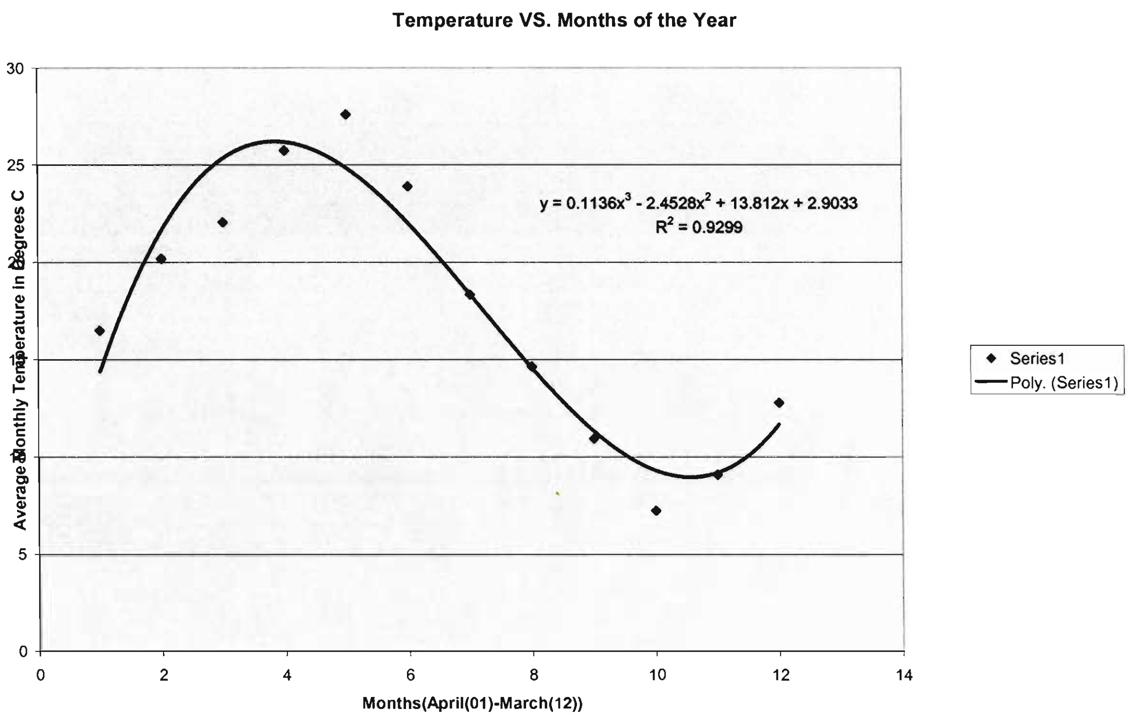


Figure 6 – Temperature VS. Months of the Year

As can be seen by Figure 6, the temperature follows roughly a 3rd order polynomial curve. Since these data points are linearly interpolated, they are of course not actually a 3rd degree polynomial, however, later sets of data do not follow a linear regression line closely, but do roughly follow the temperature curve of this original temperature graph. The later sets of data, with which it is far more important to have a more closely matching trend line, follow the 3rd degree polynomial much more closely.

By analyzing the temperature starting point of the sewage along with the final temperature point, a temperature shift requirement can be created that is the difference in temperature of the sewage from the temperature of reactor's required operating temperature.

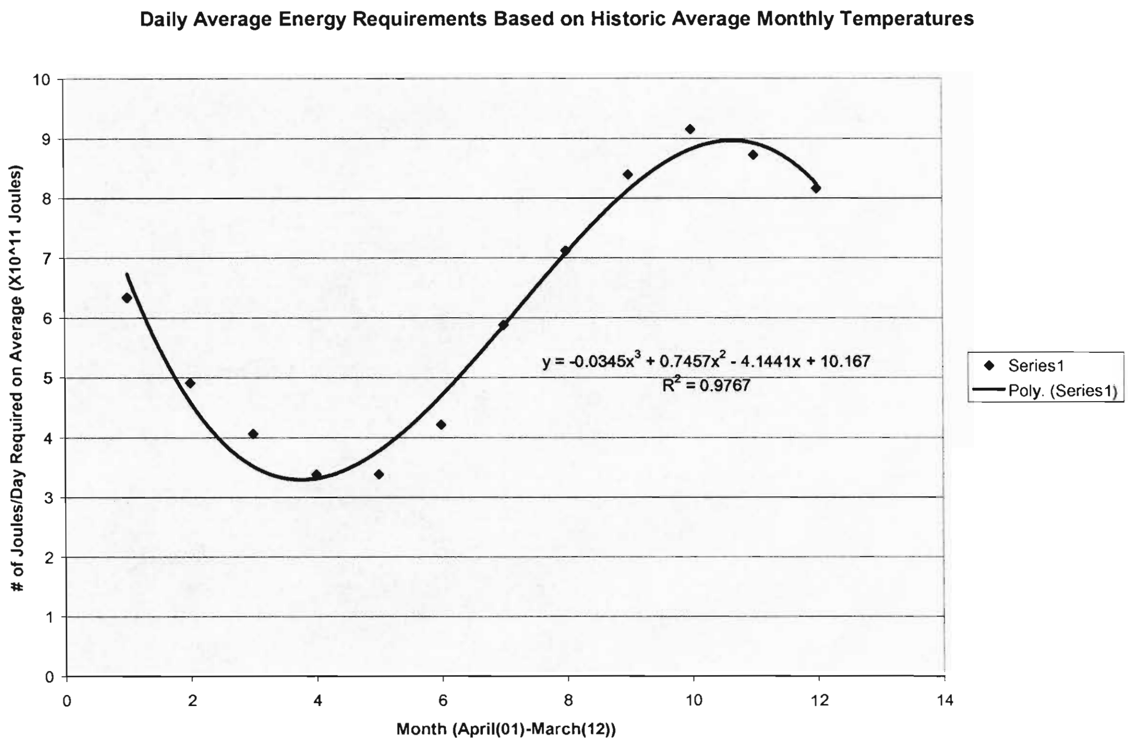


Figure 7 – Daily average energy requirements based on historic monthly temperatures

The values presented in Figure 7 represent the number of joules of heat energy that need to be added to the incoming sewage on an average day of each respective month. To explain this graph and how we produced we need to start introducing other constants and variables. The specific heat of water, though it changes with temperature, can be estimated as a constant due to the fact that it varies less than 0.2% over the temperature range we are considering, and it happens to be conveniently centered around 1000 J/Liter x °C. The whole equation proof complete with unit analysis of this combination of input temperature, specific heat, and reactor temperature can be found in Appendix 8. To determine plant feasibility, there still needs to be an analysis of the heat

heat requirement in terms of energy produced and whether or not the output can compensate for the required energy input to sustain the process. The required variables and constants for this chart are the chemical energy content of methane (in KiloJoules/Liter of gas at standard vapor pressure), the average incoming temperature of the sewage, the number of liters in a gallon (to convert our projected daily capacity into the metric system which is much more readily used throughout the world), the number of liters of methane gas produced per flush per liter of reactor space (this happens to be a constant once the plant reaches steady state, and judging from the fact that this is supposed to be the most stable system on earth, we assume it will) and finally the conversion coefficient between joules and kW x h. The last constant is not used in this plot in particular, but is required to determine a rough estimate of the value of the leftover energy you produce. The previous constants and variables were used to determine the data points on the above plot, as well as setting up for finishing up the two large calculations to come: net energy surplus, and energy surplus value.

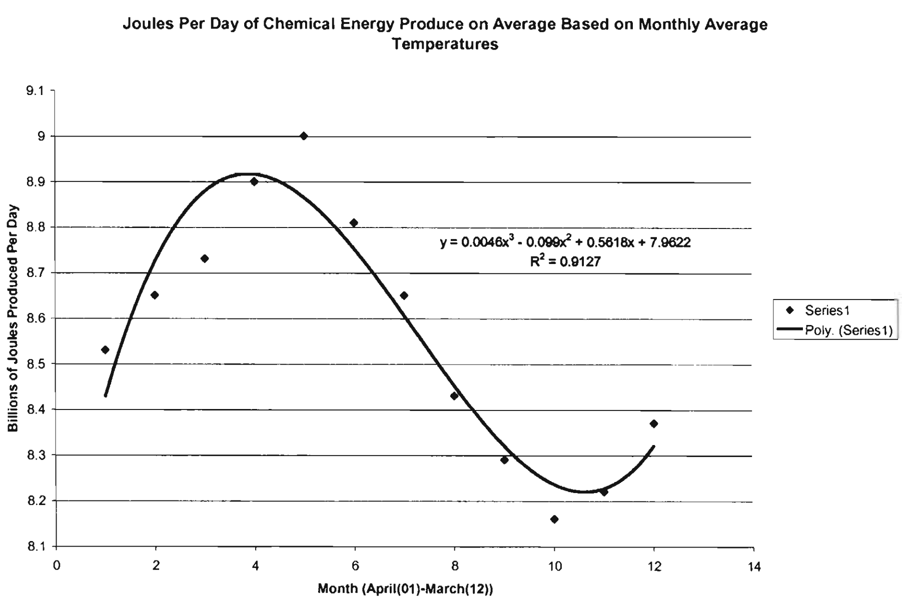


Figure 8 – Joules Per day of Chemical Energy Produced

To name a specific value for the amount of chemical energy produced by the plant in methane with confidence would be nothing more than naïve and misleading. This process is simply too young and untested to be able to say for sure how it will perform on a large scale basis, however, by scaling up the rates and values of Dr. Zhangs 1.8 liter prototype, might be able to give us a good idea of the range of the reactors output. The actual output will only be able to be determined with further prototyping. Having said that, we will now move on to the energy production estimations presented in the above graph. The first thing to be discussed in assessing the energy production is, of course, converting all of the variables and constants into metric, since it is much easier to communicate with the rest of the world in metric, as well as converting between units such as joules and kW*h's. Once again, since the energy production is directly proportional with daily capacity and NOT flush, or reactor sizes, once again we don't have to consider any calculations dealing with multiple flushes or separation of batches, we can simply use the projected daily capacity of 65 million gallons per day. Converting this into liters gives us 245 million liters per day. Using the tables in Appendix 8 we can fill in the entire heat production equation which is derived once again, in Appendix 8. With the heat requirement variable and projected capacity variable established, all of the factors and constants have been considered. An examination of the data is now possible, and design feasibility will be able to be determined in terms of heat energy input and output, all you have to do is use the tables of values (chemical energy of methane<variable>, average monthly temperature<variable>, the number of liters per gallon<constant = 3.7843L/Gallon> and the number of methane gas produced per liter of reactor space<constant = 7.61 L_M/L_R>) .

The ultimate goal in determining the chemical energy produced per day, and the heat energy required per day is to determine whether or not the plant is economically self sustainable. According to our calculations, only during three months of the year does the required heat input exceed the amount of chemical energy produced, and in these three months, the balanced heat equations value is really rather close to zero considering the enormous amounts of energy it produces in its "hot season." Seasons are an important term when considering Anaerobic Digestion, they refer to the times when a reactor is self sustainable without stores of energy, and when it is not. We have shown, that for our process, even with a safety factor of four times projected negatively impacting values, we have managed to bring our cold season down to just less than three months. This is a very good length for a reactor cold season, especially considering the only other major plant to come close to that that actually exists has a cold season of almost 5.5 months (Bucklin Point, also in Rhode Island, but seriously subsidized by the government, and crippled as a viable business by their low methane conversion efficiency and really high HRT's (almost 2 weeks as compared to our 6 hours). What is left is the required heat per day, which is in the range of $(1.81) \times (10^8)$ joules per day to $(3.62) \times (10^8)$ joules per day. With heat per day calculated, all of the variables and constants are compiled on a threshold graph. Going in the x direction of Figure 8 will lead you along with the date, providing a monthly interpretation of the year. In the y direction the graph is defined by data points that include temperatures, joules per day required, joules per day produced, and the joules per day required. Combining these together with all the other data, variables, and heat plots for the input and output, will give a description of the threshold plot. This plot was designed to contain all of the important data points used in this section, and providing them to the reader in a complete one page, easy to follow graph. Please do not get us wrong, this graph is not meant to be read and understood by people who have not read our paper yet: a good understanding of the heat balance of an anaerobic system is required to understand anything of value from the plot. The plot is as follows, with the data key in the lower middle-left hand side of the center:

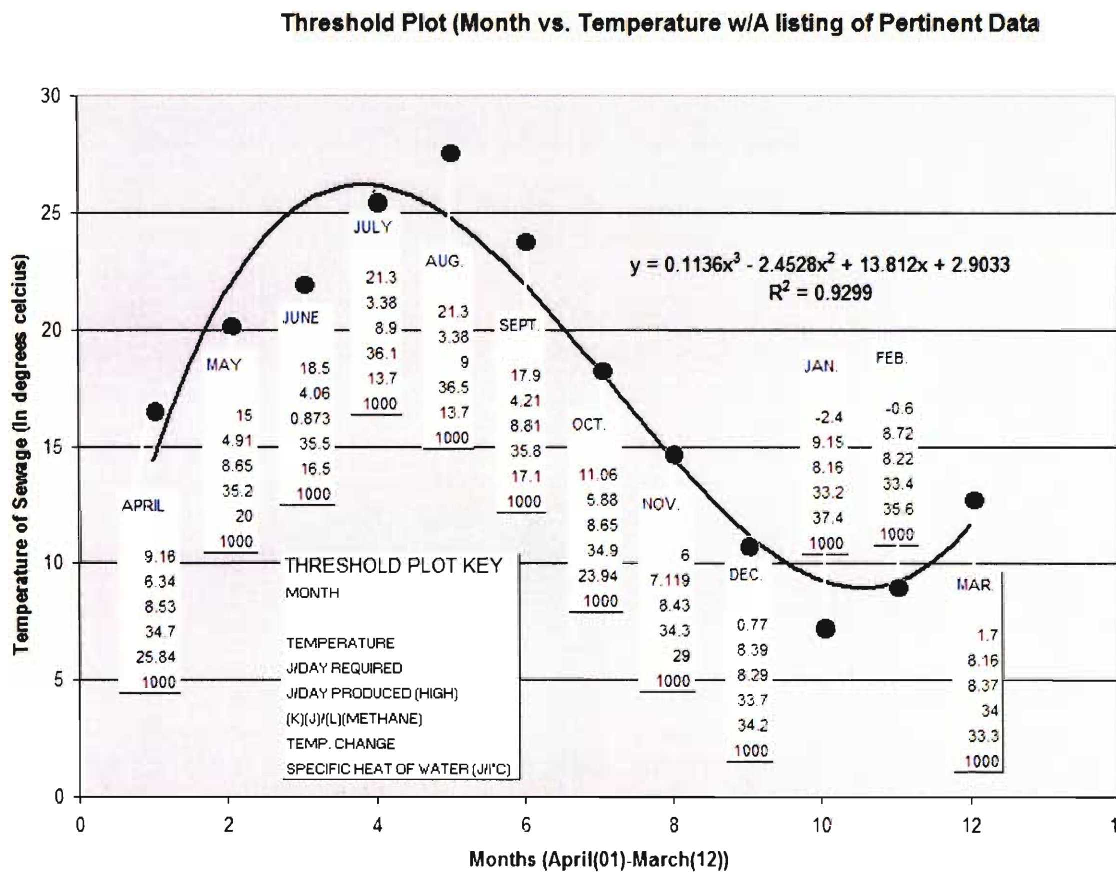


Figure 9 – Threshold Plot

The plant design is complete in terms of statistical data. Remaining to be done is to convert that data into a working projection by demonstrating what the data implies in terms of methane energy that is harvestable in terms of methane energy required to be stored or sold as futures in order to ensure the reactor will run through its cold season. The following is a graph of the total chemical energy produced minus the total amount of heat energy required top keep the system running:

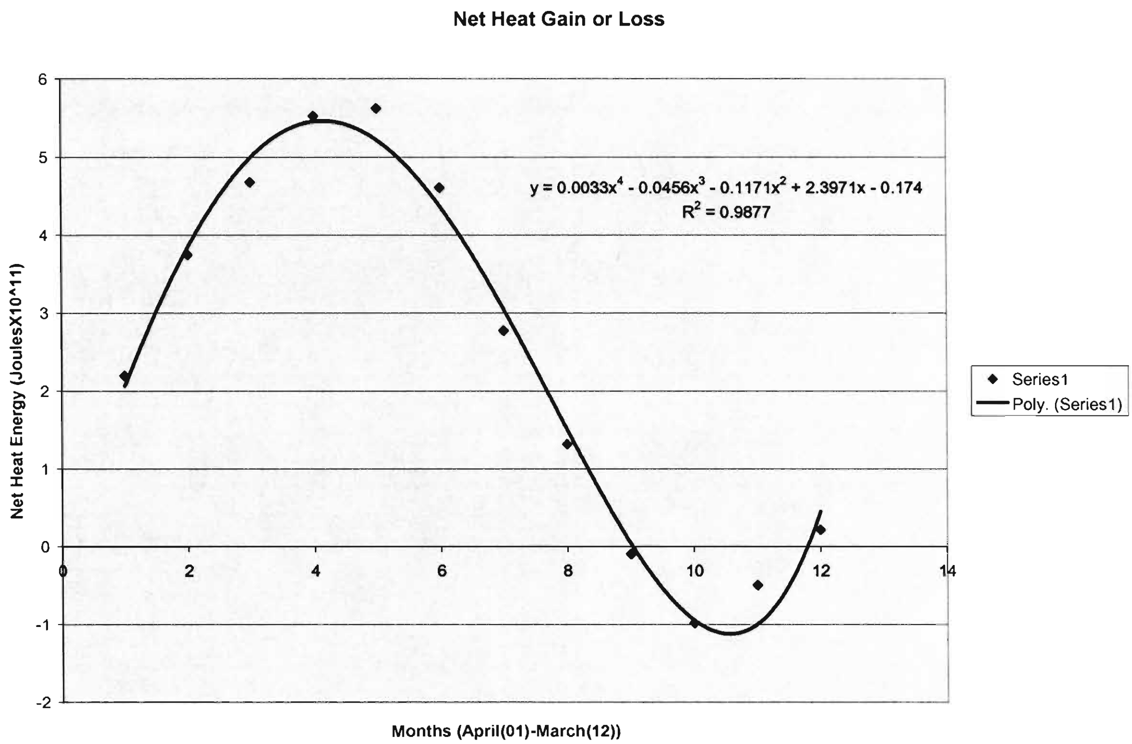


Figure 10 – Net Heat gain or loss

To determine the net methane of the facility, the sewage input in terms of liters per day must be multiplied by energy per liter of methane. Next, multiply this by liters of methane per liter of reactor space (7.61 liters of methane per liter of reactor space). Resulting is a range of methane energy produced, which is 8.892 x (10^9) joules per day to 8.015 x (10^9) joules per day.

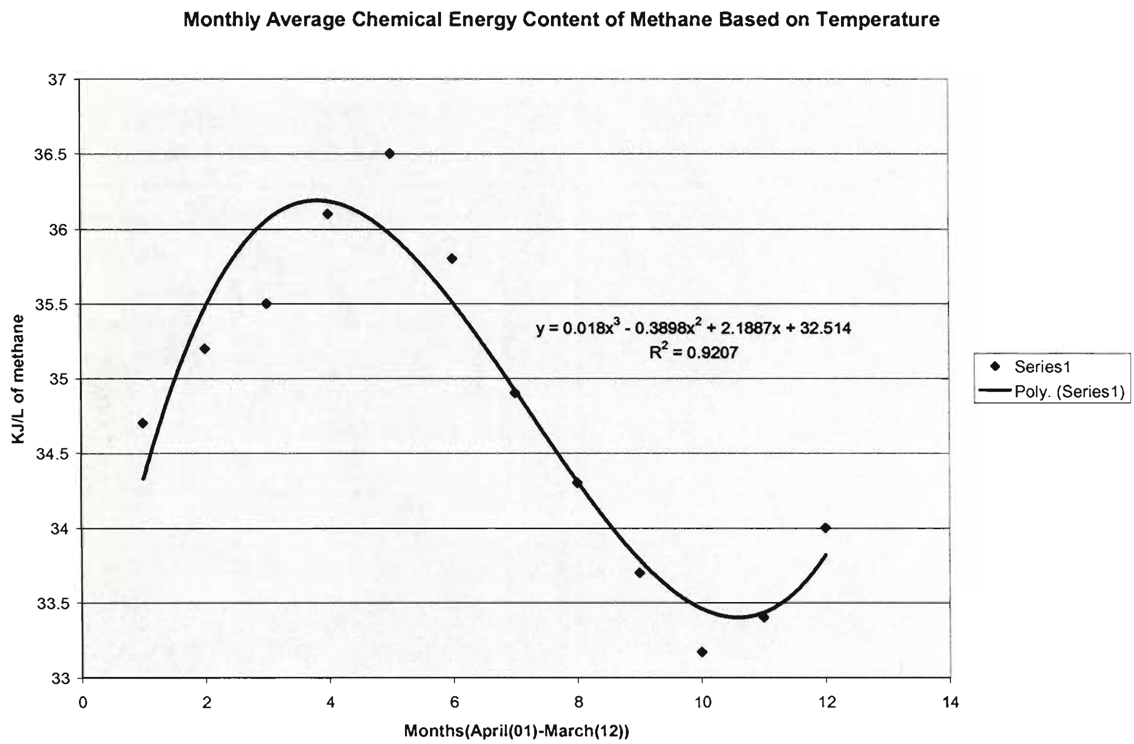


Figure 11 – Monthly average chemical energy content

As shown in Figure 12 by all the data surrounding the implementation of the variables and the constants involved in the design process, the anaerobic based facility will work because the energy required to run the system is fully compensated by the energy produced, even greatly overcome. The plot below is a monthly time plot of the average daily chemical energy production minus the average daily heat energy required by the process. As you can see, the total average single day per month test (a total of twelve days per year reflecting the average heat requirements and energy production fluctuations that are inherent to the process with climate change).

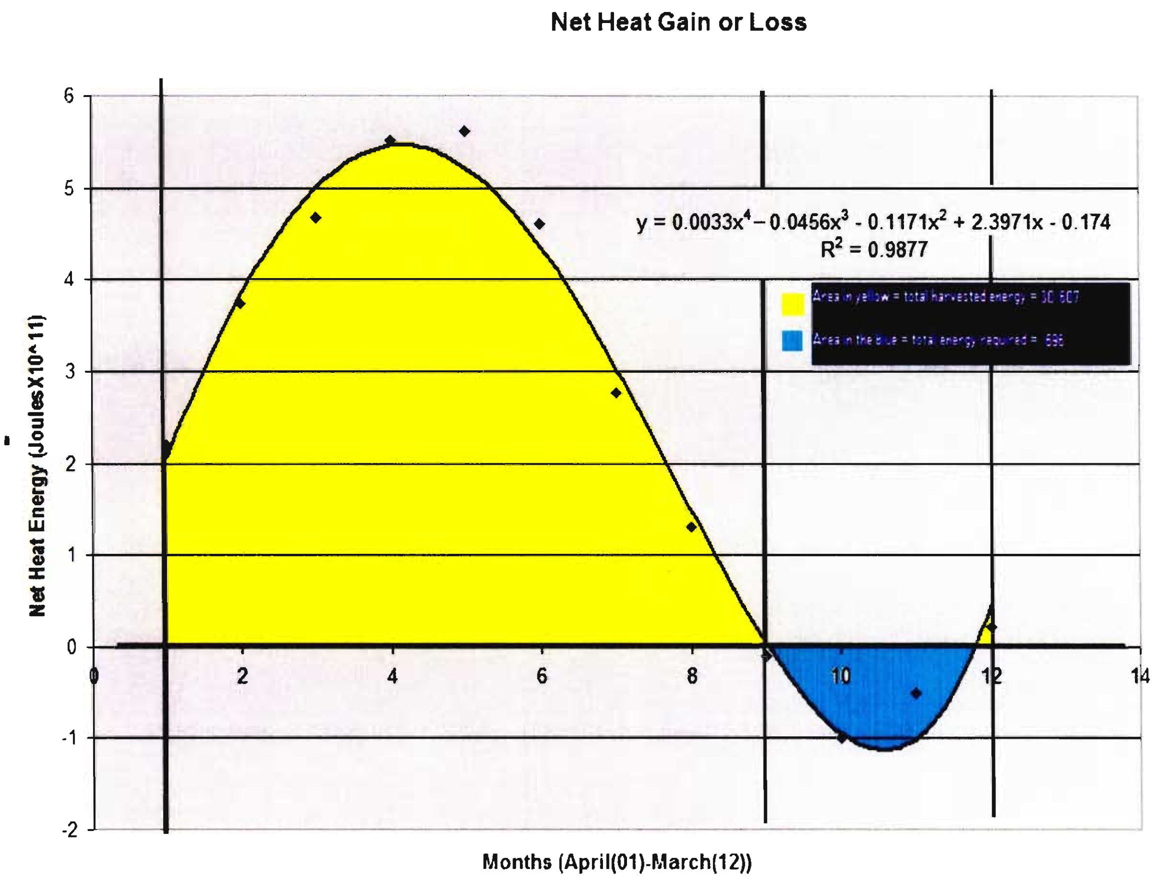


Figure 12 – Net heat gain or loss

These 12 sample days can be multiplied by 30 to give a better picture of the massive year end productions of methane energy as compared to the heat energy required to be expended. The final values are as follows:

Chemical Energy of Methane Produced:	918.21 trillion joules
Total Heat Energy Used:	20.901 trillion joules
Total Energy Bottom Line:	897.309 trillion joules per year

This total year long energy balance clearly shows that the plant will theoretically produce on average almost 44 times more energy than it uses. This final heat balance analysis shows that if the process can be scaled up to this size while still keeping within the desired tolerances and constants used for this simulated model. Due to the facilities revenue from fertilizer, the cost of this energy is essentially free, pending the actual results of the Anaerobic Digestion Process at this scale..

4.4 Operation

The Anaerobic Digestion Facility will operate year round, utilizing and or selling as much of the methane gas produced as possible, and storing the remain gas in tanks. During the initial stages of the facilities operation there will be a period of time before a useable quantity of methane can be produced. For this reason, the initial start up of the facility will require funding for the fuel of the fleet of trucks, as well as the electrical generators for the operation of the facility. Once the facility has reached an acceptable level of material in all tanks, the methane gas production will be enough to keep the facility self sufficient.

The employees required to operate facility consist of five major departments, management, maintenance, research and development, sales engineers, and the truck drivers. Management consists of the company president, a head of each department, who oversee their respective departments and are responsible for all scheduling and hiring for their respective departments. The maintenance department will require 20 to 30 people with mechanical ability to operate and repair the various pumps and stirring equipment throughout the facility. Research and development will consist of about 10 to 20 people and can be divided into two different sub-level departments, fertilization and Anaerobic Digestion. These two teams of engineers will be assigned to work together to develop better methods for using the process and the facilities equipment to create usable products. The sales department is named sales engineers because there is some customization that must occur for each farm. Firstly, each farm will produce different crops and each crop requires different nutrients at different times of the season, therefore it is up to the sales engineer to determine by discussing the matters with the farmer, which dates and methods will work best for his crop. Secondly, the sales engineer will be responsible for the continued relationship with each of the farms, performing the necessary soil tests after the application and during the growing season, and filing all of the necessary forms and paper work with the local and state governments. The sales staff requires between 20-30 people, working year round to acquire customers until the facility has reached its maximum level of out put. Finally the fleet of truck drivers is directly related to the number of trucks that the facility has obtained at this point.

The production of fertilizer will also occur year round, and stored in underground tanks until the beginning of spring before crop seeds are planted, and for certain crops, another fertilizer spreading after the vegetative growth has matured. The time span for spreading the fertilizer before seeding is small. For this reason the facility requires a substantially large fleet of trucks. During times of fertilization the entire fleet will be fitted with dirt tires and attached with fertilizer spreader for fertilizer delivery to participating farms. For the remaining months of the year the fleet will be mounted with regular on road tires and spend time removing the wastes from various locations for processing at the Anaerobic Digestion Facility.

Provided the projections of this project are correct, which can only be determined after a facility of this size and nature has been constructed and operated for around a years time, the facility will generate more fertilizer and methane gas than it can use or distribute, and will be required to look for other means of using these produced resources. Some of the potential areas for distribution are to cities and towns which use methane powered municipal vehicles like garbage trucks and busses for example.

5 Feasibility Analysis

5.1 Legal Feasibility

In order to operate a waste water treatment plant in the state of Rhode Island there are a few different applications that our Waste Water Power Plant must complete as well as their respective policies that the plant must adhere to. Our facility under Rhode Island law is considered to be a major project, or the construction of an "advanced waste water treatment facility". In order to construct a facility of this nature, the owner of the facility must apply to the Commissioner or the Director of the Department of Environmental Management for an Order of Approval. This application must be submitted at least ninety (90) days prior to operation along with a fee of $150.00 per application along with plans, specifications and an operating plan as stipulated in Rules and Regulations for the Treatment, Disposal, Utilization and Transportation of Sewage Sludge document by the State of Rhode Island Department of Environmental Management. [9]

Due to the fact that we will need to transport the biosolids from other waste water treatment facilities in the state, as well as transporting the fertilizer to its final destination, the preferred mode of both of these materials transportation is by truck. The only regulation around the transportation of sludge is that it must be transported in vehicles which are properly sealed, watertight and covered while in transit so as to prevent any leaking or dropping of sludge, composted sludge or treated sludge.[9]

When determining a location for our facility, we will have to take in special consideration to what kind of land is surrounding the property our facility sits on. During our proceeding with the Commissioner or the Director of the Department of Environmental Management for an Order of Approval, at a minimum all of the owners of the abutting plots of land will be invited to voice their opinion, as well a public hearing to allow the public to voice their opinion on the application. The Director of the Department of Environmental Management will simply be referred to as the commissioner for the remainder of this section.[9]

The sewage that will be treated at our location will eventually produce fertilizer that can be used to feed plant life. There are a few different way to dispose of treated sewage as well as different classes of the levels of toxicity which determine where the treated sewage/fertilizer can be applied. The first method for the disposal of treated sewage that is not hazardous waste although still has some levels of toxicity is called Land Disposal. Due to its inherently dangerous health risks, land disposal has a long list of regulations put in place to protect Rhode Island's drinking water. To start with the site of the disposal of the treated sludge must not fall within 200 feet of a body of water surface, or within 1200 feet of a freshwater river.[9] Also if the site in question is part of the watershed of any surface water used as a public drinking supply, not if it lies within 1000 feet of a private drinking water well. Finally, the sludge can not be disposed of within 600 feet of a domestic, commercial, or industrial building as well as within 200 feet of a property line.[9]

For the purpose of monitoring the condition of the ground water, the Commissioner may require the installation of approved monitoring devices of which the treatment facility will be required to fund. The sites of which the sludge is to be disposed of must have an implemented drainage system to prevent excessive runoff into un monitored areas as well as to prevent the collection of standing water on the surface. Once the fertilizer or treated sludge is applied, it must be covered by six inches of soil daily for four days, meeting the requirement of two feet of soil after the treated sludge application.

Another method of disposal is the Land Application of treated sludge, which is less hazardous than the previously mentioned Land Disposed of sludge, for use as fertilizer. The regulations are very similar although less strict than the previously mentioned. The regulations that limit the amount of sludge that can be applied to land for the purposes of fertilizer are set by the U.S. Department of Agriculture at the point where the soil has been supplied with the adequate amount of nitrogen for crop production using good agricultural or silvicultural practices. Land application of sludge is restricted to Class A Biosolids Sludge, while land disposal can accept classes A, B, and C. [9]

The use of this type of fertilization for food crops is permitted by law, although there are large time restrictions placed. The soil of food crops of which the portion consumed by humans grows above ground must wait 14 months before harvesting after application. The soil for food crops which grow under ground in the same sludge fertilized soil must wait a total of 20 months before they can be harvested from. Due to this restriction, the use of this fertilizer will be restricted to farms which alternate fields during growing season. Although, there is no restriction placed on the use of the sludge for silvicultural fertilization, forestry for example. Animals are not allowed to graze on treated soil for a period of thirty days.[9]

Both the land disposal and the land application of sludge require numerous amounts of documents and testing to be done before the application of the fertilizer. A Submission of Approval as its called consists of proof that the site meets all of the requirements in the rules its respective application process. A radius plan for example, by a land surveyor will outline all of the surrounding area as well as the condition of the soil. [9] The chemical, mineral, and bacterial requirements of Class A Biosolid sludge can be found in Appendix 7. The reason why the other forms of biosolids requirements are not included in this project is because Class A Biosolids is the only class which the Anaerobic Digestion Facility produces.

5.2 Technical Feasibility

We think that it is important to point out, at least somewhere in this paper, that this entire process and all of the calculations derived from it is completely based on theoretical analysis. All of the processes and technologies we are proposing have not been utilized on a large scale basis ever. In fact the largest running prototype of any of our systems, has been 1.8 liters. This project is mainly supposed to propose what looked to us to be the most feasible course of investigation for a large scale analysis.

5.3 Economic Feasibility

To determine the economic feasibility of an Anaerobic Digestion facility the most likely revenue streams have to be located in order to provide any investors with an acceptable rate of return. The most feasible revenue stream to begin the operation of the facility was determined to be the removal and treatment of bio-waste and eventually the application of fertilizer pose the best opportunity. The sale of electricity while larger in theory is not as predictable as revenue from agriculture. These two markets are complimentary to each other, where the same customer, or farm, which produces the bio-waste, can also make use of the nitrogen rich fertilizer which can be harvested after the Anaerobic Digestion process.[3] Creating these relationships between our facility and the farmers will cut their manure removal costs as well as cut their fertilizing costs. As explained in more detail in the technical feasibility section above, the methane gas harvested from the decomposition and the Anaerobic Digestion process will be used to control all of the electricity and heating costs for the facility, as well as the fuel for the fleet of transport vehicles for the sludge and fertilizer. By reducing the operating costs to minimal or nothing the revenue generation ability of the facility increases tremendously.

The chosen territory in which the fleet of transport vehicles will travel at the moment has been restricted to New England states only. According to statistics in the 2002 Census of Agriculture [10] the total number of farms applying fertilizer in New England is about 47,000 and the total number of acres in these farms amounts to about 2.75 million acres which were treated with natural and chemical fertilizers. These numbers make up our feasible target market. Revenue estimations are made by estimating the percentage of market capture within a range beginning at 2% and ranging up to 10%, then by raising or lowering the amount of charge per gallon of liquid fertilizer produced, the total revenue we theoretically will received can be calculated, similarly the per acre and average per farm charge for the fertilization of fields. Please see attached excel chart for details.

The price to farmers for the fertilizer and waste management will not be exact due the variances in types of fertilizer required for different major crop types. Depending on the nutrient requirements, fertilizer mixtures will be premixed before transport to the farms for application. With the amount of liquid fertilizer tanks, the major types of fertilizer for each application season can be produced in mass quantity for the major crops of New England. This ability to provide a mass quantity of fertilizer will allow the facility to be the sole provider of fertilizer to many New England farms. We can estimate the price to farmers based on their current rates of fertilizer spending. According to a study done at the North Carolina State University [11], the average price for an acre of fertilization for crops such as corn, tobacco and wheat, is around $200.00 yearly. By adjusting the price of the fertilizer, taking in considerations for any extra additives that must be used to balance the nutrient levels to the proper amounts, to a number which either matches or beats the average price per acre farms in our target area currently pay, we expect to receive between two and ten percent of the target market. The added benefit for the farmer in this situation is the reduced or eliminated cost of waste removal incurred. Waste removal costs for farmers are always increasing due to the limited amount of space in landfills.[11]

The legal regulations to applying any form of biosolid treated fertilizer or sludge to land are extensive due to the overwhelming cost to treat this type of material as well as the hazards that would be caused by improperly treated sludge that is applied to land. Due to the advancements in the process that have been outlined in the previous sections, this facility will produce only fertilizer which can be applied without fear of contamination, although because the laws are older, the same rules still apply to this facility as other waste water treatment facilities. This facility along with every location where the fertilizer is to be applied must complete a Submission for Approval, therefore one of the responsibilities of this facility will be to not only complete all of the paper work associated with the land application of this fertilizer, but also to monitor ground water levels as well as metals content of the soil as outlined by the state of Rhode Island. Doing this will take all of the legal burden off of the farmers, and put it in the hands of professionals who complete these forms all of the time. [9]

Agriculture and food processing will be the two largest sources of customers for this facility. The facility sales engineers will develop relationships with these small businesses and determine the price of its service on a client to client basis, due to the many difference in supplies entering the facility, as well as the differences in products produced by the facility. Due to the expense created in the shipping of treated or untreated material, it would be entirely too costly to operate without a fleet of trucks for dry and liquid transport of sludge. The relationships with agriculture industries in the surrounding areas pose the greatest market for long term co-dependencies due to the recycling process. Also, while the food processing industry does not use the product this facility creates, they do have the expense of removing the waste created during their processes, which can be completely eliminated, minus the expense of this facilities trucking service.

The trucking portion of this facility will consist of a combination of three trucks, and will most likely be the second biggest cost of development due to the increase in the facility's profitability for the greater amount of material it can process. With the quantity of trucks that this facility will require for this operation, to buy them used would cost more than buying them in new, because of the savings when ordering such a quantity. The facility requires transport of liquids and solids, as well as the application or the injection of the liquid fertilizer. The quantity or trucks is especially high because of the immense quantity of liquid fertilizer that the facility will produce, and the application of liquid fertilizer is not only easier, but also faster in terms of the whole digestion process until the treated sludge or fertilizer is applied to the field. The cabs used for the transport of materials will be Peterbilt Government Utility Type Tankers with cab model number 335. Compared to other tanker truck companies, the Peterbilt trucks offer the highest longevity and lowest lifecycle costs in the industry, at about the same prices of other truck manufacturers, also they offer custom specking options and body installation packages so we can customize them for our purposes. [5] The projected market capture ranges from two percent to ten percent, for our purposes we have determined feasibility at the largest level of market capture which is ten percent. The time span in which the fertilizer must be distributed to the projected market capture of farms is about two months. This means that the facilities truck fleet must apply fertilizer to fields at a rate of about 80 farms per day. To accomplish this distribution the facility will require 60 of these vehicles, at a cost of about $50,000 each after the bulk discount; this number may increase in the future if the speed of digestion increases or if more or larger tanks are built. The trailers we will require are split into three categories, the dry transporters, the liquid transporters, and the fertilizer application trailers. The dry trailers will be used to transport dry solid waste from various locations, cornstalks and news papers for example, and the tanks will be used for the transport of liquid material like biosolids from waste water treatment facilities. For this service the facility will require 30 of the dry trailers and 30 of the liquid trailers. The average cost of each one of these trailers is about $45,000. In addition there is a necessity for trailers to apply the fertilizer to the farms. The facility will require 30 trailers which can be purchased through Newton Crouch Inc. and cost about $25,000 each. In addition the facility must purchase 30 sets of dirt tires to give the truck cab the ability to traverse over the farmland spreading the fertilizer, at a cost of about $600 a set. During the fertilizer spreading season on average 50% of the farms will require us to apply the liquid fertilizer for them, the other 50% have their own means of liquid fertilizer application already at the farm. For this reason, the distrubition of the fertilizer will be done by the spreaders and the 30 remaining trucks and liquid transport tankers.

Other sources of income exist that have not been mentioned in this economic feasibility analysis. These include the sale of electricity that is not used by our facility, and cost saving attributed with Waste Water Treatment Facilities in Rhode Island having to dispose of partially treated or untreated biosolids. The sale of fertilizer and the removal of bio-waste will be able to continue the operation of the facility until these other forms of revenue generation can be fully researched and tested.

Another potentially large cost for the facility is the quantity of liability and automobile insurance necessary. The facility will take every measure to prevent problems, although in case something were to happen, the facility must be prepared. The amount of liability insurance required is estimated at five percent of our yearly revenues, for a two percent market capture, an amount of $500,000. Automobile insurance for the trailers will be around $3000 per year per cab, and half that for each of the trailers, for a total auto insurance cost of $315,000.

In conclusion, as you can reference in the Appendices 5 and 6, the construction and operation of the Anaerobic Digestion Plan will require funding in the amount of $307.03 Million. This amount, after adding in compounded interest, will require approximately an average of 16 years until the facility's revenues reach the break even point based on three different market projections. Due to the very low operating cost of the facility the facility will continue to generate profit due to the approximately 30 year life span of its fixed capital resources.

6 Conclusions

Originally, this project was designed to see how close to breaking even an Anaerobic Digestion plant could get based on modern technologies, due to the fact that the technologies implemented in all current large scale plants was not economically feasible as a stand alone process. The Anaerobic Digestion process is interesting because it provides a method of sewage treatment which produces almost no pollutants. The three main forms of income of notable size are government sewage treatment fees (the taxpayer money that goes toward sewage treatment), fertilizer (the main non-gaseous product of the system), and energy. Energy is the most profitable of the three producing an estimated 6.8 billion joules of energy per day, or roughly 18.9 million kilowatt hours per day (corresponding to approximately $1.26 million worth of possible electrical sales per day in Rhode Island). Upon our investigation into the leading edge technologies in this area, and subsequent scaling to size and combining the four new processes, we found that not only is the plant system viable, but it is so efficient that any one of its three main incomes are enough to support the plant financially. Notice that we did not do an extensive economic feasibility analysis about the electrical production. This is due to the fact that the electricity production of the plant could only be measured at the very end of the project, once all of the scientific research into the process was completed. Earlier in the life of the facility the revenue generation will focus primarily on the fertilizer sales, because the numbers from the fertilizer sales are much more concrete and accurate than the energy production analysis. This is largely due to the fact that no matter how much sewage you take in, if it is human waste approximately the same proportion will always come out of it as methane. The energy generation is largely dependent on atmospheric temperature, the intensity of the sun, and very new observational data on a small prototype scaled up almost 36.5 million times it's actual size. The particular sizing on this plant was made to match the average main treatment plant size for a small state, or approximately the ability to handle 65 million gallons per day.

Appendices

A1. Rhode Island Municipal Waste Water Treatment Facilities

WASTEWATER TREATMENT FACILITY/SUPT.	POPULATION CENSUS 2000	ESTIMATED POPULATION SERVED BY SEWERS	DESIGN FLOW (MGD)	AVERAGE DAILY FLOW (MGD)	MAJOR TREATMENT SYSTEMS
Town of Bristol **Matthew Calderiso** Bristol Sewer Commission 2 Plant Street Bristol, RI 02809 TEL: 253-8877 FAX: 253-2910	22,469	16,900	3.8	2.8	RBC's Chlorination Dechlorination
Town of Burrillville **John E. Martin, III** Burrillville WWTF PO Box 71 Harrisville, RI 02830 TEL: 568-9463 FAX: 568-9464	15,796	8,000	1.5	0.7	Activated sludge Chlorination Phosphorous reduction Dechlorination
City of Cranston **(US Filter-PSG)** **Christian Bratina** Water Pollution Control Facility 140 Pettaconsett Ave. Cranston, RI 02920 TEL: 467-7210 FAX: 781-5260	79,269	77,000	19	13.2	Activated sludge Chlorination Dechlorination
Town of East Greenwich **Joseph Macari** East Greenwich Town Hall PO Box 111 East Greenwich, RI 02818 TEL: 886-8649 FAX: 886-8652	12,948	2,500	1.24	0.8	RBC's Chlorination
City of East Providence *serves*: East Providence Barrington **Tom White** E. Providence WWTF Crest Ave. Riverside, RI 02915 TEL: 433-6363 FAX: 433-4059	 48,688 16,819	47,935 39,000 8,835	10.4	6.7	Activated sludge Chlorination Dechlorination

Town of Jamestown **Douglas Ouellette** Jamestown Sewer Division 44 Southwest Ave. Jamestown, RI 02835 TEL: 423-7295 FAX: 423-7229	5,622	1,720	0.75	0.4	Extended Aeration Chlorination
Narragansett Bay Commission **Bucklin Point** *serves*: Central Falls Cumberland East Providence Lincoln Pawtucket Smithfield **John Oatley** NBC-Bucklin Point WWTF 102 Campbell Ave. East Providence, RI 02914 TEL: 434-6350/222-2220 FAX: 438-5229	 18,928 31,840 48,688 20,898 72,958 20,613	<u>119,809</u> 17,637 11,093 8,852 9,433 72,644 150	46	23.1	Activated sludge Chlorination Dechlorination
Narragansett Bay Commission **Fields Point** *serves*: Johnston North Providence Providence **Carmine Goneconte** NBC-Fields Point 2 Ernest St. Providence, RI 02905 TEL: 461-8848 FAX: 461-0170	 28,195 32,411 173,618	<u>208,743</u> 15,925 32,090 160,728	65	45.5	Activated sludge Chlorination
Town of Narragansett **Scarborough Facility** **Doug Nettleton** Narragansett Town Hall 25 Fifth Ave., P.O. Box 777 Narragansett, RI 02882 TEL: 782-0682	16,361				Dechlorination

City of Newport (Earth Tech) *serves*: Middletown Newport U.S. Navy Base **Shaun Niles** Newport WWTF 250 J.T. Connell Highway Newport, RI 02840 TEL: 845-2000 FAX: 845-2014	 17, 334 26,475	38,385 7,435 20,950 10,000	10.7	8.4	Activated sludge Chlorination
New Shoreham **Ray Boucher** New Shoreham Sewer Commission PO Box 220 New Shoreham, RI 02807 TEL: 466-2027 FAX: 466-3237	1,010	750-winter 8,500-summer	0.3	0.1	Extended aeration Chlorination Dechlorination
Quonset Point RI Dept. of Economic Development **Dennis Colberg** Quonset Point WWTF 1330 Davisville Rd. North Kingstown, RI 02852 TEL: 294-6342 FAX: 294-7927		6,000	2.35	1	RBC's Chlorination
Town of Smithfield (US Filter-PSG) **Steve Wold** US Filter Operating Services PO Box 17249 Smithfield, RI 02917 TEL: 231-1506 FAX: 231-7089	20,613	13,000	3.5	1.4	Activated sludge Chlorination Dechlorination
South Kingstown Regional WWTF *serves*: Narragansett South Kingstown University of RI **Bernard Bishop** South Kingstown Town Hall 180 High St. Wakefield, RI 02879 TEL: 788-9771 FAX: 789-3070	 16,361 27,921	25,396 8,982 9,771 6,643	5	2.4	Activated sludge Chlorination Dechlorination

Town of Warren **(Woodward and Curran)** **David Komiega** 427 Water St. Warren, RI 02885 ADD3 TEL: 245-8326 FAX: 245-8713	11,360	8,000	2.01	1.8	Activated sludge Chlorination Dechlorination
City of Warwick **Joel Burke** Warwick Sewer Authority 300 Service Ave. Warwick, RI 02886 TEL: 739-4949 FAX: 739-1414	85,808	28,000	5	3.4	Activated Sludge Chlorination
Town of Westerly (Aqua Source) **Scott Duerr** Weston & Sampson P.O. Box 2924 Westerly, RI 02894 TEL: 596-2847 FAX: 348-9504	22,966	10,000	3.3	2.5	Activated Sludge Chlorination
Town of West Warwick *serves*: Coventry Warwick West Warwick **Michael Roberts** West Warwick Regional WWTF 1 Pontiac Ave. West Warwick, RI 02893 TEL: 822-9228 FAX: 823-3620	 33,668 88,808 29,581	30,000 804 1,282 28,272	7.9	5.2	Activated Sludge Chlorination
City of Woonsocket (US Filter-PSG) *serves*: North Smithfield Woonsocket Blackstone, MA **Roger Boltrushek** Woonsocket WWTF 11 Cumberland Hill Rd. (rear) Woonsocket, RI 02895 TEL: 762-5050 FAX: 762-5143	 10,618 43,224 8,804	52,200 2,700 48,000 1,500	16	9.3	Activated Sludge Chlorination

New England Treatment Company/SYNAGRO **Michael Madden** NETCO 15 Cumberland Hill Road Woonsocket, RI 02895 TEL: 765-6764	-	-	-	-	Sludge incineration

A2. Facility Construction Companies (RI)

Name	Address	Phone	Web	Email	Contact Name
BMCO Industries Inc	159 Frances Avenue, Cranston, RI 02910	(401) 781-6884	http://www.bmcoindustries.com		
Aquarion Services Company	87 Margin, Westerly, RI 02891	(401) 596-2847			
Aquatronics Industries Inc	865 Waterman Avenue, East Providence, RI 02914	(401) 438-5140			
Geremia James J & Associates Inc	272 West Exchange Street, Providence, RI 02903	(401) 454-7000			
MGD Technologies	789 Broadway, East Providence, RI 02914	(401) 431-6431			
MGD Technologies	225 Newman Avenue, Rumford, RI 02916	(401) 431-6431			
Professional Services	Esmond Mill Drive, Smithfield, RI 02917	(401) 231-1506			

A3. Rhode Island Water Resources Department Information

Name	Address	Phone	Web	Email
Office of Water Resources	235 Promenade Street, Providence, RI 02908	(401) 222-3961	http://www.state.ri.us/dem/programs/benviron/water/index.htm	wresourc@dem.state.ri.us
Art Zeman	Director of Facility Design			art.zeman@dem.ri.gov
Bill Patenaude	Inspector of Operation & Maint.			bpatenau@dem.state.ri.us
Department of Environmental Management	235 Promenade Street, Providence, RI 02908-5767	(401)222-6800		

A4. Construction Cost Evaluation

The reactors we are intending to build have never been built on such a scale as we are suggesting. In fact the largest reactor of the type we are proposing has never been larger than 1.8 liters so the construction cost is rather difficult to determine. For every gallon of reactor space in a regular anaerobic digester of the same volume, there is approximately 1.5 gallons in our system (due to the second set of reactors used in hydrolysis). However, the hydraulic retention time of the reactor is ¼ that of a regular plant. This is considering a safety measure of 400% as our digester has an HRT of roughly 1/16 that of a normal plant, but this safety factor is reasonable as this whole process is so unknown (we used the same safety factor for calculations throughout the paper). Knowing this, our reactor will need to be .375 the size of a plant that handles approximately the same daily load. In addition to this, we presented some of the construction details to Phil Richardson, a civil engineer my dad knew from college. He has been the head designer and construction foreman for almost every kind of building, form sewage treatment plants to malls. When we compared the materials and apparatus needed to construct the advanced plant vs. the old style plant, he estimated that the cost would be roughly 2.5-3 times as expensive to construct per liter of simultaneous reaction volume (the interior volume of the anaerobic digester not including the hydrolysis process). Now that we had our rough ratios worked out, we found out that the cost of the most recent plant built in the U.S. to serve as a full service sewage treatment plant was Bucklin Point in Rhode Island. This plant has an interior volume of 50 million gallons and had an approximate construction cost of $210 million. This number is not exact because Bucklin Point was not originally an Anaerobic Digestion plant, but was rather slowly brought into being one. At this point we need to convert the estimated cost of Bucklin Point and interpret it to a 65 million gallons per day capacity giving a projected cost of approximately $273 million if Bucklin Point was the same size. Multiplying by our constants gives us a projected construction cost of approximately $281 million. Unfortunately, this number most likely has a very larger error percentage, but due to the lack of information, this is the best guess we could come up with.

A5. Revenue Evaluation

	MA	ME	NH	VT	CT	RI	New England Totals
Commercial fertilizer, lime, and soil conditioners							
farms, 2002	2,945	3,053	1,318	2,473	1,978	451	12,218
acres treated, 2002	107,375	239,758	60,752	262,248	99,981	13,718	783,832
Cropland fertilized, except cropland pastured							
farms 2002	2,671	2,824	1,200	2,319	1,820	422	11,256
acres treated, 2002	99,678	230,385	55,538	244,028	93,310	12,746	735,685
Pastureland and rangeland fertilized							
farms, 2002	554	574	325	618	469	72	2,612
acres treated, 2002	7,697	9,373	5,214	18,220	6,671	972	48,147
Manure							
farms, 2002	1,498	1,928	955	2,187	1,141	170	7,879
acres treated, 2002	29,537	95,447	36,826	237,859	42,632	2,920	445,221

	Total Market Capture		2.00%		5.00%		10.00%
Total Farms Treated 2002	33,965		679		1,698		3,397
Total Acres Treated 2002	2,012,885		40,258		100,644		201,289
Charge Per Acre Treated	$250.00		$250.00		$250.00		$250.00
Total Yearly Revenue			**$10,064,425.00**		**$25,161,062.50**		**$50,322,125.00**
Average Acres Per Farm	59.26						
Average Total Per Farm Charge Per Year	$14,815.88						

A6. Return on Investment Evaluation

Cost Evaluation (Millions)

Fixed Costs
(millions)

Item	**Cost**
Construction	281
Truck Cabs	3
Truck Trailers	2.7
Fertilizer Spreaders	0.75
Labor	4.98
Insurance	0.05

	avg salary	number of	total
Truck Drivers	35000	60	2100000
Management	60000	7	420000
Maint	38000	20	760000
R&D	56000	10	560000
Sales	57000	20	1140000
Total			4980000

	Cost per market capture		
Variable Costs	0.02	0.05	0.1
SOA Fees*	0.1	0.25	0.5
Deprecation and maintance costs	2.81	5.62	8.43
Operation Costs Per Year	0.1	0.25	0.5
Total Fixed Costs	292.48		
Total Variable Costs	2.91		

Year	1	2	3	4	5	**5 Year Total**
Required Funds	100.40	100.40	100.40	2.91	2.91	307.03

Revenues	2% MC	5% MC	10% MC
	10.06	25.161	50.322

*Submission of Approval Fees required for the application of treated sludge to farmland at $150.00

101,895.00	254,737.50	509,475.00

2% MC Revenue Years Untill Repayment of Initial Investment =	30.519881
5% MC Revenue Years Untill Repayment of Initial Investment =	12.202615
10% MC Revenue Years Untill Repayment of Initial Investment =	6.1013076
Average 10% MC Revenue Years Untill Repayment of Initial Investment =	16.274601

A7. Class A Biosolids Limit

CLASS A BIOSOLIDS LIMITS

(A) Metals

METAL	LIMIT, mg/kg (dry weight)
Arsenic	41
Cadmium	39
Chromium	1200
Copper	1500
Lead	300
Mercury	17
Molybdenum	75
Nickel	420
Selenium	36
Zinc	2800

(B) Pathogens

The following pathogen limit must be met:

PATHOGEN	LIMIT
Fecal Coliform Bacteria	Less than 1000 Most Probable Number per 1 gram of total solids (dry weight)

A8. Reference for section 4.4

Appendix 8 is designed to function as a reference guide for section *4.4 Construction Plan*; containing equation sets, data tables, and diagrams that will serve as useful verification points in regards to the literature derived from them. Starting the appendix are the equation sets pertinent to the statistics contained within section *4.4*.

Input Capacity Conversion Equation Set

(65 mg/d) **x** (1 d/24hrs) **x** (3 hrs/flush)

Heat Energy Requirement Equation Set

Lower Heat Requirement = (65 mg/d) **x** (3.7843 l/d) **x** (9945 J/l°C) **x** (5.6 °C) =

(3.62 **x** *10^11 J/d)*

Upper Heat Requirement = (65 mg/d) **x** (3.7843 l/d) **x** (1003 J/l°C) **x** (27.78 °C) =

(1.81 **x** *10^13 J/d)*

Chemical Energy Output Equation Set

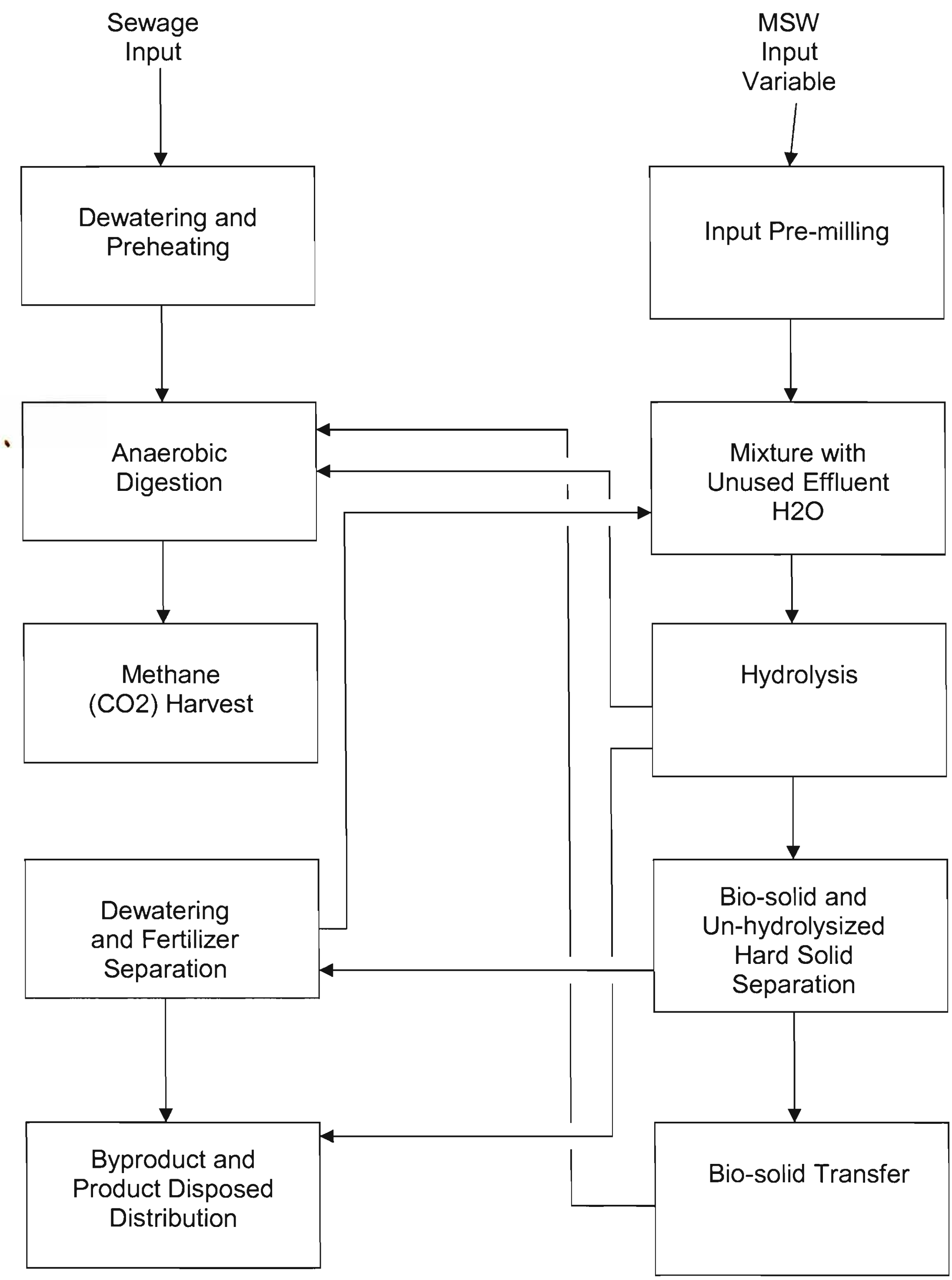
Upper Energy Requirement = (65 mg/d) **x** (3.7843 l/d) **x** (36.5 kJ/l of methane) =

(8892.84 mkJ/d) = *(8.89284* **x** *10^12 J/d)*

Lower Energy Requirement = (65 mg/d) **x** (3.7843 l/d) **x** (32.9 kJ/l of methane) =

(8015.74 mkJ/d) = *(8.01574* **x** *10^12 J/d)*

Below is a projected process flow diagram of an anaerobic based facility. There is great importance of creating a projection that serves as a layout for determining the sequential order of processes. The format resulting from the diagram will dictate the anaerobic facility's physical blueprint and act as a guide in the design procedure.



The process flow diagram entails much of the same characteristics as a process flow diagram for a current waste management facility such as, input pre-milling, mixture with unused effluent H_2O, hydrolysis, bio-solid and unhydrolysized hard solid separation, bio-solid transfer, and dewatering. Also, contained in the process flow diagram of an anaerobic facility are the steps involving the anaerobic process. As shown here, after the normal bio-solid treatment procedure hydrolysis is complete, the remaining product can than be processed through anaerobic digestion tanks to further break down the bio-solid into a usable byproduct. Likewise, incoming sewage can now be directly fed into the anaerobic tanks. Due to the nature of the anaerobic process, a much more efficient procedure for breaking down the sewage is being used, thus providing a drastically better output ratio of untreatable substance. Demonstrated in the diagram and talked about previously are two main anaerobic factors; the incoming sewage is immediately treated by digestion, and treated bio-solids can be further processed after hydrolysis by digestion.

Lastly for Appendix 8 are the data tables referred to in section *4.4 Construction Plan*. Below are self titled data tables that require no explanation due to the fact that they are simply data tables, or collections of statistical characteristics and calculations.

Threshold Plot												
DATE	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
TEMPERATURE	9.16	15	18.5	21.3	21.3	17.9	11.06	6	0.77	-2.4	-0.6	1.7
J/DAY REQUIRED	6.34	4.91	4.06	3.38	3.38	4.21	5.88	7.119	8.39	9.15	8.72	8.16
J/DAY PRODUCED (HIGH)	8.53	8.65	0.873	8.9	9	8.81	8.65	8.43	8.29	8.16	8.22	8.37
(K)(J)/(L)(METHANE)	34.7	35.2	35.5	36.1	36.5	35.8	34.9	34.3	33.7	33.2	33.4	34
TEMP. CHANGE	25.84	20	16.5	13.7	13.7	17.1	23.94	29	34.2	37.4	35.6	33.3
SPECIFIC HEAT OF WATE	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

(J/(L*C))

Monthly Required Heat												
DATE	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
JOULES PER DAY	6.34	4.91	4.06	3.38	3.38	4.21	5.88	7.119	8.39	9.15	8.72	8.16

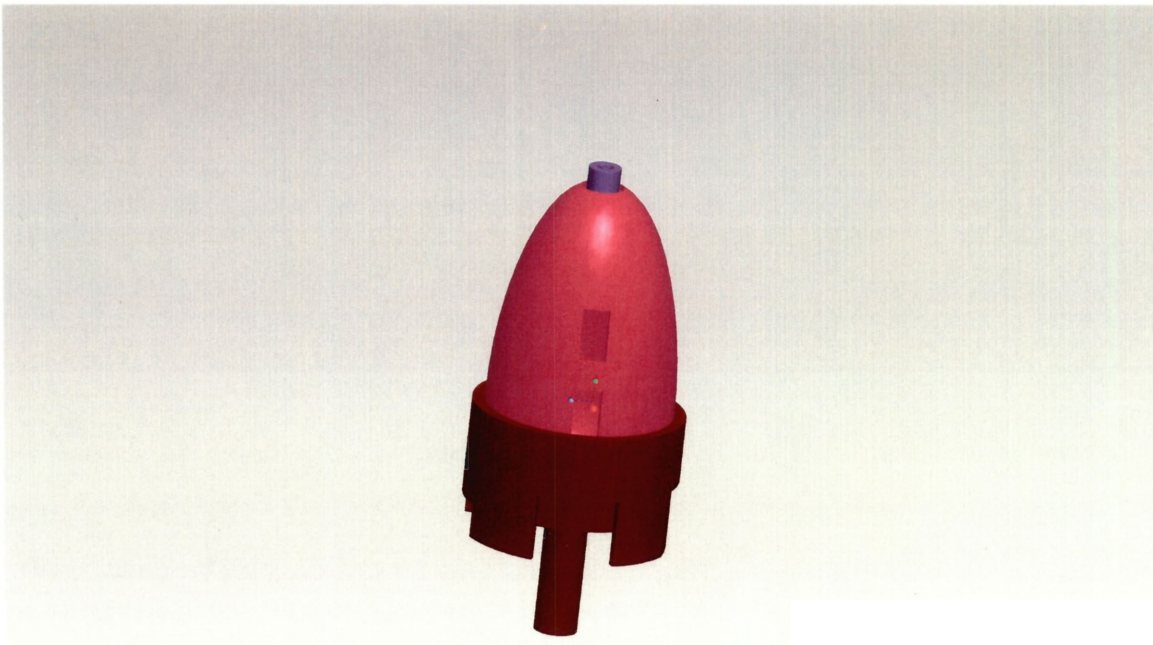
Methane Chemical Energy Constant												
Per Month DATE	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
(K)(J)/(L)(METHANE)	34.7	35.2	35.5	36.1	36.5	35.8	34.9	34.3	33.7	33.2	33.4	34

Chemical Energy Produced Monthly												
DATE	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
JOULES PER DAY	8.53	8.65	0.873	8.9	9	8.81	8.65	8.43	8.29	8.16	8.22	8.37

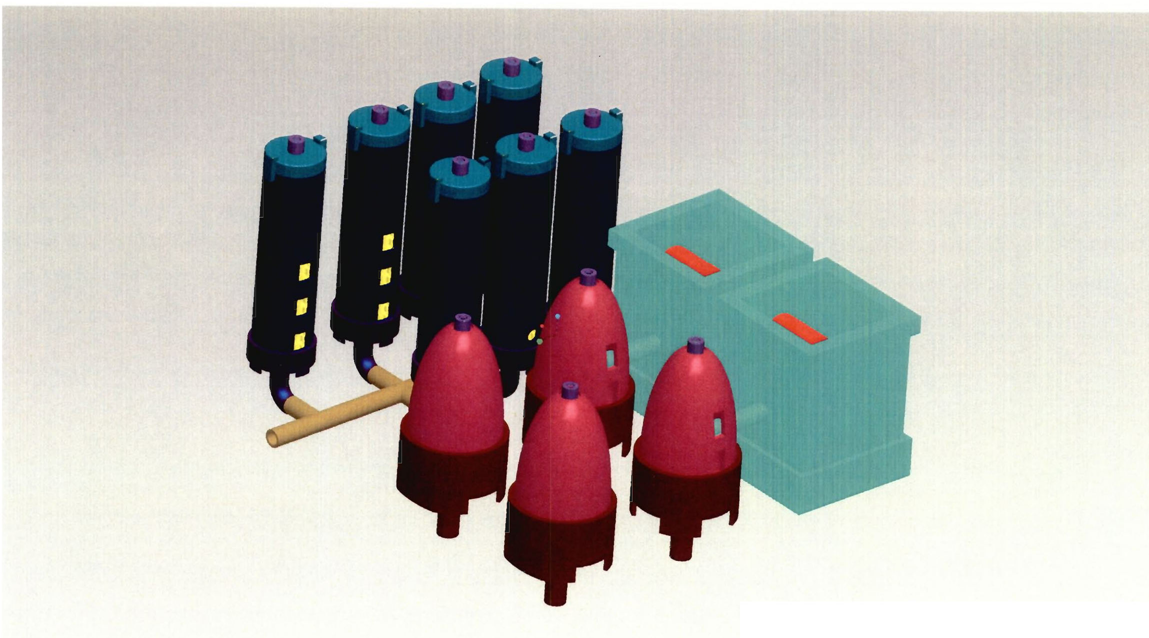
Monthly Average Temperature												
DATE	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
DEGREES CELSIUS	16.47	20.17	22.02	25.7	27.6	23.9	18.32	14.62	10.9	7.22	9.07	12.8

A9. ProEngineer Drawings

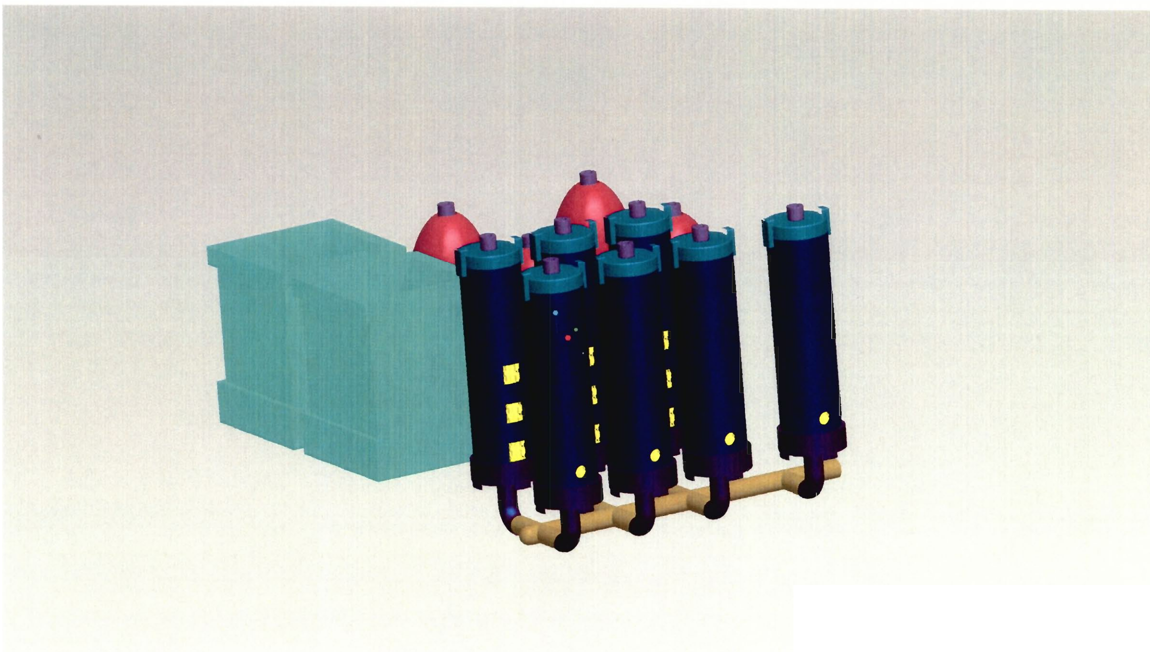
Hydrolysis Reactor



Plant Floor 1



Plant Floor 2



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