Anaerobic Digestion of Food Waste Including the Impact of the Commercial Food Waste Disposal Ban in Massachusetts

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By

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Dulguun Gantulga

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Jourdan R. McKenna

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Approved:_____________________

Professor Robert W. Thompson, Advisor

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Abstract

With today's energy consumption, the world is running out of nonrenewable energy sources.[54] The most commonly used energy source is natural gas that mainly consists of a compound known as methane. It was discovered that methane could be recovered by anaerobic digestion of organic matter such as food waste, sludge and etc. Further processing of methane creates a potential renewable energy source. Simultaneously, one should note that waste management of excessive amount of solid organic waste has been a great concern for our environment. Different countries, states and farms have developed a system that uses food waste and manure to create methane at local anaerobic digesters that is further processed into electricity. Currently, these communities are promoting different approaches to engage the locals with anaerobic digester plants to work together. In this research paper, we discussed the basics of anaerobic digestion and digester plants, implementations of laws that promote anaerobic digestion and recycling of food waste in the state of Massachusetts and their impact on the local community.

Introduction

Anaerobic digestion is the process of molecular breakdown of biodegradable material using microorganisms under a controlled environment to generate biogas and energy from organic matter. This technique to recover energy was noted in the 17th century, further in the 19th century the consistency of the produced biogas as a renewable energy was explored. Most recently in the 20th century, anaerobic bacteria for commercial digestion were discovered.[3] Compared to Europe, the United States of America is relatively new to industrial anaerobic digestion. The US Environmental Protection Agency of the United States and different states recently started promoting anaerobic digestion for biogas and electricity production. The state of Massachusetts started endorsing programs that promote collaboration between anaerobic digesters and commercial organizations to produce renewable energy.[42, 49]

With its high decomposition rate, food waste along with manure have been classified as the most considerable solid organic matter for anaerobic digestion. Thus, collection of food waste from waste producers is being promoted in different states. This is believed to increase the production of renewable energy sources.[22, 61] States such as California, Vermont, Connecticut, and Massachusetts are promoting the ban of commercial food waste disposal at incinerators and landfills.[19, 20, 70] This action protects the environment and allows production of copious amounts of biogas, heat, electricity, and fertilizer. The ban in Massachusetts declares that if a commercial organization produces one or more tons of food waste per week, they are not expected to send their food waste to landfills or incinerators.[20] Organizations and institutions who were affected by the commercial food waste ban were responsible for discovering a method that allowed the waste to get recycled or reused. This prohibition has been effective since October 1, 2014 in

Massachusetts and roughly affected nearly 1,700 businesses and institutions.[20] With the increasing number of eligible anaerobic digesters in MA, this ban allows efficient energy recovery from residual waste. Some advantages of anaerobic digestion include reduction of greenhouse gas emissions at landfills, better waste management and possible business and employment opportunities for residents.[50] In the United States, there are currently over 191 anaerobic digesters operating on farms alone, and approximately 1,500 have been constructed at wastewater treatment plants.[6] As of April 15, 2015 there are currently six eligible anaerobic digesters in Massachusetts that distribute electricity to the grid.[75]

Anaerobic digestion takes place in anaerobic digesters; the digester consists of various components that allow the systems to function as they do. There are four main stages of anaerobic digestion that is performed inside the digester – hydrolysis, fermentation, acetogenesis, and methanogenesis.[12] Each stage involves different anaerobic bacteria and form different end products, however the final products are methane, carbon dioxide, and fertilizers.[12] The produced biogas consists of 60-70% methane, 30-40% carbon dioxide, and some other gases such as hydrogen, ammonia, carbon monoxide and sulfur gases depending on the sludge consistency.[4, 11]

Introduction to Anaerobic Digestion

History of Anaerobic Digestion

Anaerobic digestion is a biological process of digesting of biodegradable materials using microorganisms under an oxygen free environment. The final products of anaerobic digestion consist of 60-70% methane, 30-40% carbon dioxide, and some other gas and solid waste.[4] In the commercial world the methane produced by the digestion is usually further processed to electricity.[13] Thus, anaerobic digestion can be simply understood as a complex process of conversion of organic waste to a combustible energy source. [30]

It should be noted that anaerobic digestion has always been part of our ecosystem. In the 17th century scientists discovered and officially recorded the possibility of using anaerobic digestion to fulfill the need of the modern world. Robert Boyle and Stephen Hales first noted that when the sediments in streams and lakes were disturbed, a flammable gas was released.[8] By 1808, the presence of methane in the gases produced by cattle manure was discovered by Humphrey Davy. The technology grew and advanced to greater levels within a short period of time. In Exeter, England in 1895 a new technology was developed using a septic tank to generate gas for the sewer gas destructor lamp to generate light, which is simply the production of light from combustion of gaseous fuel such as methane, hydrogen and carbon monoxide.[29] By 1904, England also constructed the first dual purpose tank for sedimentation and sludge treatment; this tank was installed in Hampton, London. In 1907, Germany issued a patent for the lmhoff tank - an early form of an anaerobic digester, which consisted of a chamber suitable for the reception and processing of sewage. Dedicated and profound research on the concept of anaerobic digestion for production of renewable energy began in the 1930's.[3, 8]

Processing Stages of Anaerobic Digestion

Anaerobic digestion involves several complex biological and chemical procedures. These procedures take place at anaerobic digester facilities. Based on the digester techniques, procedures at digesters may vary, however it can be summed into four different stages – hydrolysis, fermentation, acetogenesis, and methanogenesis. These processes involve two different temperature states - thermophilic and mesophilic, the temperature of thermophilic environment is usually between 41ºC to 122 ºC and mesophilic temperature ranges between 20 ºC to 45 ºC.[4, 12, 66]

First, the biomass goes through hydrolysis, which is the chemical reaction that involves transformation of the organic compounds using bacteria into liquefied monomers and polymers such as proteins, carbohydrates, and fats. These compounds are later converted into amino acids, monosaccharides, and fatty acids; fatty acids undergo a thermophilic process with an acidic pH value, while amino acids and sugars are processed between 50ºC – 55 ºC with a pH between 4.5 and 7.[12] The final product of this process allows the compounds to be easily accessible for further breakdown. Hydrolysis is dependent on factors such as the size of particles in the chemical reaction, acidity, and absorption and adsorption rates. The following *Equation 1* provides a simple example of hydrolysis where a molecule of an organic waste is broken down into sugar and hydrogen molecules:

Equation 1: $C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$ [4,12]

During fermentation, the products of hydrolysis are transformed by acidogenic bacteria into short chains of volatile fatty acids, alcohols, hydrogen, carbon dioxide, and organic acids. Volatile fatty acids are processed thermophilicly with a lower pH, and alcohols are processed between 50ºC – 55 ºC with a pH between 4.5 and 7.[4,12, 66] The following *Equations 1, 2,* and *3* display typical reactions produced by acidogenesis, glucose being converted to ethanol, propionate and acetic acid:

Equation 2: $C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$

Equation 3: $C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$

Equation 4: $C_6H_{12}O_6 \rightarrow 3CH_3COOH$

When acetogenesis occurs, the remainder of acidogenesis products, such as propionic acid, butyric acid, and alcohols are transformed with the help of acetogenic bacteria into hydrogen, carbon dioxide, and acetic acid. Acetic acid undergoes a mesophilic process with neutral pH. In addition, hydrogen and carbon dioxide are processed at 41ºC – 44 ºC with a pH of 7 to 8.[4, 12, 66] *Equation 5* below represents the transformation of glucose to acetate:

Equation 5: $C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$

During the final stage of anaerobic digestion, known as methanogenesis, microorganisms called methanogens convert the hydrogen and acetic acid to methane gas and carbon dioxide. The methane, which is about 55% of the composition and carbon dioxide the remaining 40-45% of the composition of the biogas go through a mesophilic process with neutral pH.[4, 12]

It is worthwhile to mention that microorganisms from hydrolysis and fermentation stages are more robust than others.[66] This means that the acid and methane forming bacteria have different survival conditions that make it optimal for them to thrive. Acid-forming bacteria can survive with fluctuating temperatures, in a wide array of pH conditions, with or without oxygen, and on a broad range of organic compounds as a nutrient source. Methane-forming bacteria on the other hand, can survive when the temperature is held constant, in a narrow array of pH conditions, and with simple organic acids as a food source.[66]

Although anaerobic digesters are oxygen-free environments, the addition of a microaerophilic process allows for sludge granules to shield anaerobes from oxygen poisoning, which often times has proven to increase the production of biogas. There are, however, dangers of adding oxygen to the anaerobic digester's oxygen-free environment. One of these dangers occurs if the oxygen in the system is not fully consumed and the produced biogas contains oxygen.

The process of anaerobic digestion is summed up in the following Figure 1. During pre-treatment the waste is prepared and sorted.[66] The waste that is not biodegradable and/or the waste that slows down the digestion is removed from the feedstock. The transition of pre-treatment and anaerobic digestion can produce heat. During anaerobic digestion the biogas is released. The produced biogas can be used to generate heat and it can also be used for combined heat and power units. This allows for the production of electricity with less consistency of toxic compounds. During post treatment the remainder of the digested waste is transformed into fertilizer or digestate since the composition of the treated waste is very high in nutrients that is beneficial for soil such as nitrogen, potassium, and phosphorous. Figure 1 was created based on the conducted research and is discussed further in the upcoming sections.

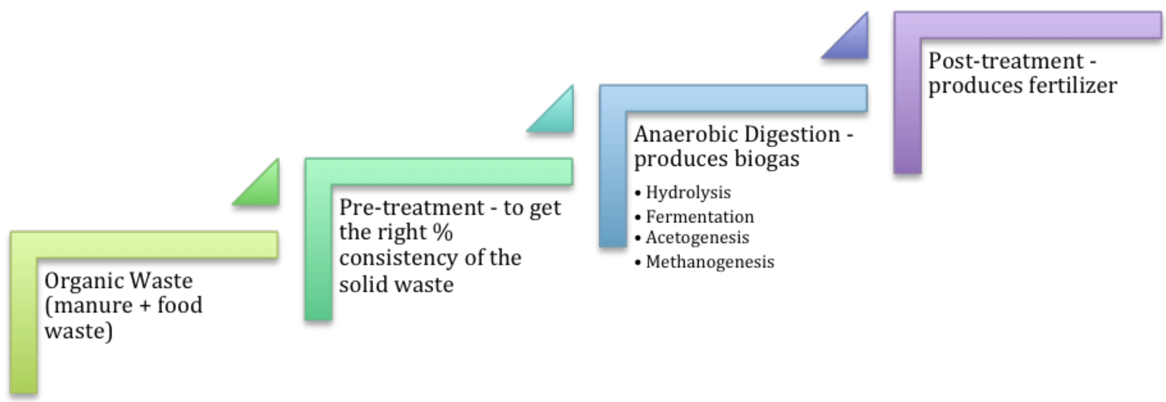

Figure 1. Summary of Anaerobic Digestion

Factors that influence anaerobic digestion

Types of anaerobic bacteria

Microorganisms that play a role in anaerobic and aerobic digestion can differ not only by class and living conditions, but also by their generation times. Anaerobic microorganisms include acidogenic bacteria and methanogens. The acidogenic bacteria consist of bacteroides with a generation time of 24 hours, clostridium with 24-36 hours, and acetogens with 80-90 hours. Methanogens on the other hand, consist of methanosarcina barkeri taking 5-15 days and methanococcus with 10 days. [66]

Retention Time of Anaerobic Digestion

The residence or retention time is the time needed for the feedstock to fully digest or degrade. The residence time of the feedstock depends on several variables, such as the amount and type of feed material, the configuration, and whether it be a one-stage or a two-stage system. Operating a single-stage thermophilic system would deem a residence time of approximately 14 days, while a mesophilic digestion system operates much more quickly. In contrast, in a two-stage mesophilic digester, residence time can vary between 15 and 40 days. [66]

Types of Feedstock and Methane Production

Various digestion substrates differ by their yields of biogas production. Considering non-agricultural waste, agricultural raw materials, and agricultural waste, non-agricultural waste produces the highest yields in biogas, while agricultural waste produces the lowest amount of biogas. Fat is an example of a non-agricultural waste product; it produces 800 m^3 gas/ t substrate. In contrast, cow manure is an example of agricultural waste, producing as little as 25 m^3 gas/ t substrate. The following list of waste products and raw materials compares the yields of non-agricultural waste, agricultural raw materials, and agricultural waste:

Material Type	Type of Substrate	Biogas Yield [m^3 gas/ t substrate]
Non-Agricultural Waste	Grease Separator Residue	800
Non-Agricultural Waste	Food Waste	240
Non-Agricultural Waste	Bio-Waste	120
Agricultural Raw Materials	Ray Grass	110
Agricultural Raw Materials	Silage Maize	190

Agricultural Raw Materials	Fodder Beet	110
Agricultural Waste	Pig Manure	30
Agricultural Waste	Cow Manure	25

Table 1. Biogas Yields of Various Digestion Substrates[81]

When the aim of the anaerobic digestion is the maximum production of biogas, the level of putrescibility becomes the main focus; putrescibility is simply the rotting potential. With a greater level of putrescibility, the higher the gas production will be. [8]

One should note that to obtain the maximum amount of methane, some digesters use co-digestion meaning that they combine manure and food waste.[66] This can be explained by the fact that the already digested product - manure, contains anaerobic bacteria from the previous digestion and the existing anaerobic bacteria supports the process. Thus, it helps the industrial digestion and speeds up the process. This will be discussed further in the literature review and discussions sections.

Configuration of Anaerobic Digesters

Even though there are different techniques and styles for anaerobic digesters, they all share the same main components: input, digester, and output.[56] Anaerobic digesters process municipal wastewater, industrial wastewater, and municipal solid waste (MSW) as an input depending on the design of the digester. Food waste and manure fall under the category of MSW, which makes the two compounds most advantageous when combined together. The resulting product yields a highly controlled process of capturing methane. Furthermore, if the objective of the anaerobic digester rests solely on maximizing methane production and minimizing the production of carbon dioxide, wastes which contain proteins and fats should be used as the main source of waste in the digester.[56] Although food waste and manure are processed through the same digester, they must be sorted prior to digestion in order to prevent the pumps from becoming clogged. Anaerobic digesters capable of processing MSW include single-stage wet digesters, dry fermentation, and two-stage digesters. [7, 56]

There are some anaerobic digester facilities that are even more specific with their separation process. For example at an anaerobic digester in Greater Manchester in the UK, waste materials are broken up into five different types. The first group consists of fine or organic materials, which are mainly small particles of organic and non-metallic materials. Light materials make up the second group, which are mainly non-recyclable plastic, paper, card, and textiles. The third group is ferromagnetic metals that are separated for recycling, while the fourth group is made up of non-ferromagnetic metals, which are all other types of metals. The fifth and final group consists of heavy residue, which is mostly stones and similar materials that are used as aggregate. This five-stage system is one of many examples of a system incorporated at an anaerobic digestion facility.

Anaerobic digesters are able to be designed and engineered to manage a multitude of various process configurations.[56, 64, 66, 76] Some examples of these configurations depend on temperature, solids content, batch or continuous, and complexity. In a temperature configured anaerobic digester, the tank can be made to be either mesophilic or thermophilic. Due to greater processing temperature, the thermophilic systems produce biogas more quickly and have a greater potentials to kill pathogens, however the capital cost to operate thermophilic systems is much greater than those of a mesophilic system.

A second type of anaerobic digester can depend on its solids content.[56, 64, 66, 76] If the content contained by the anaerobic digester is wet, it will require a wet process to run, and vise-versa for dry content. In a wet anaerobic digester, feedstock is pumped and stirred, while in a dry system the feedstock is stacked. In comparison, dry systems are generally cheaper to run and produce more in the long run. On the other hand, wet systems have a lower set-up capital cost. In the 1980's, research proved that biogas production for single-stage dry systems were just as high and sometimes greater than that of wet systems. Dry systems however, pose more challenges than wet systems. Some of these challenges include handling, mixing, and pumping of the material. Even though dry systems are more costly, dry systems are tougher and more flexible than wet systems in terms of accepting material such as rocks glass, metals, plastics, and wood pieces.[56, 64, 66, 76] Although rocks, glass, metals, plastics, and wood pieces are not biodegradable, they are able to pass through the digester without causing any issues. Pre-treatment with such materials involves removal of pieces greater than 2 inches and upkeep of the solids content. Typically, the solids content ranges between 20-40 percent total solids. In dry systems, material moves via plug flow, which is when materials are added in on one end and the digester pushes older materials towards the opposite end. Batch and continuous anaerobic digesters are widely used for industrial purposes.

Continuous flow digesters are more popular due to the fact that they do not require being opened and restarted because of cold weather every couple of weeks, unlike batch flow digesters. In addition, batch digesters provide uneven gas production and lack stability in terms of the microbial population. Continuous flow anaerobic digesters on the other hand, have a history of producing more biogas and are more cost effective. Although batch flow digesters are not as popular, they have the advantage of reducing complexity and are sometimes used as dry systems.

In order to surpass the obstacles that coexist with batch flow digesters, typically many batch digesters are used with various changeover times in multi-stage configurations.

In addition to temperature, solids content, and batch or continuous digester configurations, there are also anaerobic digesters that differ due to their complexity.[56, 64, 66, 76] Anaerobic digesters can be arranged as a single unit or alongside other systems. Some systems require multiple anaerobic digesters, which have both advantages and disadvantages. Advantages of having multiple digesters include production of more biogas, process flexibility and greater efficiency, while disadvantages include a higher capital cost, a higher operating cost, and a greater management requirement. The organic loading rate of a single-stage digester bares limitations due to the incapability of methanogenic microorganisms to handle the temperature reduction that is caused from rapid acid production during hydrolysis. Two-stage digesters on the other hand, separate hydrolysis and acid-producing fermentation methanogenesis, which provides a greater loading rate, but also requires additional reactors and handling systems.

Based on the type of organic feedstock and the digester techniques, the anaerobic digesters can be sorted as covered anaerobic lagoon digester, plug flow digester, complete mix digester, and dry digestion.[21, 56, 64, 66, 76] These technologies have different ways of handling the waste and the consistency of the by-products from the digestion may differ. The details will be discussed further.

Types of Anaerobic Digesters

Covered Anaerobic Lagoon Digester

The covered anaerobic lagoon is a large anaerobic lagoon with a large retention time and a high dilution factor. These digesters are frequently applied with flush manure management systems that release manure at 0.5 to 2 percent solids. The anaerobic lagoon is carefully lined with a flexible gas tight cover and rests at ambient temperature. The retention time for these digesters is between 30-45 days depending on the size of the supply. The covered anaerobic lagoon provides stable, reduced odor, nutrient rich effluent, pathogen and weed seed reduction, and produces biogas for energy use on farms. Covered lagoon digesters are preferred for warmer climates, as the methane production increases with warmer temperature. [56, 64, 66, 76]

Plug Flow Digester

Plug flow digester has a long, narrow concrete tank with a rigid or sometimes flexible cover. The digester is built below grade to limit the demand for supplemental heat. This specific type of digester is used only at dairy operations that accumulate manure by scraping. Retention time for plug flow digester is usually between 15 to 20 days and the input manure is of 11 – 14 percent total solids. Plug flow digester is not dependent on the outer weather conditions. [56, 64, 66, 76]

Complete Mix Digester

Complete Mix Digester consists of insulated digester vessels, and most importantly it maintains a constant temperature throughout the process. Fresh organic waste is mixed with partially digested material. The main temperatures ranges are noted as psychrophilic at 20 degrees of celsius, mesophilic from 35 to 41 degrees of celsius, and thermophilic from 50 to 60C. The temperature range is based on the organic waste type. The retention time for complete mix digester is 10 to 20 days. It is the most suitable digester for wastes with 3-10 percent total solids such as manure and pre-prepared food waste. [56, 64, 66, 76]

Dry Digester

Dry digester is a covered digester that is suitable for waste 20 - 42 percent total solids and usually the residence time is between 9-45 days depending on the input material and processing temperature. [56, 64, 66, 76]

Applications of Anaerobic Digestion

Anaerobic digestion yields many purposes, including use in industrial and domestic purposes in order to manage waste and produce fuels. Waste management is the "generation, prevention, characterization, monitoring, treatment, handling, reuse and residual disposition of solid wastes" and additionally, is a vital component in sustaining our environment. Anaerobic digestion of waste reduces the emission of landfill gas into the atmosphere. [67]

Anaerobic digesters are used vastly as a source of renewable energy. The produced biogas has applications in fuel production in combined heat and power gas engines, or upgraded to natural gas-quality biomethane. When it comes to the biogas yield, several factors come into play. First, the reactor configuration plays an important role, in addition to MSW. Between biogas yield and reactor efficiency, reactor efficiency is more vital to a company when understanding financial importance of a digester. Biogas yield and MSW throughput rate on the other hand, are important when determining a system's efficiency.[21] In addition to biogas, anaerobic digesters also produce a nutrient-rich digestate, which farmers often use as a fertilizer.[66]

Maintenance of Anaerobic Digesters

When it comes to anaerobic digesters, one of the most important key factors is maintenance. Anaerobic digesters cannot operate on their own and without attention to detail, they will not work properly. For example, nutritional needs of the bacteria degrading the waste have to be considered and monitored. The bacteria must be provided with a precise ratio of carbon and nitrogen to survive. If this ratio is obstructed, ammonia can build up to levels great enough to hamper the bacteria. The carbon-nitrogen (C/N) ratio is dependent on digestibility of the sources, which can vary depending on the type of feedstock.[66] The ideal conditions for anaerobic digesters are near-neutral constant temperature and have a comparatively uniform feeding rate. If anaerobic conditions are not sustained, imbalances may develop, such as a buildup of organic acids, resulting in an even greater acidity. Such imbalances are typically controlled by chemical buffers and methanogens, as they consume the acids. However, these controls are not guaranteed; if too much feed were to be added, organic acids would produce at a greater rate than they are being consumed. [56, 64, 66, 76]

Additionally, if inhibitory compounds cluster or if the feed stream does not have natural temperature buffers, then the controls will break down. Process inhibition is practically unavoidable. If solid concentrations in an anaerobic digester rise above 40 percent total solids, this can likely reduce contact available for the anaerobic digesters' microorganisms. The total solids composition of municipal solid waste generally ranges between 30-60 percent, thus water is sometimes added to the system to make the solid concentration of the waste more effective to process, in other words to change the total solids composition. It is important that fresh water is used as the water additive, as process water can cause the buildup of inhibitory compounds in a digester. The anaerobic digestion does not produce water along with methane and carbon dioxide production. The inorganic materials sorted by the MSW stream additionally have to be transported after the process. In most cases, the separated material is brought to a recovery facility or landfill. [56, 64, 66, 76]

Converting Waste to Electricity

Energy can be produced in various ways, using different configurations, temperatures, and such depending on the type of material being processed and the desired outcome. Dry material such as paper, wood, and plastic are typically processed through thermal conversion technologies from municipal solid waste (MSW). This allows for the materials to be quickly transformed into energy. Usually, the digesters are connected to the electric grid and the excess or produced energy is sold to the grid. After much research, it was discovered that if 50 percent of the food waste generated in the United States each year was anaerobically digested, enough electricity would be generated to power 2.5 million homes for a year.[13, 25, 30]

Literature Review

To strengthen our background knowledge in anaerobic digestion, we have reviewed several scientific publications. The executive summaries of the articles are presented below.

Texas Manure Digester Complex was published by Diane Greer in 2012. The article discussed the nation's largest anaerobic digester, known as Huckabay Ridge that was constructed in 2006 in Stephenville, Texas by the Environmental Power Corporation (EPC). The facility's plan was to process cow manure and organic substrates into biogas. The plant hoped to sell renewable natural gas (RNG) and renewable energy credits (REC's) at premium prices. Unfortunately, falling natural gas prices and the downfall of national climate legislation pushed EPC into bankruptcy and Huckabay went into receivership. In November of 2010, Houston-based Element Markets (EM) purchased Huckabay Ridge, gave the plant a second chance at growth. EM is a private producer and marketer of renewable natural gas and environmental commodities. Element Markets invested almost $12 million in improvements to the farm. Huckabay Ridge consists of eight 916,000-gallon above ground digester tanks, capable of digester manure from 10,000 dairy cows mixed with organic substrates. The farm is able to produce 200 million-cubic feet/ day of renewable natural gas (RNG). In order to remove carbon dioxide and hydrogen sulfide, a low pressure amine process is conducted on the biogas. Prior to pipeline injection, the gas is dried using a glycol treatment. When the process is complete, the gas is then sold to Pacific Gas & Electric in California under a ten year agreement between the two companies. When EM first purchased Huckabay Ridge, their first task was to put the plant back online. In late January 2011, the digesters were reseeded and capable of producing biogas only one month later. EM's improvements relied on health, safety, operating procedures, and reenergizing the team. Element Markets installed a natural gas pipeline in the plant for heating of the digesters. EM also built a laboratory on the plant with a full-time technician to ensure that the feedstock was being optimized. After conducting tests on the manure for pH, moisture, and even COD levels, the organization came to the realization that the manure required a greater amount of hydration. Huckabay Ridge feeds 120,000 to 150,000 gallons of manure and 30,000 gallons of substrate to the digesters. EM is currently investigating future technologies to clean out the digesters and is additionally looking at building a liquids storage lagoon. Huckabay is able to profit from its biogas production, as well as revenue from composting activities in the days to come. [34]

*Hereford Manur*e was published by The Wall Street Journal on January 24, 2006. The article referred to Hereford, Texas, a town which has had a prevalent issue with cow waste for four decades, producing as much as tens of millions of tons of cow waste. The town has effortly tried to turn the waste into something useful, such as electricity, fertilizer and pellets for wood stoves. A Dallas company came up with a new solution: burn the manure as fuel to produce ethanol from corn. 2006 was a big year for Hereford, as Panda Energy International Inc. worked tirelessly to construct a digester capable of producing 100 million gallons of ethanol per year, eliminating the need to burn costly natural gas in order to produce ethanol. Many farmers in Hereford signed contracts with Panda agreeing to supply them with their manure for free. Cattle are a $2.7 billion dollar industry in the small town, generating as much as 6,300 tons of waste in a single day. This waste creates countless issues, including odor, attraction of flies, dust, and is even considered a fire hazard due to the generated heat. The town of Hereford has generously given the president of Panda Energy, Mr. Carter, 382 acres of their land to build his plant. This deal is beneficial to the town not only because it deals with the manure problem they are facing, but it also allows farmers to save hundreds of thousands of dollars that they once paid to transport their manure.[38]

The Role Of Bio-Fuels In Satisfying US Transportation Fuel Demands was published in Energy Policy in 2008. The article addressed the concern for petroleum reserves, which has been in effect for over 50 years. A study was conducted on liquid energy sources since much of the US industry has been updated to use liquid fuels. These applications exist in transportation, home heating, industry and manufacturing, and in some electricity generation. Agricultural products exist that can be optimized to produce liquid fuels, acting as both a sustainable and environmentally friendly option. Some agricultural products can even be converted to ethanol or biodiesel fuels. The United States is the world's largest consumer of energy, consuming 23% of the total energy and containing only 4.6% of the world population. China and India follow as being large consumers of energy, with China coming in at a whopping 62% and India at 32%. Solar energy is a vital component in energy as it created the majority of forms that we utilize. Aside from solar energy, there is also nuclear, geothermal, and tidal energy. Solar energy, however, can only be considered sustainable if and only if there is more solar energy being created then there is being used. Ethanol on the hand, has been proven to be energy-neutral. The energy investments of ethanol are almost identical to the available amount of energy product.[5]

Industrial Model of an Anaerobic Digestion: A Case Study for Undergraduate Students by Ignacio Durruty and Maria Ayude begins with the discussion of limitations in undergraduate chemical reaction engineering courses. Durruty and Ayude address pH as being an important parameter that should be taken under high consideration when dealing with the anaerobic digestion system. Methanogenic bacteria possess a pH of 6.5-7.2, while acid-producing bacteria herald a pH of 4.2-8.5. These two branches of bacteria share a connection, as acid-producing bacteria produce acetic acid, which is then consumed by methanogenic bacteria. Due to this similarity, the net production must be balanced to keep the bioreactor from collapsing. In addition to pH, the available nutrients is another important parameter. In this case study, an industrial digester was analyzed or the case study also asked undergraduate students to turn a written report that introduces the model building, solution method, interpretation of results, and sensitivity analysis, by the end of this time period. This project bears three goals: to present and discuss a serial-parallel reaction system based on an authentic biological system, generate a representative computer-based design problem and help undergraduate students attain a deeper realistic learning approach to chemical engineering fundamentals. The assignment or objective of the project is to model an industrial digester used for the treatment of wastewater as a combination of ideal reactors. The anaerobic digester reactor consisted of three zones: the first zone is the mixing zone, in the second zone the flow develops longitudinally, while the production of gas develops in the opposite direction, and finally the third zone consists of the deposition of the particulate material. In this experiment, students measured the Chemical Oxygen Demand (COD), which measures the concentration of organic matter in water.

Based on the case studies, Durruty and Ayude concluded that for a single reaction system, the hydraulic retention time (HRT) can be found graphically by plotting the inverse of reaction rate vs. the integration variable. For a serial-parallel multiple reaction system, however, this type of graphical analysis would prove to be useless. The first necessary step that must be taken to find the HRT is to develop and validate a model capable of displaying the process. Next, a parametric study can assess how changes to parameters can alter the process and can also explore various option scenarios that can be utilized by the system. [24]

Algae Anaerobic Digestion was written by Carlos Zamalloa, Elien Vulsteke, Johan Albrecht, and Willy Verstraete in 2010. The article discussed how energy produced from fossil fuel accounts for as much as 60% of the planet's greenhouse gas emissions. One option of producing energy without the emission of harmful gases is anaerobic digestion. With an anaerobic digester, biogas can be produced from both solid and liquid residues, and even from biomass crops. Due to their high lipid, starch and protein concentrations, microalgae works well as a biomass source. Compared to conventional crops, microalgae are capable of doubling their biomass in a mere 24 hours and the land in which they cultivate on is not required to be fertile, unlike human food crops. Additionally, microalgae can be cultivated using fresh water, salt water or wastewater, which saves money in the long-run. The largest benefit to using microalgae is that their conversion to biogas is able to be performed without and production of greenhouse gas. Although microalgae bears several advantages, there are also disadvantages to using microalgae. Microalgae has a high expenditure for infrastructure and a hefty energy requirement. This article proposes a new approach to decrease the cost and energy consumption used in the anaerobic digestion process of algae to biogas to further produce electrical and thermal energy. An assessment was conducted in order to approximate the cost and revenue of producing energy using macroalgae as feedstock in an open pond. At 8-10% photosynthesis conversion efficiency, the biomass products are estimated to be 77-96 g of dry matter (DM) per square meter per day, while the reasonable target production is in the order of 27-62 g. When this theory was tested, however, the biomass produced from the algae was less than expected. The chemical composition of microalgae is said to be very dependent on environmental factors such as light intensity, temperature and nutrients availability. Microalgae contain lipids in the range of 2-90% DM, which is an attractive compound for AD as lipids possess a high methane yield theoretically compared to other compounds. Microalgae has a positive production in terms of methane, as over 60% methane is produced in each individual yield. [73]

R. Labatut et al. completed a research on *'Biochemical methane potential and biodegradability of complex organic substrates'*, this research paper analyzes different mono and co-digestion samples using biochemical methane potential assay. This experiment tested various types of biomass. It should be noted that manure, dairy product - they all have different compositions of fat, lipids, and sugar. This can be explained by the fact that there are so many different ways to handle the dairy operations, as well as age, breed of the animal become an important factor for the manure and dairy production biochemical composition. The experiment involved wide range of biomass from used vegetable oil to soda. The researchers calculated the theoretical methane yield based on the nutritional composition and compared it to the experimental outcomes. One of the findings from the experiment was that co-digestion of certain compounds produced synergistic effects, meaning that it yielded more methane, as this process accounts for an increase in methane and a decrease in carbon dioxide. This effect can be linked to acidity of the pH, and ammonia composition, volatile acid composition and etc. Finally, they found out that substrates with more lipids and easily-degradable carbohydrates produced more methane.[77]

Laws and Permitting in Massachusetts

Background

The state of Massachusetts has as many as 27 permitted food materials processors, 23 of these processors can treat one ton of waste per day, while one will process 40-50 tons per days, two will process 51-70 tons per day, and three will process 71-100 tons per day. [47]

The United States Environmental Protection Agency (EPA) has established permitting practices for co-digestion anaerobic digester systems. The federal regulations include air, solid waste and water. Federal air regulations require that if an on-site combustion device triggers federal emissions thresholds then it must be monitored by the state and follow all state requirements. Federal solid waste requirements do not require permits for manure, however, other organics may need to be accepted depending on the state. [10]

Waste management processing must follow regulations under the Resource Conservation and Recovery Act (RCRA), which covers non-hazardous wastes and landfills. Federal water regulations follows Concentrated Animal Feeding Operations (CAFOs) and require that the plants obtain a National Pollutant Discharge Elimination System (NPDES) permit. CAFOs that are considered to be large by their state are required to maintain Nutrient Management Plans (NMPs) to solidify that the facility is dealing with its manure properly. Massachusetts is one the few states which offers a consolidated or general permit process. Additionally, the state of Massachusetts has also established specific requirements for off-site waste acceptance. Massachusetts solid waste permits ensure that anaerobic digestion systems receive no more than 100 tons of waste per day. In January 2014, the Executive Office of Energy and Environmental

Affairs (EEA) passed a ban on commercial food waste that required all organization disposing of one or more tons of waste each day to donate their waste to AD facilities or composting and animal-feed operations, which took effect on October 1, 2014. [10]

In a report published in 2013, titled Anaerobic Digestion of Food Waste in New England, it states that although AD has existed for decades, it has only began to achieve interest from the United States in the past 20-30 years. AD can be used and optimized at three varieties of facilities, which includes wastewater treatment plants and water pollution control facilities, manure farms, and stand-alone facilities. Food waste made up an estimated 21 percent of the solid waste stream, compared to 18 percent in 2008. In the United States every year, 34 million tons of food waste gets distributed to landfills, where it produces dangerous greenhouse gases that are toxic to the environment. This ongoing issue has caused local, state, and national interests to focus on diverting this waste to a more useful avenue. [28]

The relevant legislation and regulations for each state fall under four general categories: zoning laws and permitting, demand for biogas, net metering, and access to source separated organic materials (SSOM). As far as zoning laws and permitting goes, the Mass Environmental Policy Act and Regulations requires that most project proposals be submitted as Environmental Impact Reports, which include parameters on how wetlands, endangered species, conservation land, air quality emissions and related factors will be effected. Site Assignment Regulations for Solid Waste Facilities also requires that a permit process be undergone in order to determine if a piece of land is suitable for a solid waste facility. These such facilities must follows rules set by the state, which consists of not discharging unpermitted pollutants, not creating a public nuisance, and not presenting a significant threat to public health, safety, and the environment.[28]

The Massachusetts Contingency Plan additionally orders that all proposed facilities have licensed site professional to evaluate impact on human health, safety, and the environment. The demand for biogas is the second factor that must be considered. The Renewable Energy Portfolio Standard (REPS) requires a percentage of the state's electricity to come from renewable energy. Alternative Energy Portfolio Standard (APS) provides requirements and incentives for alternative electricity technologies, which includes biomass conversion technologies from organic sources including food waste as a Class I Renewable Energy Source. A third important factor revolves around net metering, which is a system in which solar panels or other renewable energy generators are connected to a public-utility power grid and surplus power is transferred onto the grid, allowing customers to offset the cost of power drawn from the utility. In Massachusetts, the amount of net metering permitted increased from 60 kWh to 2MWh per facility in 2008; this is the value of credits of energy created by AD facilities, which has increased to nearly retail value. In addition, net metering customers were granted allowance to allocate net metering credits. [28, 41]

Commercial Food Waste Disposal Ban

The Massachusetts food waste disposal ban took effect on October 1, 2014. The ban requires that all institutions that dispose of one or more tons of food waste per week can no longer send their food waste to landfills. The compliance options available for institutions and commercial food waste producers allow them to pay a hauler to take their food waste to off-site disposal facilities or to even create a composting or on-site waste recycling facility. [20]

Under the new Massachusetts regulations, small composting operations have become easy to set up and operate. This is true as facilities composting less than ten tons of waste per week do not have to follow state permitting requirements and can be established with grant money and repaid with energy. Additionally, mid-sized operations can also benefit from some benefits. Mid-sized operations are considered to be facilities composting 10-105 tons of waste per week and no more than 30 tons of waste per day. These mid-sized sites are exempt from participating in site assignments, a two-step process that takes place prior to moving to the Department of Environmental Protection (DEP) and the local board of health. Mid-sized operations must, however, obtain a General Permit and ensure no unpermitted discharge of pollutants or threats to public health, include managing storm water and odor control plans, locate a minimum of 250 feet away from any pre-existing water supply well, ensure a carbon-to-nitrogen ratio that is proper, as well all handling of organic materials taking place in sealed tanks, and the keeping of proper records for at least three years. Large facilities on the other hand, must obtain all necessary site assignments. [41, 42]

The Massachusetts food waste regulations include an exemption from the site assignment process for anaerobic digestion operations, a general permit for digestion operations receiving a maximum of 100 tons per day, site-specific permits for facilities receiving more than 100 tons per day, and revisions to wastewater regulations allowing digesters at publicly owned treatment works to receive organic waste from off-site. The goal of such detailed regulations is to divert 450,000 tons of food waste a year from landfills and incinerators, and direct that material to composting facilities or anaerobic digesters. The facilities convert food waste into a biogas that can be used for heat and electricity. [41, 42]

The ban covers large restaurants, grocery stores, universities and other institutions. Prior to the ban, about 97 percent of all Massachusetts food waste ended up in a landfill, or incinerator.

Harvest Power was founded in 2008 and has a management team with deep experience in composting, renewable energy, supply chain management, engineering, law and finance. The company is bringing something new to the table by adding food waste to the process. Paul Sellew, the CEO of Harvest Power aims to create a more sustainable future by helping communities better manage and beneficially reuse their organic waste.[39]

Anaerobic Digestion Benefits in Massachusetts

According to the Executive Office of Energy and Environmental Affairs, the state of Massachusetts accounts for 800,000 tons of food waste per year. A study showed that one supermarket chain’s efforts to recycle their food waste saved them $20,000 annually per store. Chris Flynn, President of the Massachusetts Food Association, says “If all 400 supermarkets in Massachusetts recycled their organics, the industry could realize more that $4 million in savings per year.” By reducing food waste, sewer and electricity costs associated with drain disposal can be reduced as well. Additionally, disposal costs will be reduced and the costs of sending food scraps to composting facilities rather than landfills or incinerators are much less. Massachusetts’ efforts to compost food waste also helps the community by strengthening the local economy by supporting composting professionals. The environment is protected in turn, by conserving minimal landfill space and reducing water treatment discharge. The final product of the compost is useful as a soil for lawns, athletic fields and farms, so nothing is wasted.[63]

There are five simple steps that the Energy and Environmental Affairs recommends taking in order to reduce food waste. These steps are to manage purchases, donate food that is still fit for consumption to hunger relief agencies, donate food for animal feed purposes, and to hire a hauler to collect food waste and bring it to composting facilities, respectively. [61]

A study conducted by NRDC estimated that Americans throw away 40% of their food. Declining capacities at conventional solid waste disposal facilities, combined with the fact that there are more beneficial things to do with food waste and other organics than to throw them in a landfill or burn them have led to partial food or organic waste bans in California, Connecticut, Massachusetts, Vermont, as well as in cities such as Seattle, San Francisco, and New York in the last few years. In the past, organics have been transformed into compost or animal feed. The difficulty with these avenues is that the volume of the waste stream is far in excess of what existing small composting facilities can handle. Larger facilities that might be able to increase capacity tend to be located far from urban and suburban centers that generate the waste. Many facilities are aware of the need to create an infrastructure to handle the copious amounts of waste but a more comprehensive national program is needed so that landfills are no longer an option. Anaerobic digestion is one of the most promising technologies to manage the large amount of organic waste generated near city centers. Resulting methane created from the AD process can generate energy in place of traditional fossil fuels. A large-scale system can generate as much as 8-10 MW of electricity, which is enough to power 8-10,000 homes, while diverting thousands of tons of organics from landfills. Furthermore, the residual materials can be used as compost or soil amendments for farms and other facilities. A single system would require hundreds of thousands of tons of segregated organic materials annually. Waste bans, such as the recently ensured commercial food waste ban, help develop a reliable supply or food waste and organics for anaerobic digestion facilities. [36]

The Big Y supermarket chain has been working since the 1990s to reduce food waste from its 30 Massachusetts stores. The management of the Boston Red Sox's stadium, Fenway Park, has been diverting their food waste away from landfills and toward commercial composting facilities since 2011 with the help of their chefs. The Boston-based food rescue organization Lovin' Spoonfuls collects 8,000 pounds of perfectly good but unsaleable produce and prepared foods weekly from supermarkets, farmers and others, and delivers it to soup kitchens and homeless and domestic violence shelters to feed people in need. The anaerobic digestion process diverts a minimum of one ton of greenhouse gases for every ton of food waste that is treated. An additional benefit in composting and anaerobic digestion is the jobs that come out of it. Paul Sellew's company, Harvest Power, employs 50 in the state and 550 nationwide, up from zero only four years ago. "The good news and the bad news about these regulations is that there's so much food waste out there to address," says Ashley Stanley, Lovin' Spoonfuls' founder and executive director. "Such a big part of the problem is that we've lost the ability to place the appropriate value on food. These regulations see that and do something powerful." [43]

Massachusetts Financial Support for Anaerobic Digesters

Financial assistance is available for facilities currently involved or planning to become involved with anaerobic digestion. In fact, the DEP recycling loan funds provide low-interest financing for Massachusetts recycling projects and even allows food waste projects to have priority over all else. In addition, the DEP Sustainable Recovery Program Municipal Grants fund projects including composting and anaerobic digestion operations that divert solid waste from simply being disposed of and "wasted." These grants offer compensation in return for creating green energy by means of net metering. [41]

MassDEP Sustainable Materials Recovery Program (SMRP) Municipal Grants offer funding to cities, towns and regional entities. In addition, certain non-profit organizations that provide services to MassDEP for recycling, composting, reuse and source reduction activities that will increase diversion of municipal solid waste and household hazardous waste from disposal are also awarded grants. Grants are available for recycling and composting equipment, Pay-As-You-Throw programs, waste reduction enforcement, school recycling, and organics capacity development projects. MassDEP accepts applications between early April and mid-June annually. In order to receive a grant, four qualifications must be met. These qualifications include simply reviewing the application guidelines, attending a grant information session, meeting the minimum eligibility criteria, and completing and submitting a grant application. Massachusetts prides itself in sustainability and alternative energy and seeks to help any and all organizations who want to join in its efforts. [10]

During the Patrick Administration in MA, $3 million worth of low-interest loans were made available to private companies building anaerobic digestion facilities. DOER is also making $1 million available in grants for anaerobic digestion to public entities through MassDEP's Sustainable Materials Recovery Grant Program. MassDEP and DOER have awarded the first AD grant of $100,000 to the Massachusetts Water Resources Agency (MWRA) for its wastewater treatment plant at Deer Island. [49]

Massachusetts alone, provides financial and technical assistance for anaerobic digestion projects. The state financially assists work in anaerobic digestion by awarding grants and loans to renewable energy developers, as well as offering assistance programs to them. The Sustainable Materials Recovery Program (SMRP) offers municipal grants to towns, cities, regional entities, and non-profit organizations who work to recycle, compost, reuse and source reduction activities that prevent waste from merely being disposed of. [10, 41, 43, 49] In Massachusetts, there is what is known as Green Communities. The Green Communities Division (GCD) allows for all residents of MA to allocate clean energy that reduces the cost of long-term energy, while strengthening local economies. The GCD strives to better energy efficiency and heighten the production and use of renewable energy in public establishments. In addition to the Sustainable Materials Recovery Program and the Green Communities Division, Massachusetts also has the State Revolving Fund (SRF), which gives cities, towns, and other local government-controlled units low-interest loans for clean drinking water and wastewater-related projects. The MassCEC Commonwealth Organics-To-Energy program also financially supports local organizations. For example, they provide financial support to educate businesses and communities about organics-to-energy technology and allow these members to actively involve themselves in projects relating to the matter. The Massachusetts Renewable Portfolio Standards (RPS) specifically provides anaerobic digestion based production, delving into the conversion of biogas into electricity. The U.S. Department of Energy is responsible for providing numerous financial support for both public and private clean energy projects. The Patrick Administration's goal for 2014 was to divert 450,000 tons of food waste per year from incinerators and landfills. Instead, the organization wants to bring this waste to composting facilities and anaerobic digesters so that it can be converted to heat and electricity. If this goal is achieved, the Patrick Administration will have cut greenhouse gases, lowered disposal costs and preserved landfill space throughout Massachusetts. In order to successfully implement their goal, the government is highly supporting the farmers and assisting anaerobic digester project developers. [10, 41, 43, 49]

Eligible Anaerobic Digesters

Currently, there are three farms in Massachusetts with anaerobic digesters that accept food waste. These farms include Longview Farm in Hadley, Jordan Farms in Rutland, and Barway Farm in South Deerfield. There are also three stand-alone AD facilities in the state, which consists of Ken's Steakhouse in Framingham, MA, Garelick Farms and Dean Foods in Franklin and Lynn, MA, and Kraft Foods Atlantic Gelatin in Peabody, MA. Ken's Foods is a steakhouse and salad dressing manufacturer that operates a private AD facility capable of processing pre and post consumer food wastes. Garelick Farms and Dean Foods are wastewater treatment facilities with five million gallon capacity AD systems, which digest byproducts of milk production. Kraft Foods on the other hand, is a food processing plant that is currently constructing an AD facility to process their waste. Furthermore, four facilities have been proposed in Massachusetts in Bourne, Dartmouth, Hamilton, and Lexington. Bourne plans to process 300-400 tons of food waste per day with their upcoming facility, while Dartmouth plans to upgrade their gas-to-energy facility with the $400,000 in grants that they received from the Mass Clean Energy Results Program (CERP). The facilities' goal is to process 12 tons of waste per day, producing 650,000 kilowatt hours of electricity per year. Hamilton intends to use their current landfill as a digestion site for food waste. The town is currently looking for grant money and plans to begin building early to mid 2015. Finally, Lexington also hoped to turn their landfill into a digestion site that will be capable of processing 145,000 tons of yard and food waste per year. [78, 80]

The Jordan Farms in Rutland, MA received $360,000 from the Mass Clean Energy Center to fund feasibility studies, design and construction costs. Additionally, the Massachusetts

Department of Agricultural Resources gave over $50,000 to the Jordan Farms for other various project costs. [9] The Jordan Farms was finally completed in June of 2011. The digester is capable to digest mix of manure and food waste and produce 300KW per hour while operating. [35]

The Barstow Longview Farms is located in Hampshire, MA recently launched its anaerobic digester. The electricity produced from the processed food waste and manure is sold to the Western Mass Electric grid and used for the farm operation. [26, 40] The farm generates 21,000 MWh of electrical energy 7,040 MMBTUs of thermal energy and 30,000 tons of fertilizer each year. [57]

UMass-Amherst, meanwhile, has spurred construction of an anaerobic digester at its facility's wastewater treatment plant. This plant could handle sludge from the treatment facility, but also take in food waste from the campus and nearby towns, and deliver clean, renewable energy back to campus. The university predicts that by the year 2020, they will divert an additional 350,000 tons of waste, accounting for an increase in energy production by 50 megawatts. [78, 79]

Benchmarking

To see where the state of Massachusetts stands for recycling food waste as well as using anaerobic digestion, we have looked into various locations such as some other states in the US, and Europe. This research has allowed us to see make a comparison and evaluate the current progress of anaerobic digestion.

After conducting proper research, we have found that anaerobic digestion has been producing renewable energy sources for several decades.[66] Other places such as Europe have been very successful at implementing renewable energy source projects, including conversion of organic matter to electricity through anaerobic digestion for the past 20-30 years.[66] Promoting recycling and reusing solid organic waste among the citizens is of the main challenges for every country/state. However, with people's thoughtfulness of the sustainability of the environment, different parties have developed several different programs that allow collecting waste and using it for digestion. Even though commercial food waste ban in MA has been effective since October 2014, places such as college dining have already been recycling the food waste. (See the interviews notes for further information) This ban supports anaerobic digesters to have a constant and nutrient rich input source for digestion.[42] Several other countries and multiple different states in the US have been supporting anaerobic digestion and recycling of food waste.[10] Further, to achieve the goals of recycling, we recommend starting a program that collects food waste from households. One way to implement this is by making public awareness campaign, and by supporting haulers to send waste to local anaerobic digesters instead of sending it to landfills.

California

By the end of 2020, California is expecting to supply one third of the state's total electricity need from renewable energy sources.[19] As of 2009 11.9% of the electricity need was met from renewable energy source, out of this 11.9 % nearly 3% come from biogas.[71] There are 82 operating biomass digesters in California. One of the biggest anaerobic digester is Cleanworld Sacramento Bio-digester located in Sacramento County.[13] The bio-digester opened in late 2012 and went through expansion with the help of California Energy Commission in 2013. It consumes and processes nearly 100 tons of food waste a day. The end product is used to power electric vehicles and the digester generates nearly 3.17 million kilowatt hours of electricity per year.[13]

Vermont

The state of Vermont is currently working in legislating a law that bans all organic waste from landfills by 2020.[70] According to Renewable Energy Vermont, the state of Vermont has 'more digester per dairy farm than any other state in the US'.[15] Currently, there is an organization named Green Mountain Power (GMP) it is a local electricity utility that provides electricity from renewable energy source. GMP is promoting 'Cow Power' program that encourages farmers to send manure/organic waste to a local anaerobic digesters where the produced electricity is sent to the grid or the biogas can also be sent through a pipeline to an appropriate gas storage.[1]

Europe

The European Union (EU) is expecting to have 20% of its total energy come from renewable energy sources. [60] Some countries of EU have already met the 20% goal and are further pushing the extents of the goal.[74, 62, 53] These countries include Sweden, Norway, Finland, Austria and more. Out of all the countries of EU, Germany and United Kingdom (UK) produce the most energy by means of anaerobic digestion.[2] The government of Germany has highly supported anaerobic digestion for companies and farms and as of today there are more than 6,000 biogas plants that convert organic waste to energy.[16] Germany is implementing a nationwide food waste collecting program.[27] In 2005, the government of Germany declared a ban that prohibits untreated waste to go to landfills.[59] In March of 2013, over 100 anaerobic digesters across the United Kingdom were recorded, the reported waste processing capacity was 5.1 million tons of food and farm waste every year.[61] Similarly the government on UK is promoting energy obtained through the means of anaerobic digestion and they are expecting to produce 3 to 5 terawatt-hours of electricity from anaerobic digestion by 2020.[30] For waste management, they are planning to target on 50% of waste from households to be recycled by 2020, including food waste.[55] Annually, UK produces 16 million tons of food waste, some of which are composted, some sent to landfills due to unavailable recycling services, and others are anaerobically digested. Future actions for UK are to stop sending food waste to landfills.[33] The government of United Kingdom has also stated that they will promote reducing food waste and recycle and reuse the unavoidable waste. The UK noted that they will highly support renewable energy sources from waste.[33]

Discussions

Advantages and Disadvantages of Anaerobic Digestion

Anaerobic digestion is an eco-friendly biogas production process that helps to maintain a clean and pathogen free environment at farms and livestock producing sites. Numerous positive impacts have been recorded since its first application in the 17th century. Advantages and disadvantages of this type of renewable energy source are discussed in detail below.

Advantages

- Reduction of greenhouse emissions

Within the last 100 years, the need for electricity and accordingly the world energy consumption and production of greenhouse gases has rapidly increased.[68, 69] Greenhouse gas consists mostly of carbon dioxide, nitrous oxide, water vapor and methane. When combined together, these gaseous compounds trap heat in the atmosphere leading to global warming.[37] According to the US Environmental Protection Agency, nearly 26% of the total greenhouse gas emissions was caused by the production of electricity.[31] By using anaerobic digestion to produce energy, greenhouse gas emissions can be significantly decreased.[18] Rather than sending food waste to landfills, one can send their food waste to anaerobic digesting facility at the same cost for hauling. The digestion of food waste by the means of anaerobic digestion will decrease the CO_2 and methane emission into open spaces, thus resulting in a much smaller chance of the occurrence of any fires.

- Waste and unpleasant odor management

It has been stated that "where food waste cannot be prevented, anaerobic digestion is the best environmental option currently available." According to an article that was published on Scientific American, unpleasant odor can affect the mood, work performance, and other forms of behavior of personal.[23] When food waste starts decomposing, it releases small amounts of organic compounds that have sulfur within its composition. The presence of sulfur makes the decomposing waste malodorous. Anaerobic digesters consist of sealed tanks where the decomposing manure and waste are stored. The unpleasant odor or the chemical compounds are broken down by anaerobic bacteria, which reduces the sulfate concentration in the mass under an oxygen free environment.[11]

- Reduction of pathogenic diseases

In the consistency of manure can potentially contain several pathogens such as Hepatitis E and Influenza viruses, Salmonella, E. Colis. Factors such as temperature, pH and retention time in the digester can help to significantly reduce the number of common potential pathogens in food waste and manure.[44, 46, 52]

- Production of fertilizers

Reusable waste produced during the anaerobic digestion process can be turned into a high quality agricultural fertilizer. It is assumed that from 28,000 metric tons of waste, 9,200 metric tons of fertilizers can be produced.[48] One should note that the composition of fertilizers will vary based on its previous contents, however, it is expected that the fertilizer will mostly be rich in high concentrations of ammonium nitrate, phosphorous, and other inorganic compounds.[72]

- Not dependent on non-renewable energy sources

With today's energy consumption, the world is rapidly running out of the non-renewable energy source. According to the British Broadcasting Corporation (BBC), the world will completely run out of natural gas, oil, and coal approximately within 35-40 years from today.[32] Biogas is an alternative source of energy that is a renewable and eco-friendly process.[17] According to the EPA, if 50% of the total food waste generated each year in the USA were processed anaerobically it would produce enough supply of energy for 2.5 million houses for a year.[45] By making the anaerobic digesters accessible to most farms around the world, the human population will save enormous amounts of non-renewable energy sources.

- Financial support for farmers and digesters

Several financial benefits can be listed for farms with anaerobic digesters. Currently, the state of Massachusetts is promoting and supporting digester plants with grants to ensure a sufficient facility for recycling the food waste.[20] In addition, some potential revenue can be made from the energy sale and the sale of the digested food waste as fertilizers.[8, 25] This is further discussed in our Discussions.

Possible Challenges and Disadvantages:

We realized that waste collection could be a potential challenge for anaerobic digesters. In Eastern Massachusetts, Black Earth Compost private company offers weekly food waste removal, pick-up and delivery of food waste to local farms. To ensure an effective process, the food waste should be sorted.[58] This process requires collaboration of the citizens, thus public awareness of how food waste is used to generate renewable energy should be raised.

While interviewing ReyclingWorks, we learned that it is difficult to get the right consistency of solid and liquid waste straight from the waste producers. Thus, this could challenge the collaboration of food waste producers and anaerobic digesting facilities.

Interview Summaries

To learn the impact of the food waste ban on college campuses we conducted several interviews with representatives from dining services from colleges around Worcester. Some other organizations that were involved in the food waste disposal ban were contacted through emails. Full interview notes and correspondence can be found in the Appendix section of this paper.

Food Waste Producers

After interviewing Robb Ahlquist, the owner of The Sole Proprietor restaurant, it became known that smaller businesses and restaurants were not affected by the food waste disposal ban as they do not produce the minimum amount of food waste required to meet the ban. The Sole Proprietor previously sent their food scraps to a local pig farm but stopped doing so after one year as it was too much unnecessary and costly work for the restaurant. Currently, The Sole Proprietor disposes of their minimal amounts of food scraps and recyclable materials such as glass, cardboard, and plastic are recycled.

Unlike restaurants like The Sole Proprietor, colleges and universities, which produce much more food waste, were barely affected by the food waste disposal ban. We conducted interviews with four universities in Worcester, MA, Worcester Polytechnic Institute (WPI), Assumption College, Worcester State University (WSU), and Clark University. These four schools all had something in common, which is that they were all aware of the existence of the food waste disposal ban prior to it becoming effective. Surprisingly, neither WPI, Assumption College, nor Worcester State University send their food waste to an anaerobic digesting facility.

Chartwells at WPI sorts the produced waste into three different categories: production waste, overproduction waste, and unused/out of date inventory waste. In January 2015, the food court at the Campus Center at WPI has produced nearly 280 quarts of food production waste, 18 quarts of overproduction waste, 23 quarts of unused or out of date inventory waste. WPI works with Compass Group and recycles all organic waste to a local pig farm in Shrewsbury, MA. At the pig farm, the waste is grinded up and fed to the pigs on the farm. Additionally, WPI recycles used oil, which is later used to make soap, lipstick, and other common products. WPI receives no benefits from participating in this waste disposal process aside from removing the waste from campus at no cost to the school.

Assumption College on the other hand, has their waste hauled to a composting facility in Marlborough, MA. Before using the composting facility, Assumption College sent their waste to landfills. Each year, Assumption's main dining hall produces approximately 100 tons of waste, currently 85 tons of which are sent to the composting facility and 15 tons of recyclables which are recycled. An additional 50 tons of food waste are produced by the campus cafeteria, which is also composted. Assumption College spends about just as much to collect and haul their waste to the composting facility as they did hauling their waste to a landfill, so they broke even. Their only benefit is the positive change they made to help better the environment.

Worcester State University was not affected by the food waste ban, however, they have a dehydrator implemented in their main dining hall on campus. The campus dehydrator allows the college to store their waste and have it hauled less frequently. WSU produced 16 tons of waste last year in 2014 and 18 tons of food waste this year in 2015.WSU sends their food waste to the WeCare facility, and worked with RecyclingWorks to set up their composting protocol. Like Assumption College, WSU receives no financial benefit from sending their food waste to the WeCare facility, aside from their process bettering the environment.

Clark University employs several food waste reduction efforts. Even with these pre and post planning efforts, the college collects some food waste since they prepare extra food in order to not run out of food during dining hours. Left over food that is not served is further processed and if it is determined that it cannot be consumed, it is weighed using Lean Path and hauled to a composting facility.

Worcester Polytechnic Institute, Assumption College, Worcester State University, and Clark University have a positive outlook about the food waste ban. The universities are very proud of their recycling procedures, which allows for a better waste management system and less issues towards the environment.

Other Organizations

Recycling Works

By interviewing RecyclingWorks, we were able to learn that the company works with the Massachusetts Department of Environmental Protection (MassDEP). MassDEP has a solid waste master plan which began in 2010. This plan focuses on increasing recycling and reusing different types of waste, as it was found that majority of food waste is compostable. Thus in 2014, after two-to-three years of studying and analyzing, the MassDEP added food waste to the existing list of solid wastes that are banned for disposal.

Recycling works was established by Green Business Services for EcoTechnology as an environmental non-profit organization. RecyclingWorks is funded by the MassDEP and is a consulting company. RecyclingWorks main role is to help and find better and cost effective waste management for the businesses that are affected by the solid waste master plan. Their goal is to provide technical and consulting businesses in order to comply the ban desirably in a cost effective way. RecyclingWorks assists the waste producer by quantifying the waste that they produce, finds possible solutions to reduce the amount of produced waste, and if different actions are about to be implemented, they analyze the current situation and find the most cost effective method.

A very important part of Mass DEP's Organic's Action plan includes anaerobic digestion, which is mainly focused on renewable energy sources. Currently, there are four stand alone anaerobic digesters in Massachusetts. Although this is true, a very small percentage of food waste is sent to anaerobic digesters due to the solid and liquid consistency of the waste. There are several ways to reuse and recycle food waste, including composting, sending the waste to pig farms, sending the waste to anaerobic digesters, or by having an on-site composter. Since composting and sending food waste to an anaerobic digester are not the only ways to meet the requirement, specifically for food manufacturers and grocery stores, food donation is another possible compliance. Some of the organizations that produce significant amounts of food waste are food manufacturers, food distributors, hospitals, colleges, catering service and similar establishments. On-site waste processing is a separate option to meet the requirements of the food waste ban. Some businesses such as Whole Foods have developed an on-site technique that converts food waste into liquefied waste that is further processed to make fertilizer.

In Massachusetts, there are approximately 50 composting facilities and pig farms that accept food waste; these facilities can be found on the RecyclingWorks website. Currently, several anaerobic digesters are being built. The most efficient way to convert food waste to a proper consistency mix is being studied, which will allow organizations to send most of their food waste to anaerobic digesters, further allowing for the production of biogas and electricity.

Jordan Farms

We were given the opportunity to get in touch with an anaerobic digestion farm in Massachusetts. We interviewed Jordan Farms in Rutland, MA and learned of their process and methods in anaerobic digestion. According to the project manager at Jordan Farms, the farm produces approximately 6,000 gallons of manure per month. The produced manure is mixed with food waste in the digester tank and further processed. Jordan Farms partners up with Casella Organics, who is in charge of obtaining food waste that gets digested in the digester. Casella Organics has contracts with food waste processors and arranges the transportation of food waste to Jordan Farms. The main food waste suppliers ranges from dairy product producers to salad dressing producers. Jordan Farms also works with AGreen Energy to operate the anaerobic digestion facility. Since the food waste ban took an effect starting October 2014, Jordan Farms has received additional organic waste material, which has allowed for an increase in the gas production from the anaerobic digester. Jordan Farms runs a continuous mix facility, thus there are no batches. They bring in approximately 70-80 tons of food waste mixed with manure each day. The anaerobic digester at Jordan farms runs a 500 KW engine, typically at full capacity. The digestion produces heat as an additional output aside from fertilizer, which is used on corn and hay fields at the facility. A portion of the electricity that is produced is used to run the digester and the farm, while the rest is processed through the grid. In order to implement the anaerobic digester project, Jordan Farms worked with MA DOER, MassDEP, and MassCEC.

Final Findings

Based on the interviews that we conducted, we were able to determine the current situation of the commercial food waste disposal ban and its relevance to anaerobic digestion. Prior to starting the project, our team expected this ban to affect a greater number of organizations and some noticeable change at anaerobic digesters. Based on our correspondence with Shannon Caroll from the Jordan Farms, we learned that since the food waste ban took an effect, there has been a slight increase in the amount of food waste stock that is delivered to their farm and goes into the digester.

Based on the interviews with college dining hall representatives, we learned that most of the colleges started recycling their waste long before the commercial food waste ban came into effect. Thus, the transition stage was very smooth. We learned that the most common way to recycle the waste is to send it to composting facilities or pig farms. Food waste reduction also plays an important role for waste producers, as most of the colleges we have spoken to have methods to weigh their pre- and post- consumer waste. Based on these findings, they learn what kind of food is 'famous' and they modify their menus at dining facilities. This allows the dining facility to reduce their waste. Almost all of the colleges we collaborated with donated some amount of food to food banks.

The commercial food waste ban was an efficient method to encourage recycling of food waste. Now, we need to concentrate on using food waste as an organic feedback at anaerobic digesters. On-site waste grinders should be implemented at large waste producing facilities in order to obtain the proper solid-liquid consistency of the waste. This would allow the anaerobic digesters to easily process the waste and produce the maximum possible amount of energy.

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Appendices

Appendix A: Sample Interview Questions

- To what extent are they aware about the new food waste ban? How is the transition process going as of today?
- What did they used to do with the waste before the ban, any kind of sorting?
- How much food waste do they produce per month or week?
- Do they separate pre and post consumer waste?
- Do they have to separate the meat products from the other waste?
- How frequently the waste is collected? How long and where do they store the waste?
- Where is the waste transported to, what is it used for?
- Do they team up with any other organizations in Worcester? Is there a third party involved in food waste collection and transportation?
- When did they begin collecting food waste, how did they develop their food waste recycling techniques?
- What is the economical impact of the food waste ban on the particular organization?
- Does the food waste they collect allow them to save money somehow?
- What is their overall opinion about the food waste ban? Do they approve it or disapprove it?

Appendix B: Interview with Robb Ahlquist, the owner of the Sole Proprietor Restaurant

Date of interview: 12/12/2014

Time: 3:00-3:30PM

Location: The Sole Proprietor

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: Robb Ahlquist

The Sole Proprietor produces minimal food waste. The amount of waste is estimated using the following equation:

[Used amount of ingredients] - [Produced and distributed food] = [Amount of food waste]

They target to produce less than 1% of the whole ingredient consumption. Since the amount of waste is not that much the pre and post consumer waste does not get separate, the waste goes to the same garbage container.

One should note that the pre consumer food waste from food preparation is minimal because most of the ingredients get used in the dishes. Common pre-consumer food waste includes fish skin, bones and etc. Usually the pre-consumer waste does not involve meat waste because the restaurant used pre-cut stake and some products such as fish trimmings go to other dish preparation such as chowder and etc.

The Sole Proprietor is aware about the Food Waste Ban, however with the amount of food waste they produce, they don't meet the minimal food waste production. Thus the enforced law did not affect them. Previously, The Sole Proprietor used to send their waste to pig farms. This step involved waste sorting, farmers used to come and pick up the waste. Unfortunately, they had a problem keeping foreign objects/waste from the waste and they had to stop sending the waste to pig farms after one year. Foreign objects can be described as waste that does not directly come from food such as broken glass, napkins, straw paper, and etc. In other words foreign object is a waste that is not food mixture. Currently, recyclable materials such as glass, cardboards and plastic are recycled.

Currently, their waste gets picked up by a hauler 3 times per week in winter and 4 times per week in summer. The waste is transported to incinerating facility in Millbury, MA. The Sole Proprietor does not team up with a third party organization for waste transportation and collection.

When we asked about Mr. Ahlquist's overall opinion about the food waste ban, Robb mentioned logistics and feasibility, practicality and expense, which is not easy for a small business when new mandates and new industry come forward. He also mentioned that if offsets (such as breaking even) were involved, then it would be beneficial and there would be more buy in from a business such as the Sole Proprietor. On the other hand, if there were no offsets involved in the new mandate, the expense is put on the operator and it then becomes not in favor of the business owner.

Appendix C: Interview with Todd Saarinen Director of Retail Dining and Head Chef Michael Reno at the WPI Campus Center Food Court

Date of interview: 02/11/2015

Time: 4:00-4:30PM

Location: WPI Campus Center

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: Todd Saarinen and Michael Reno

Chartwells at WPI was aware about the food waste ban that took an effect in October 2014. Chartwells at WPI works with Compass and recycles any organic types of waste to a local pig farm that is located in Shrewsbury, MA. The food waste gets grinded at the farm and is fed to pigs.

Chartwells has been sending the produced food waste to a pig farm for the last 5 years, thus they were not affected by the food waste ban. Chartwell has two 50-gallon drums, which are used to store the waste. The owner of the pig farm comes to the campus every Tuesday and Thursday to pick up the waste.

Most common produced food waste is potato and carrot peels, fat from meat products, leftover and outdated products. The on-the shelf product gets removed and recycled, if it is not consumed within four days. The amount of production waste gets weighed hourly. One should note that Chartwells at WPI recycles the used oil and it is used to make soap and other products. Plastics and cardboards also get recycled.

By sending the food waste, Chartwells at WPI receives no benefits, aside from removing the waste from the campus at no charge to the school

Appendix D: Interview with Professor Jill Rulfs from WPI's Biology Department

Date of interview: 02/12/2015

Time: 2:00-2:30PM

Location: Professor Jill Rulfs' office, Goddard Hall 128A

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: Professor Jill Rulfs

Anaerobic digestion is similar to anaerobic metabolism or fermentation. Anaerobes or the bacteria that digests the organic matter produce alcohol, acids, acetone and etc. Anaerobic digestion involves wet and dry fermentation, in other words the water solid consistency is important for anaerobic digestion. Dry digestion produces less methane at a higher cost and it takes longer time to digest. Wet digestion involves a lot of energy input. Sometimes it needs some drying thus additional cost of drying can be added to the overall cost.

Mixture of food waste and manure is the best sludge for anaerobic digestion and it works for both wet and dry combination. Methane is produced in the digestive tract of an animal thus manure has some of the anaerobic bacteria. By adding manure to anaerobic digestion, the bacteria that are already in the manure can support the industrial anaerobic bacteria in the digester. The bacteria from the gut are the finely selected bacteria and will help the procedure to achieve greater amount of methane. This will allow increasing the production of biogas.

Advantages of anaerobic digestion at digesters include reduction of landfill fires and greenhouse gas, and odor control. These all can be accomplished since anaerobic digestion occurs in closed digesters. Anaerobic digestion can also help waste management at farms.

Further suggestion is to look up how Europe has been using anaerobic digestion for industrial and commercial use.

Appendix E: Interview with John Langlois and Peter Carnahan from Dining Services at Assumption College

Date of interview: 02/26/2015

Time: 3:00-3:30PM

Location: Phone Interview

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: John Langlois and Peter Carnahan

Assumption College was aware of the food waste ban long before it took an effect. Starting 3 years ago, the dining service at Assumption College attended several different seminars on food waste recycling, after attending conferences they started composting produced food waste. The composting facility is located in Marlborough MA and the waste gets picked up on demand. Before the composting program started, the waste used to go to landfills. Assumption College pays for the transportation of the waste.

Since the dining services at Assumption College did a research prior to the start of the food waste disposal ban, the transition between sending the waste to landfills and composting was smooth.

The main dining hall at Assumption College produces approximately 100 tons of waste per year. It should be noted that pre and post consumer waste are mixed. Out of these 100 tons nearly 85 tons get composted and the rest 15 tons consist of recyclable materials such as plastic and aluminum cans and etc. this recyclables are also recycled. The cafeteria produces approximately 50 tons of food waste yearly.

Appendix F: Interview with Steven Bandarra, Sustainability Coordinator at Worcester State University

Date of interview: 04/01/2015

Time: 3:00-3:30PM

Location: Phone Interview

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: Steven Bandarra

Worcester State University was not affected by the food waste ban because they produce approximately less than 1 ton of food waste per week. The dining facilities produce nearly 3.5 tons of food waste per month when school is in session and the number decreases during the summer months. However, it should be noted that WSU was aware of the food waste ban and they starting planning of recycling the waste starting 2012. Prior to January 2013, the food waste was sent to landfills.

They used to send their raw waste every week to WeCare composting facility years before the ban took an effect. Starting Fall 2014, the food waste is processed in a dehydrator that is located at WSU. The food waste is picked up daily and is grinded and pressed prior going in to the dehydrator. The advantage of having a dehydrator on campus is that it is more cost effective to maintain the system rather than frequently using haulers to send their waste. This also allows storing the waste for a longer time and the haulers pick up the waste less frequently. They composted 16 tons of waste last year and 18 tons this year.

One should note that some food that is about to expire or not suitable for the campus dining hall gets donated by WSU to pantries such as Rachelle's Table and Why me House. WSU also does an annual soup bowl drive for Worcester Soup Kitchen.

WSU works with WeCare and RecyclingWorks, additionally with haulers to transport the food waste. RecyclingWorks helped WSU to develop their food recycling procedures.

In regards to financing the waste management, recycling of food waste is not beneficial. Prior to using WeCare, the university sent their waste to a landfill where they would have to pay to haul it per ton of waste. Now that they have changed their process, the school still pays to haul the waste and also pays for electricity for the dehydration system on campus. The dehydrator uses a lot of electricity and produces carbon, but they were able to cut down the transportation of waste to WeCare to two trips per month instead of four, causing their financial burden to equal out to cost neutral.

Their overall opinion about recycling of food waste is very positive. They are very proud of their recycling procedures, which allows a better waste management and less issues to the environment. Worcester State is also considering sending their food waste to an anaerobic digester in the future, they are happy to send their food waste to organizations that need it.

Appendix G: Interview with Lorenzo Macaluso, Director of Green Business Services

Date of interview: 04/21/2015

Time: 11:00-11:30AM

Location: Phone Interview

Interviewers: Jourdan McKenna and Dulguun Gantulga

Interviewee: Lorenzon Macaluso

MassDEP has a solid waste master plan which started in 2010. This plan focuses on increasing recycling and reusing different types of waste. It was found that majority of food waste is compostable. Thus in 2014, after 2-3 years of studying and analyzing, the MassDEP added food waste to the existing list of solid waste that are banned for disposal. The current list includes paper, plastics, electronics, food waste and etc.

Recycling works was established by Green Business Services for EcoTechnology, an environmental non-profit organization. Recycling works is funded by the MassDEP and is a consulting organizations. Recycling works role is to support the businesses that are affected by the solid waste master plan. Their goal is to provide technical and consulting support to businesses to comply the ban desirably in a cost effective ways. Recycling works has a website that provides resources for recycling and they can be reached at a hotline as an over the phone type of assistance. Recycling works also offers assessment tools and implementation planning as a part of the assistance. They help the waste producer to quantify the waste, find possible solutions to reduce the waste, and if different actions are about to be implemented they analyze the current situation and find the most cost effective method. They also do networking, for example if a food waste producer wants to divert from sending the waste to landfills to composting, they advise them to discuss it with their current haulers and if that does not end up in an agreement they make connections with other haulers that are able to help

Part of Mass DEP's Organic's Action plan includes anaerobic digestion, which is mainly focused on renewable energy source. Currently, there are 4 stand alone anaerobic digesters in Massachusetts. However, a very small percentage of food waste goes to anaerobic digesters, this is due to the solid and liquid consistency of the waste.

There are several ways to reuse and recycle the food waste, this includes composting, sending the waste to pig farms, and sending the waste to anaerobic digesters or having an on site food waste. One should also note that composting and sending the waste to AD are not the only ways to meet the requirement, specifically for food manufacturers and grocery stores food donation is another possible compliance. However, food donation has liability concerns. Some of the organizations that produce significant amount of food waste are food manufacturers, food distributors, hospitals, colleges, catering service and etc.

The on-site waste processing is another way to meet the requirement of the food waste ban. Some places such as Whole Foods have developed an on site technique that converts food waste into liquefied waste that is further processed to make fertilizers.

In Massachusetts there are around 50 composting or pig farms that accept food waste and they can be found the Recycling Works website. Currently there are several anaerobic digesters are being built. The most efficient way to convert the waste to a right consistency mix is being studied. This will allow to send most of the food waste to anaerobic digesters which will further produce biogas and/or electricity.

Recycling Works helps to sort the waste as suitable or not suitable for anaerobic digestion. The food waste that goes into digesters need to be pumpable, in a somewhat liquid form, the ideal wastes are salad dressings and ice cream. However, some intermediate steps can transform the waste into a source material for anaerobic digestion.

Recycling Works conducted two surveys regarding the food waste disposal, before and after the ban took an effect. Pre-food waste ban approximately 1,400 businesses and organizations have already been composting their waste. After the ban the number of organizations that recycled their food was increased to 1,500. It should also be noted that some businesses that produced less than 1 ton per week have already been composting or using other methods to reuse/recycle the food waste.

Appendix H: Correspondence with Heather Vaillette, General Manager of the Dining Service at Clark University

Date of correspondence: 03/02/2015

Time: 1:25PM

Correspondence type: Email

As part of Clark University's sustainability and community engagement, Clark University took the responsibility to reuse/recycle the food waste and excess food.

Clark University tries to avoid and reduce food waste through several waste reduction efforts. At the dining halls, they determine 'the most needed amounts of each item' based on the collected data. They also use a software called Lean Path, which allows them to weigh the pre-consumer waste. By learning the types of waste from the pre-consumer process they focus on those areas for further planning.

Even with these pre and post planning they collect some extra amount of food waste because they prepare extra food to not to run out of food during dining hours. Left over food that is not served is further processed.

If the food was held at safe temperature according to HACCP, it can be cooled and used for other menu items as an ingredient. 'For example, pork loin may be cooled, marinated and shredded for pulled pork sliders. They will often plan on this with a pork loin menu item scheduled for one day and then pulled pork sliders the next day as this process actually produces the best flavor for the sliders.'

If the food that cannot be used for other purposes or during school breaks, the food is donated to organizations such as Rachel's Table, Jeremiah's Inn or a local church organization. The location that receives the food will be determined by which one is available to pick up the product.

If the food cannot be used due to processing mistakes such as dropping, burning, and if the products are spoiled or expired, the waste is weighed using the Lean Path scale and is composted. It should be highly noted that none of the food waste goes to landfill or incinerators.

Appendix I: Correspondence with Shannon Carroll from Jordan Farms

Date of correspondence: 04/15/2015

Time: 1:15PM

Correspondence type: Email

According to the project manager at Jordan Farms, Jordan Farms produces approximately 6,000 gallons of manure per month.The manure gets mixed with food waste in the digester tank. Jordan Farms partners up with Casella Organics, and it is in charge of obtaining food waste that gets digested in the digester. Casella Organics has contracts with food waste processors and arranges the transportation of food waste to Jordan Farms.The main food waste suppliers ranges from dairy product producers to salad dressing producers. Jordan Farms also works with AGreen Energy to operate the anaerobic digester facility.

Since the food waste ban took an effect starting October 2014, Jordan Farms has received some more additional organic waste material, which increased the gas production from the anaerobic digestion. Jordan Farms runs a continuous mix facility, thus there are no batches. They bring in approximately 70-80 tons of food waste mixed with manure per day.

The anaerobic digester at Jordan farms runs a 500 KW engine, and it usually runs at its full capacity. The digestion produces heat as an additional product, the digestates are used as fertilizer on corn and hay fields. Some electricity that is produced is used to run the digester and the farm, the rest goes to the grid

In order to implement the anaerobic digester project, Jordan Farms worked with MA DOER, MassDEP, and MassCEC.

Appendix J: Daniel Andersen, Assistant Professor at Iowa State University

Date of correspondence: 02/27/2015

Time: 9:45PM

Correspondence type: Email

Co-digestion is the process of mixing two, or more, substrates or feedstocks together as you perform the digestion process. The reasons why substrates are mixed is because some products are extremely digestible but contain something that slows down the digestion process, for example, one we deal with in some manures is ammonia toxicity, that is too much free ammonia which slows down the digestion product. If you can find a low-nitrogen content feedstock to mix with the manure you dilute the ammonia concentration and in so doing reduce the toxicity of that compound to the microbes.

So generally, when I think of co-digestion in anaerobic systems the main result is that we increase the organic loading rate (basically we are feeding the microbes more). This results in an economy of scale as there are often economic improvements from being a little bigger (for example adding the next 1000 gallons to a digester size is cheaper than the previous 1000 gallons because all the equipment is already there so it's just a little more supplies and a bit more labor).

When performing co-digestion people have often reported a "synergistic effect" where we get more methane produced by mixing the substances together than we would have gotten by digesting the two substrates separately (or at least we get the methane faster). This is still a relatively poorly understood topic, but what scientists are starting to think is that by mixing different things together we generate a microbial community that is somehow more diverse and robust (at least if we pick the right things to mix together). So my take on this would be that the ultimate amount of methane we could generate from the substrate shouldn't be modified. The microbial community is either capable of breaking down the substance under the conditions or it isn't, mixing them together isn't some magical way to break down new things (unless the dilution removes some sort of chemical inhibition), but what it does do is improve the rate at which things break down. What probably happens is one of the substances (the more easily broken down one) gets digestion started and this causes the microbes to start making enzymes that help in processing the other substrates more quickly.