April 2010

Methane Creation from Anaerobic Digestion

Benton Lawrence Cassie
Worcester Polytechnic Institute

Jennifer A. Lee
Worcester Polytechnic Institute

Mathew Joseph DiLeo
Worcester Polytechnic Institute

Project Number: RWT-1001

Methane Creation from Anaerobic Digestion

An Interactive Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Civil Engineering

by

Benton L. Cassie

Matthew J. DiLeo

Jennifer A. Lee

Date: April 29, 2010

Approved:________________________________

Professor Robert W. Thompson, Advisor

Abstract

Anaerobic digestion is the process in which organic material decays in an oxygen free or low oxygen environment. The process releases heat and biogas, which contains methane, carbon dioxide and traces of other gases. The first known use of anaerobic digestion was located in India, in 1859. Today, anaerobic digestion is commonly used for animal waste from farms, food waste from restaurants or food processing plants and wastewater at wastewater treatment plants. Biogas generated from anaerobic digesters can be used to generate thermal or electrical energy, which also reduces methane emissions. Anaerobic digestion can be used in many more parts of the world. The parameters that affect it's usage is the size of the plant or farm, amount of manure being produced, initial capital investment, frequent maintenance, and obeying the land use law and utility companies.

Acknowledgements

We would like to thank Professor Robert Thompson for all of his help with this project. We would also like to thank Nadia Caines and Charles Tyler from the Deer Island Waste Water Treatment Plant, Bert Waybright from Mason Dixon Farms, Debra LaVergne from the Upper Blackstone Water Pollution Abatement District and Joe Ramirez from White Energy for their time and help in the completion of this project.

Table of Contents

Table of Figures

1.0 Introduction

Throughout history, mankind has been using fuel to generate energy. Today, electricity is one of the most heavily relied upon energies in industrialized nations. In 2007, approximately 4.2 billion kilowatt-hours of electricity were generated in the United States.[1] Figure 1-1 illustrates the breakdown of fuels that were used to generate electricity.

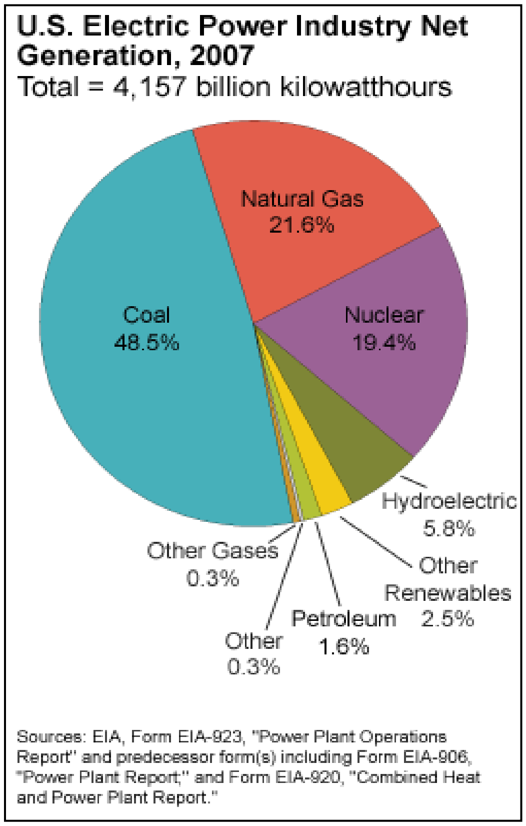

Figure 1-1:US Electric Power Industry Net Generation in 2007
(Source:http://media.photobucket.com/image/us.gif)

Approximately 72% of electricity generated in 2007 was produced by coal, natural gas, and oil. These are the leading energy sources used today. These fuels are known as fossil fuels. Since a quarter of the Earth's known coal resources are located in the United States, coal is the most common fuel in the United States.

[1] EIA, Form EIA-923, "Power Plant Operations Report," www.eia.gov, 04/10/10.

Fossil fuels are formed when organic materials, such was plants or animals, decay underground near an underground heat source. The combination of heat and pressure over millions of years creates fossil fuels, such as coal, oil and natural gas. Fossil fuels are used because they can produce relatively high levels of net energy, when compared to other fuels.[2]

Fossil fuels take millions of years to replenish and the world is using fossil fuels at a rate far greater rate than they are being replenished. Different alternatives must be sought to conserve fossil fuels and construct a much cleaner energy source to produce electricity. In figure 1-1, only 8.3% of electricity being produced in the U.S. was used by renewable energy.

The main advantage of fossil fuels is their high efficiency. But recent findings about their environmental impact have raised many new concerns. Burning fossil fuels produces sulfur-dioxide, nitric-oxide and other pollutants, which either causes air pollution or requires expensive scrubbers. Even with proper pollution controls, waste material such as ash, carbon dioxide and other gases are produced. Many of the gases produced are released into the atmosphere where they can cause acid rain or act as greenhouse gases. Burning pure natural gas produces no solid waste material and releases less carbon dioxide than petroleum or coal[2].

With growing concern for the environment and sustainability the government is pushing for renewable alternative sources for energy. Reducing the amount of carbon emissions will greatly reduce the impact that global warming has on the environment. The use of renewable resources will also ensure a reliable energy source as fossil fuel supplies dwindle. Renewable resources will also help the US to diversify their energy sources so they do not become reliant on one single source, which can prove disastrous if that source becomes compromised.

[2] Commission, California Energy. (2006). *Energy Story- Fossil Fuels*. Retrieved December 15, 2009, from Energy Quest: http://www.energyquest.ca.gov/story/chapter08.html

2.0 Background

This chapter will discuss all the background information that was deemed important to this project. Information in this section will serve as a knowledge base for the other sections in this paper. The background will cover the anaerobic digestion process, the products and waste production in the United States.

2.1 Anaerobic Digestion

Anaerobic digestion was practiced in the 10th Century for heating baths in Assyria by biogas, gas produced by the breakdown of organic matter. In the 17th century, Jan Baptita Van Helmont of Belgium discovered that decaying organic matter produces flammable gas. In 1808, the British chemist Sir Humphry Davy discovered that methane gas was present in cow manure. The first known plant to use anaerobic digesters built in a leper colony in Bombay, India in 1859.[3] Today, Germany converts half of their biogas generated from sewage sludge digestion to fuel cars. However, the most common use for anaerobic digestion is on farms and in waste water treatment plants.

Anaerobic digestion occurs when organic material decays in an oxygen-free or low oxygen environment. Anaerobic methane recovery occurs in bio-digesters, where organic matter is digested, and produces a fuel called biogas. This process conserves nutrients and reduces pathogens in organic matter. David House states in his book, 1000 lbs of human waste can produce 0.6 cubic meters of biogas.[4]

[3] Penn State University. (2010). *A short history of AD: Penn State University*. Retrieved December 15, 2010, from Penn State Univeristy: http://www.biogas.psu.edu/pdfs/ShortHistoryAD.pdf
[4] House, D. (2006). *The Biogas Handbook.* Aurora: House Press.

Anaerobic digestion occurs when organic material is broken down by bacteria in four major processes: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis is the process in which carbohydrates, proteins, fats are converted to sugars, fatty acids, and amino acids. Acidogenesis is the process in which the sugars, fatty acids, and amino acids are converted to carbon dioxide, ammonia, and carbonic acids. Acetogensis is the process which creates acetic acid and carbon dioxide. The final process, methanogenesis, is when biogas is formed. Biogas contains a mixture methane and carbon dioxide gases. The extracted methane can provide a fuel for heat and electricity.[5] Figure 2-1: Anaerobic Digestion Phases (Source: University of Strathcylde, 2010) shows a summary the anaerobic digestion processes.

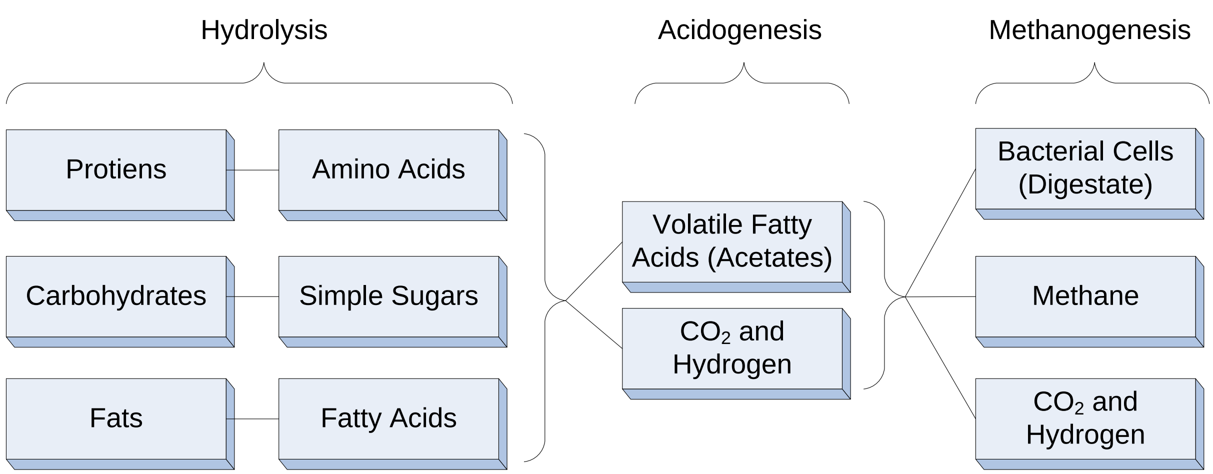

Figure 2-1: Anaerobic Digestion Phases (Source: University of Strathcylde, 2010)

There are two common types of digesters used for anaerobic treatment: batch and continuous. Batch digesters are the simpler of the two because the material is loaded in the digester and then allowed to digest. Once the digestion is complete, the effluent is removed and the process is repeated.

---

[5] Anaerobic Digestion.Com. (2010). *Advantages and Disadvantages: Anaerobic Digestion DotCom*. Retrieved November 13, 2009, from Anaerobic Digestion DotCom: http://www.anaerobic-digestion.com/html/pros___cons.html

In a continuous digester, organic material is regularly fed into the digester with the constant loading and unloading of effluent. The material moves through the digester either mechanically or by the force of the new feed pushing out digested material. There are three types of continuous digesters: vertical tank systems, horizontal tank or plug-flow systems. Continuous digesters are most common for large-scale operations.[6]

Temperature is carefully controlled in anaerobic digestion systems. There are two common environments for anaerobic digesters: thermophilic and mesophilic. The difference between the two environments is the temperature at which the organic material, or sludge, is digested.

Thermophilic digestion operates around 50 to 60 °C (120 to 140 °F). The quick breakdown of sludge allows digester volume to be small, relative to mesophilic systems. The average digestion time is approximately three to five days. Thermophilic digestion require more insulation and more heat energy and are more sensitive to incoming materials and temperature changes, compared to the mesophilic digestion system. [7]

Mesophilic digestion operates around 35 to 40 degrees °C (95 to 105 °F). The average digestion time is 15 to 20 days. Mesophilic is more common in wastewater treatment plants because thermophilic treatment due to cost and more energy is required to have more sophisticated control & instrumentation, as a thermophilic system would need.[8]

---

[6] U.S. Department of Energy. *Anaerobic Digestion Types and Designs.* 2010. http://www.energysavers.gov/your_workplace/farms_ranches/index.cfm/mytopic=30004 (accessed December 2, 2009).

[7] Industrial Gas Plants DotCom. (n.d.). Biogas Plant: Industrial Gas Plants DotCom. Retrieved November 19, 2009, from Industrial Gas Plants DotCom: http://www.industrialgasplants.com/biogas-plant.html

[8] Industrial Gas Plants DotCom. (n.d.). Biogas Plant: Industrial Gas Plants DotCom. Retrieved November 19, 2009, from Industrial Gas Plants DotCom: http://www.industrialgasplants.com/biogas-plant.html

There are three common types of anaerobic systems: farm based, food processing and centralized systems. Farm based systems are typically designed for manure from one farm, or the manure from several nearby small farms.[9] Food processing systems are typically on the same scale as farm-based systems. Centralized systems involve materials from many farms and food processing plants. Each type of anaerobic system will have different gas productions due to the difference in the feedstock for the digesters. Figure 2-2 demonstrates how different waste materials affect biogas production.

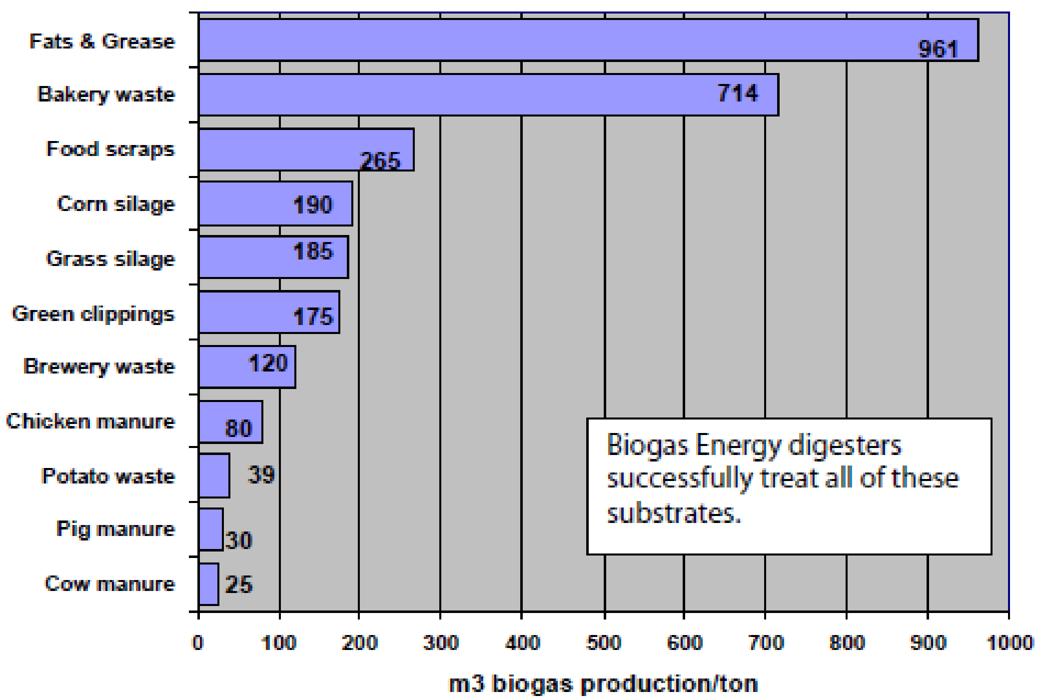

Figure 2-2: Biogas Production by Feedstock (Source: Basisdaten Biogas Deutchland, Marz 2005: Fachagentur Nachwachsende Rohstoffe e.V.)

Due to its small input and local needs, lower cost components that involve lower levels of control may be used. Farm-based systems have been successfully operated throughout North America, with the first one built in 1979, located at Mason Dixon Farms, in Gettysburg,

[9] "Guide to Anaerobic Digesters," *AgSTAR,* Program, The United States Environmental Protection Agency, http://www.epa.gov/agstar/operational.html, 04/10/10.

Pennsylvania.[10] Many farm-based systems provide sufficient heat and/or power for the farm, to provide a surplus power to local electrical lines.

Food processing sites may be similar to farm-based systems. They also may be designed for removing organic matter from wastewater. Food processing systems will likely be sized to meet either the heating requirements of the facility, or to manage the byproducts produced on-site or from several food processing facilities.[11]

Centralized systems involve materials from many farms and food processing plants.[12] Other materials, such as source-separated organics, are often added to boost gas production. Often the digestate is immediately transferred to remote field storages to allow for easier handling for land application. In many instances, heat from the centralized system is used nearby at another commercial facility or residences.

[10] Environmental Protection Agency. (2010, April 20). AgSTAR Program: EPA. Retrieved April 20, 2010, from EPA Web site: http://www.epa.gov/agstar/profiles/masondixon.html
[11] Government of Ontario. (2010, February 17). Anaerobic Digestion Basics. Retrieved March 1, 2010, from Government of Ontario Web Site: http://www.omafra.gov.on.ca/english/engineer/facts/07-057.htm

[12] Government of Ontario. (2010, February 17). Anaerobic Digestion Basics. Retrieved March 1, 2010, from Government of Ontario Web Site: http://www.omafra.gov.on.ca/english/engineer/facts/07-057.htm

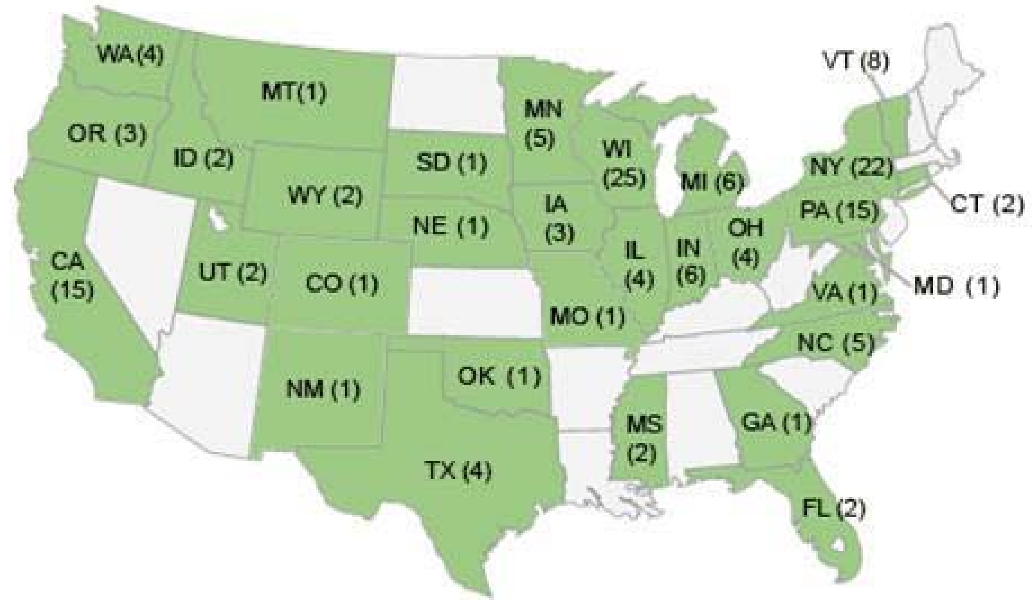

Figure 2-3: Livestock Farms with Anaerobic Digesters (Source: http://www.epa.gov/agstar/operational.html)

According to the EPA, as of April 2010 there were 151 operating anaerobic digesters on commercial livestock farms. Figure 2-3 shows the number of farms with anaerobic digester by state, Appendix A.2 contains a complete list of digesters, locations and operations. Of the 151 operational digesters, 130 capture the biogas to generate electrical or thermal energy. Table 2-1 lists the energy generation and methane emission reduction of these 151 agricultural anaerobic digesters. One major issue that is not factored in here is the reduction of fossil fuels. Every unit of biogas used to generate heat or electricity reduces the amount of fossil fuels consumed.[13]

Table 2-1: Impact of Agricultural Anaerobic Digesters

Impact of Agricultural Anaerobic Digesters	
Electricity Generation using Biogas	340,000,000 MWh
Other Energy Project using Biogas	52,000 MWh
Methane Emission Reduction	45,000 tonnes/year
• Equivalent CO_2 Reduction	944,000 tonnes/year
Source: http://www.epa.gov/agstar/operational.html, 04/10/10.	

[13] "Guide to Anaerobic Digesters," *AgSTAR,* Program, The United States Environmental Protection Agency, http://www.epa.gov/agstar/operational.html, 04/10/10.

2.2 Methane and Biogas

Methane is a colorless, non-poisonous, odorless, and flammable gas with a wide distribution in nature. Methane (CH_4) has a molecular weight of 16.04 containing 74.87% carbon and 25.13% hydrogen. It's also a major component of the outer planets of our solar system as well as cooking fuel. Methane is also used in the manufacturing of hydrogen, hydrogen cyanide, ammonia, formaldehyde, and organic synthesis. Figure 2-4 shows a methane molecule.[14]

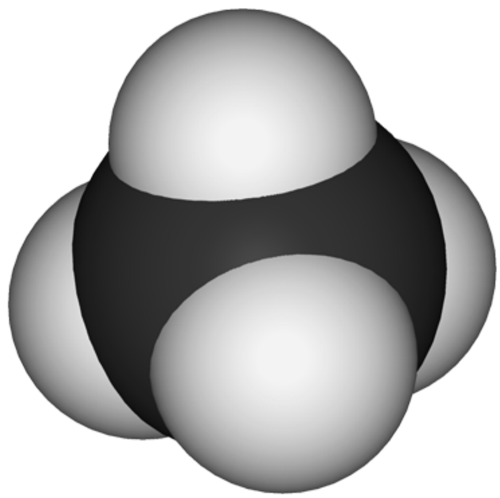

Figure 2-4: Methane Molecule (Source: http://www.globalwarmingart.com)

Methane is a primary component of natural gas that contains a mixture containing approximately 75% methane, 15% ethane (C_2H_6), and 5% other hydrocarbons. Methane is a potent greenhouse gas; it absorbs infrared radiation that would normally escape. Methane can also trap heat 20 times more effectively than carbon dioxide over a 100 year period.[15] Landfills, coal mining, biomass burning, and waste water treatment are human influenced sources of methane production. Methane is also produced from the anaerobic digestion of organic matter,

---

[14]"Chemical of the Week: Methane," http://scifun.chem.wisc.edu/chemweek/METHANE/Methane.html, 04/15/10.
[15] "Shakhashiri, B. Z. (2010). *Chemical of the Week-Methane: Univerisity of Wisonson - Madison*. Retrieved November 10 2009, 2010, from Univerisity of Wisoncon Website: http://scifun.chem.wisc.edu/chemweek/METHANE/Methane.html

whether this is occurs in a man-made anaerobic digester or underwater in a swamp to produce swamp gas.[16]

Biogas is technical terminology for the gas that is produced from anaerobic digestion. Typically, the gas is comprised of approximately 60-80% methane, 20-40% carbon dioxide and often contains traces of gases such as hydrogen sulfide, ammonia and hydrogen.[17]

2.3 Wastewater in the US

Nearly 75% of the population (approximately 200 million people) of the United States in 2005 relied on public sewer systems to remove and treat waste water. There were over 16,000 waste water treatment plants in the United States that processed over 40 billion gallons of sewage a day in 2000. From that 40 billion gallons of sewage produced daily an estimated 8 million tons of sludge was created each day. Sixty percent (near 5 million tons daily) of the sludge created from the treatment of wastewater was used for beneficial purposes in 2005. These beneficial purposes include applications in agriculture, forestry and site reclamation.[18]

2.4 Dairy Farm Costs

The AgSTAR program is an Environmental Protection Agency (EPA) program that aims to reduce methane emissions from livestock waste management operations through the use of biogas recovery systems. The program is run by the EPA, U.S. Department of Agriculture (USDA), and the U.S. Department of Energy (DOE). The program conducted a study in 2008 to determine the average cost of an anaerobic digestion system for dairy farms of varying sizes. The study covered 28 farms which included 2 covered lagoons, 16 plug flow digesters, and 10

[16] "Chemical of the Week: Methane," http://scifun.chem.wisc.edu/chemweek/METHANE/Methane.html, 04/15/10.
[17] "Biogas Production," http://www.biogas.psu.edu/terminology.html, 04/15/10.
[18] "U.S. Wastewater Treatment Factsheet," Center for Sustainable Systems, University of Michigan, 2009, Pub No. CSS04-14.

complete mix digesters. The capital costs included the cost of the digester, engine, design, and installation. Table 2-2 shows the equations that were used to estimate the capital costs. Two equations were used; the first equation was to estimate the total capital cost and the second equation was used to estimate the cost per cow. These equations are only applicable to plug digesters, such as the digesters at Mason Dixon Farms (Section 3.3, page 23). The equations used were to determine the capital cost and the capital cost per cow. [19]

Table 2-2: Dairy Farm Capital Cost Estimating Equations

Dairy Farm Capital Cost Estimating Equations			
	Equation	Y	X
Equation 1	$y = (536 \times x) + 678{,}064$	Capital Cost ($)	Number of Dairy Cows
Equation 2	$y = (12{,}960 \times x)^{-0.332}$	Capital Cost/Cow ($)	Number of Dairy Cows
Source: http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf, 4/01/10.			

Figure 2-5 and Figure 2-6 show the estimated capital cost of digesters. Figure 2-5 shows the estimated total capital cost. This chart shows that there is a positive linear relationship between the number of cows and the cost of the digesters. According to Equation 1 from Table 2-2, the minimum estimated amount for a digester system is $678,064, but for practical purposes the EPA starts their estimates at one million dollars. Figure 2-6 shows the estimated total capital cost per cow. This chart shows that there is a negative exponential relationship between the cost per cow and number of cows. Therefore, the larger the farm, the more economical the design and installation of the digesters will be. These costs exclude utilities charges, hydrogen sulfide treatment, and post digestion solids separation systems.[20]

[19]Environmental Protection Agency. "Anaerobic Digestion Capital Costs for Dairy Farms: Environmental Protection Agency." *Environmental Protection Agency.* February 2009. http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf (accessed April 1, 2010).

[20] Environmental Protection Agency. "Anaerobic Digestion Capital Costs for Dairy Farms: Environmental Protection Agency." Environmental Protection Agency. February 2009. http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf (accessed April 1, 2010).

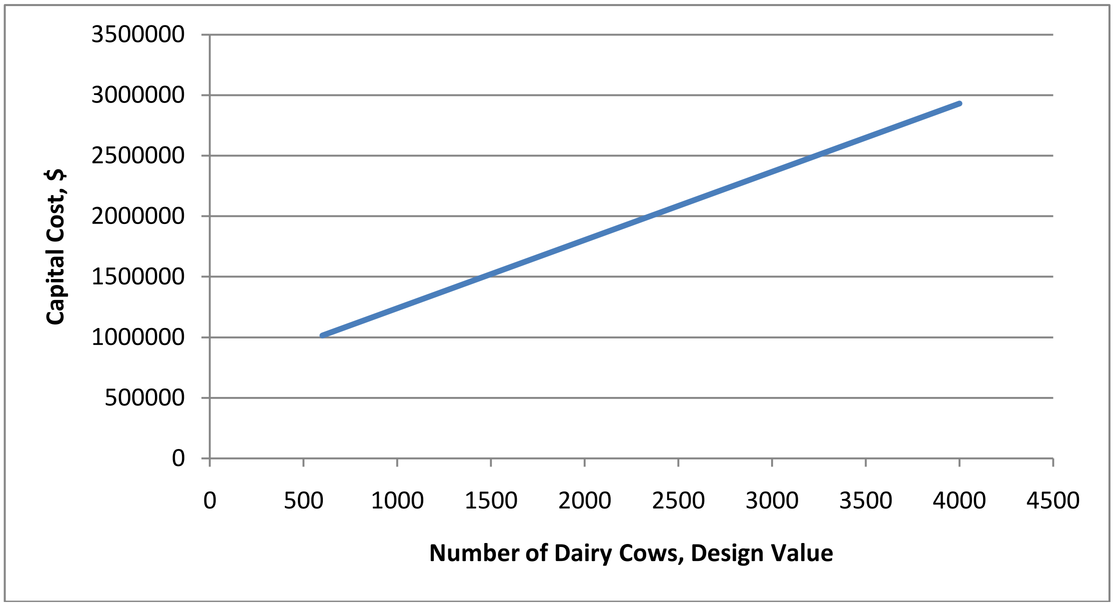

***Figure 2-5: Estimated Capital Cost (Source: http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf*, 4/01/10.)**

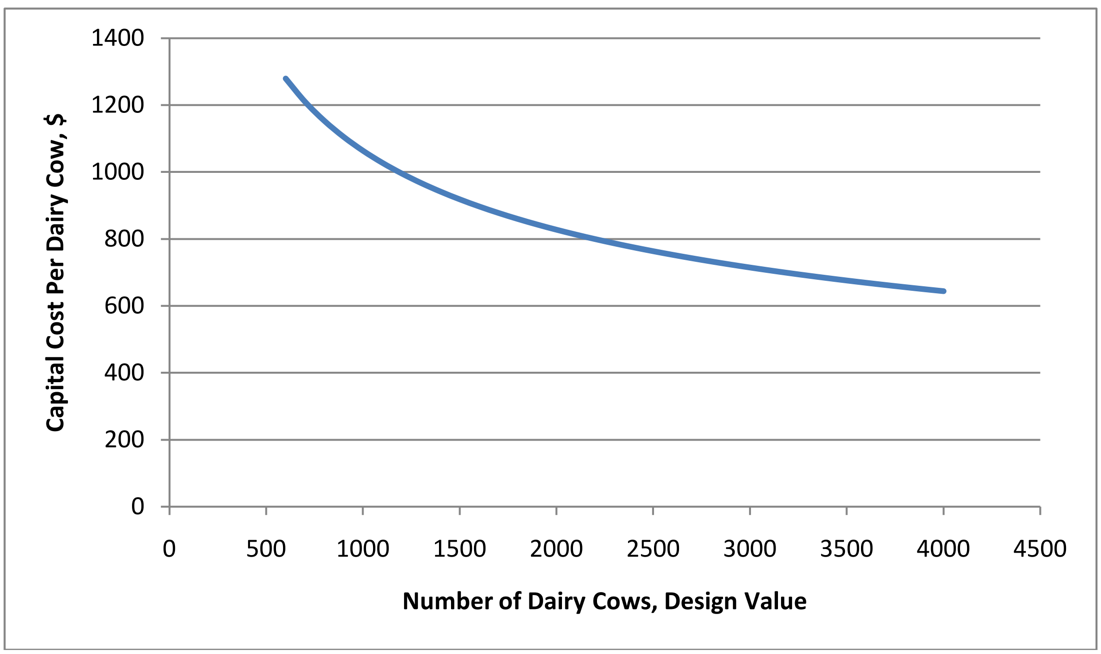

***Figure 2-6: Estimated Capital Cost Per Cow (Source: http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf*, 4/01/10.)**

3.0 Case Studies

This section of the paper will involve case studies that make use of anaerobic digesters and alternative methods for creating electricity. The cases studies will involve examples of wastewater treatment plants, agricultural digesters and food processing plants. The locations that will be studied are: Deer Island Waste Water Treatment Plant in Boston, MA, Point Loma Wastewater Treatment Plant in San Diego, CA, Mason Dixon Farms in Gettysburg, PA and South Shropshire Biodigester in Ludlow, England.

3.1 Deer Island

Deer Island, formerly an island, is manmade peninsula located in Boston Harbor. It treats wastewater from 43 communities in Massachusetts to ensure Boston Harbor remains one of the cleanest harbors in the United States.[21] In 1985, the state was found in violation of the Clean Water Act. The Massachusetts Resource Water Authority (MRWA) was created and took over the Metropolitan District Commission (MDC), which was originally developed in 1913.[22] The MWRA was court-ordered to build the Deer Island Wastewater Treatment Plant during the Boston Harbor Project. It took eleven years to build new primary and secondary treatment plants to reduce the pollution of Boston Harbor. Figure 3-1 shows an aerial view of Deer Island.

[21] The Boston Harbor Association. (2009). Deer Island: The Boston Harbor Association. Retrieved October 14, 2009, from The Boston Harbor Walk Web site: http://www.bostonharborwalk.com/placestogo/location.php?nid=7
[22] Providence College. (2010). *Boston Harbor: Providence College*. Retrieved January 31, 2010, from Providence College: http://www.providence.edu/polisci/students/boston_harbor/

Figure 3-1: Deer Island Water Treatment Plant, Boston, MA (Source: Dan L. Perlman, www.ecolibrary.org)

Deer Island is 204 acres with 2.6 miles of coastline including sixty acres of land that is dedicated to parks and recreation with two miles of trails.[23] It is the second largest wastewater treatment plant in the United States. It has twelve egg-shaped anaerobic digesters that are approximately ninety feet in diameter and 130 feet tall, as seen in Figure 3-2. The plant has three million gallons a day capacity, but during the month of November 2009 the plant had an average flow of 1.08 million gallons a day.

The purchase and installation of the digesters cost over 100 million dollars of the 4.6 billion dollar project. The egg shape reduces the internal surface area of the digester tank therefore reducing buildup of sludge, also reducing maintenance costs.[24] All of the digesters are continuous and run at a mesophilic stage. Digesters are similar to a stomach because they produce gases and acids that must be handled in a constant temperature.

There are many wastewater treatment plants that don't utilize anaerobic digestion. Charles Tyler, Deer Island's program manager of process operations, stated anaerobic digestion is a type of technology that is more long term. The turn-around period to obtain a profit is affected by the high initial cost of the system; which can be difficult for state organizations which are given an annual budget.

---

[23] Boston Harbor Islands Partnership. (2010). Explore Deer Island: Boston Harbor Islands Partnership. Retrieved January 31, 2010, from Boston Harbor Islands Partnership: http://www.bostonharborislands.com/deer

[24] Providence College. (2010). *Boston Harbor: Providence College*. Retrieved January 31, 2010, from Providence College: http://www.providence.edu/polisci/students/boston_harbor/

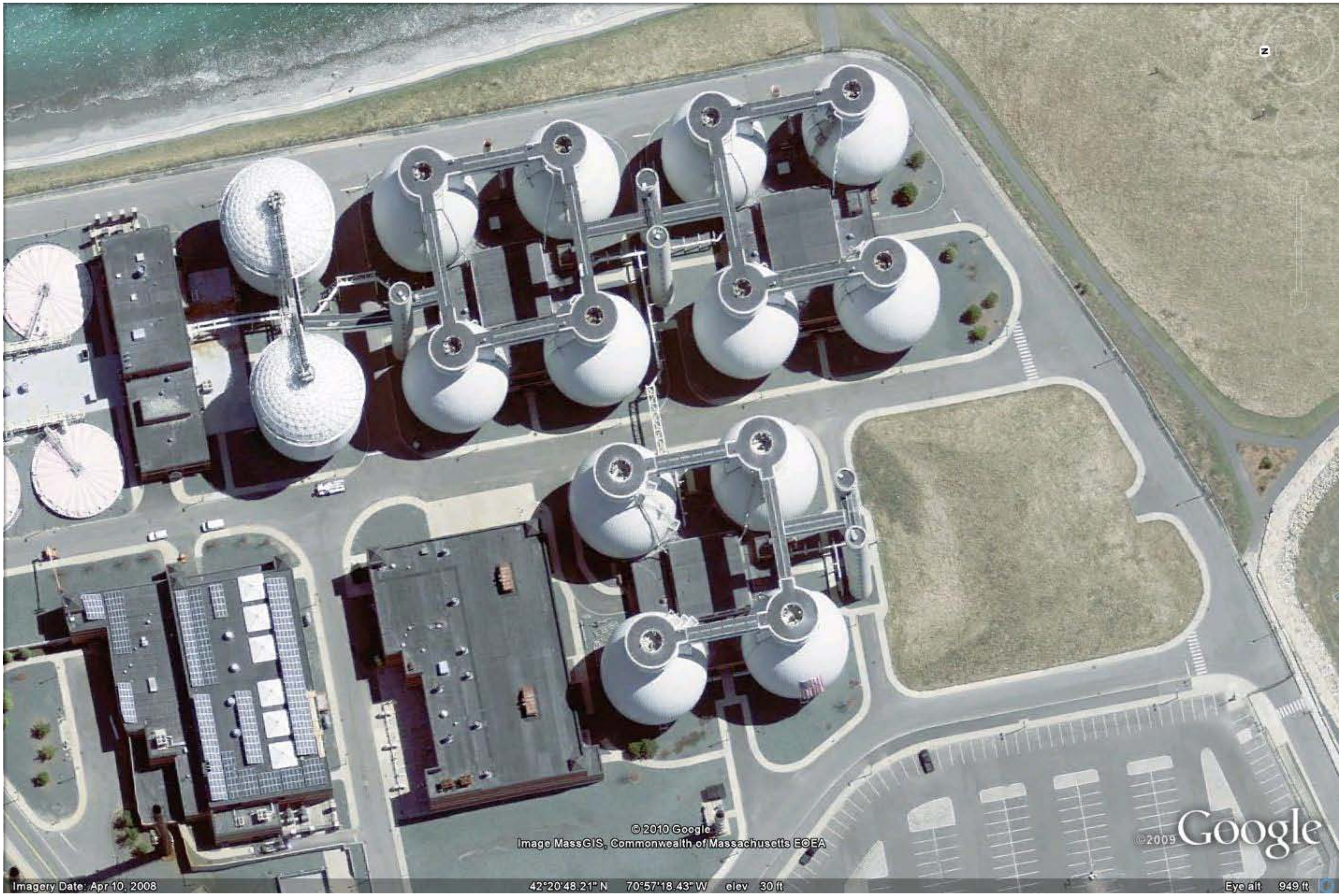

Figure 3-2: Aerial View of Deer Island Wastewater Treatment Plant Digesters (Source: Google Earth)

One danger with the anaerobic digesters is that workers at the site must contain the explosive biogas in a closed system, which can be highly dangerous if not properly maintained. All biogas generated by the digesters is carefully monitored, at digesters and along pipelines and storage tanks to ensure that they are not leaks. Also the pH level must be carefully monitored because variations could cause the digesters to foam over. Figure 3-3 shows the process that Deer Island uses to treat effluent.

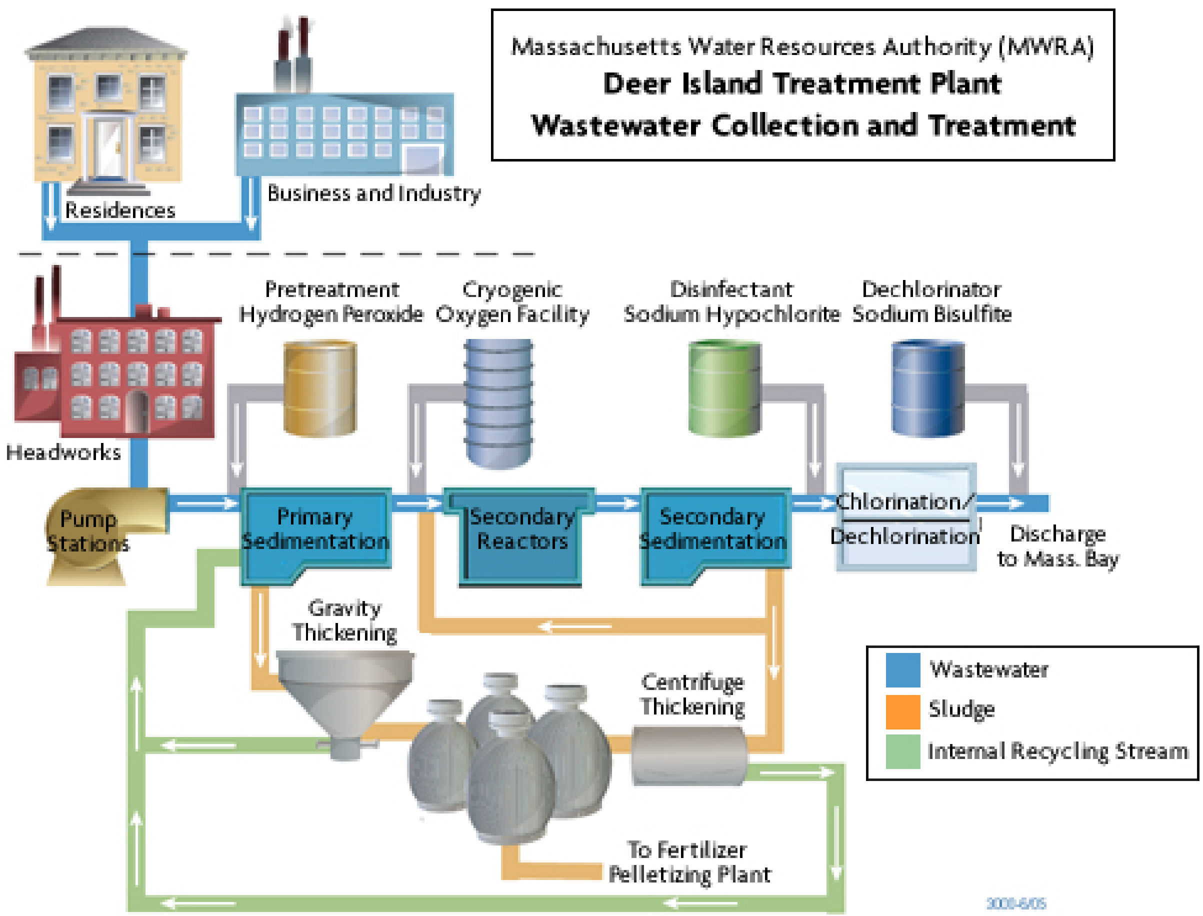

Figure 3-3: Deer Island Wastewater Treatment Plant Process (Source: www.mwra.state.ma.us)

Feedstock for the digesters must be between five and six percent solids. The sludge from primary sedimentation is approximately one half percent solids. The sludge then enters the settling tanks before the digesters, where it is thickened to the ideal five to six percent solids. After 15-18 days in the digester, the digested sludge contains approximately two to three percent solids. There is currently no nutrient limit for the water being discharged from Deer Island. However, the plant is responsible for the monitoring and reporting of nutrient levels in effluent[25]. Table 3-1: Deer Island Wastewater Treatment Plant Daily Residual Treatment Performance shows the daily residual treatment performance for Deer Island.

Table 3-1: Deer Island Wastewater Treatment Plant Daily Residual Treatment Performance

Deer Island Wastewater Treatment Plant Daily Residual Treatment Performance										
Digested Sludge to Holding/Storage					Solids Destruction					
	Total digested Sludge & Scum	pH	Volatile Solids	Solids Leaving Digestion	TS Destroyed	Detention Time in Digesters	Temperature	Alkalinity	Total Gas Generated	Gas Used at Thermal Plant
	MGD		%	Dry TS Tons	%	Days	°F	Mg $CaCO_3$/L	KSCF	KSCF
Average	0.991	7.5	67.2	116.6	50.6	20.6	97.4	5128	4586	4534
Maximum	1.372	7.6	68.0	154.2	55.6	26.6	98.9	5360	5652	5652
Minimum	0.790	7.4	66.0	94.5	43.5	15.3	94.1	4720	3719	3197
Std. Dev.	0.128	0.1	0.5	13.9	3.4	2.9	0.9	205	481	551

Source: "Residual Treatment Performance Overview," Deer Island Treatment Plant: Operational Performance Overview, November 2007.

The sludge from the digesters is then pumped seven miles through fourteen inch pipeline to a drying plant Quincy, MA. The pumped sludge is then centrifuged to twenty five percent solids and then put into kiln. The kiln effectively kills any remaining pathogens and excess water. The water from the drying plant is pumped back to Deer Island. The drying plant is owned by an independent contract that purchases the sludge and retains all the money from the fertilizer.

[25] Tyler, C. (2010, December). Deer Island's program manager of process operations. (J. L. Benton Cassie, Interviewer)

3.2 Point Loma Wastewater Treatment Plant

The Point Loma Wastewater Treatment Plant (PLWTP) is located on 40 acres in San Diego, California. It began operation in 1963 and serves fifteen communities in a 450-square-mile area. The plant treats approximately 175 million gallons of wastewater per day, but has a treatment capacity of 240 million gallons per day.[26] Similar to Deer Island, PLWTP contains eight anaerobic digesters which provide energy to the plant. However, unlike Deer Island, the PLWTP uses the biogas created to generate electricity and sells any excess electricity back to the grid.[27]

The biogas generated is primarily utilized to provide space cooling and heating for the plant. All excess biogas produced by the digesters is used to fuel two internal-combustion engines in the plant's Gas Utilization Facility that run generators with a total capacity of 4.5 MW of electricity. The electricity is generated using cogeneration, meaning that thermal energy generated from electricity generation is captured and used to heat digesters. The generated electricity is used to power everything in the plant from computers to lights, and then all excess electricity is sold back to the electrical grid. In 2000, the PLWTP saved the city of San Diego saved $3 million in operational energy costs and was able to sell $1.4 million of electricity back to the grid due to the amount of digesters of the plant and the amount of waste coming in.

The sludge produced from the primary clarifying (sedimentation) processes is pumped into one of the eight digesters on site. Figure 3-4 shows the waste treatment process that the PLWTP utilizes. The sludge remains in the digesters for approximately two weeks where it is

---

[26] "Point Loma Wastewater Treatment Plant," http://www.sandiego.gov/mwwd/facilities/ptloma.shtml, 04/01/10.
[27] U.S. Department of Energy. (2010). Wastewater Treatment Gas to Energy for Federal: U.S. Department of Energy. Retrieved April 20, 2010, from U.S. Department of Energy Website: http://www1.eere.energy.gov/femp/pdfs/bamf_wastewater.pdf

reduced in volume. After about two weeks, the digested sludge is pumped from the PLWTP through a seventeen mile pipeline to the Metro Biosolids Center for further processing. The Biosolids Center removes water through the use of centrifuges and then the solids are sold as fertilizer for agricultural, parks or soil builders.[28]

Table 3-2: Point Loma Wastewater Treatment Plant Daily Residual Treatment Performance

Point Loma Wastewater Treatment Plant Daily Residual Treatment Performance									
	Digested Sludge to Holding/Storage				Solids Destruction				
	Total Digested Sludge & Scum	pH	Volatile Solids	Solids Leaving Digestion	TS Destroyed	Detention Time in Digesters	Temperature	Alkalinity	Total Gas Generated
	MGD		%	Dry TS Tons	%	Days	°F	mg $CaCO_3$/L	KCSF
Average	1.041	7.15	57.91	88	61.27	-	-	2375.83	2201.87
Maximum	1.089	7.23	59.4	96	75	-	-	2850	2385.6
Minimum	0.9741	7.11	54.9	81	51.35	-	-	2150	2079.9
Std. Dev.	0.0351	0.04	1.41	5.51	7.5	-	-	251.99	93.51
Source: http://www.sandiego.gov/mwwd/pdf/pm/2008plantoperations.pdf									

[28]City of San Diego. (2010). 2009 Annual Monitor Reports: City of San Diego. Retrieved April 20, 2010, from City of San Diego web site: http://www.sandiego.gov/mwwd/pdf/pm/2009annualnc.pdf

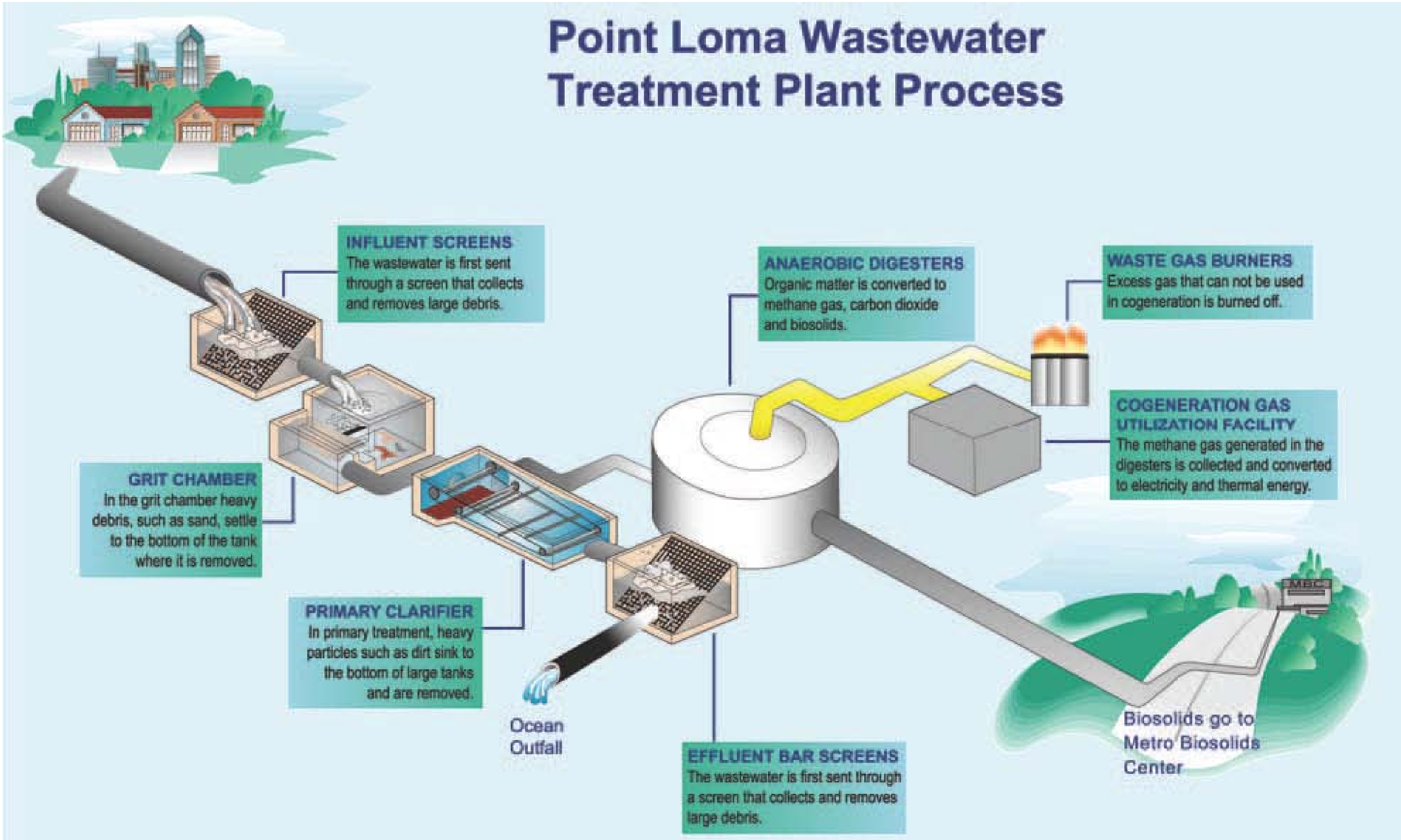

Figure 3-4: Point Loma Wastewater Treatment Plant Treatment Process (Source: http://www.sandiego.gov/mwwd/pdf/ptlwprocess.pdf)

Figure 3-5: Aerial View of Point Loma Wastewater Treatment Plant in San Diego, CA (Source: Google Earth)

3.3 Mason Dixon Farm

Mason Dixon Farm has the oldest operating farm digester in the United States. Located in Gettysburg, Pennsylvania, it is on a dairy farm that was built in 1978. Today it houses approximately 2,400 cows and three digesters. The cattle waste is gathered daily as feedstock for the digesters.

The cylindrical shape of the digesters reduces internal surface area by nearly forty percent as compared to a rectangular design. The reduced surface area reduces surface buildup and maintenance costs. It has a generating capacity of 600 kW.[29]

The digester is maintained at 105 F°, which is within the mesophilic range. The biogas that is generated by the digesters is used to run electricity generators. The biogas is also used to run a generator that powers the milk chillers. Heat from the generators is captured and utilized to aid in heating water that is used for the digesters. Any leftover heat is used to heat the multiple barns and farmhouses. The farm produces enough electricity to power itself and five neighboring farms. Any excess electricity, on average about seventeen percent, is sold to power grid at fair market value[1].

The digester produces not only biogas but also nutrient-rich solid residues. All waste solids are separated from spent slurry and composted to destroy weed seeds and remaining pathogens before used for cattle bedding or fertilizer. The solids are used primarily as cattle bedding and any excess is used as fertilizer. The waste solids provide adequate bedding and have greatly reduced mastitis infections in the cattle, a highly contagious bacterial infection common in cattle that temporarily ceases dairy production. All the waste liquids are dispersed by a central pivot irrigation system. The system includes four miles of perforated eight-inch PVC pipe that is buried under the ground[1].

---

[29] Environmental Protection Agency. (2010, April 20). AgSTAR Program: EPA. Retrieved April 20, 2010, from EPA Web site: http://www.epa.gov/agstar/profiles/masondixon.html

Bert Waybright, one of the designers of the digesters stated that the digesters cost five to six cents per kilowatt to operate[30]. This cost is add on to their residential retail price of electricity could be a significant increase in initial cost, prior to selling electricity back to the grid. Figure 3-6 displays the average price of electricity throughout the U.S. in the year 2007. A full list of the retail values for the year 2008 can be found in the Appendix A. With different ranges with cost around the U.S., it can be determined that electricity produced by anaerobic digestion is competitive in most regions.

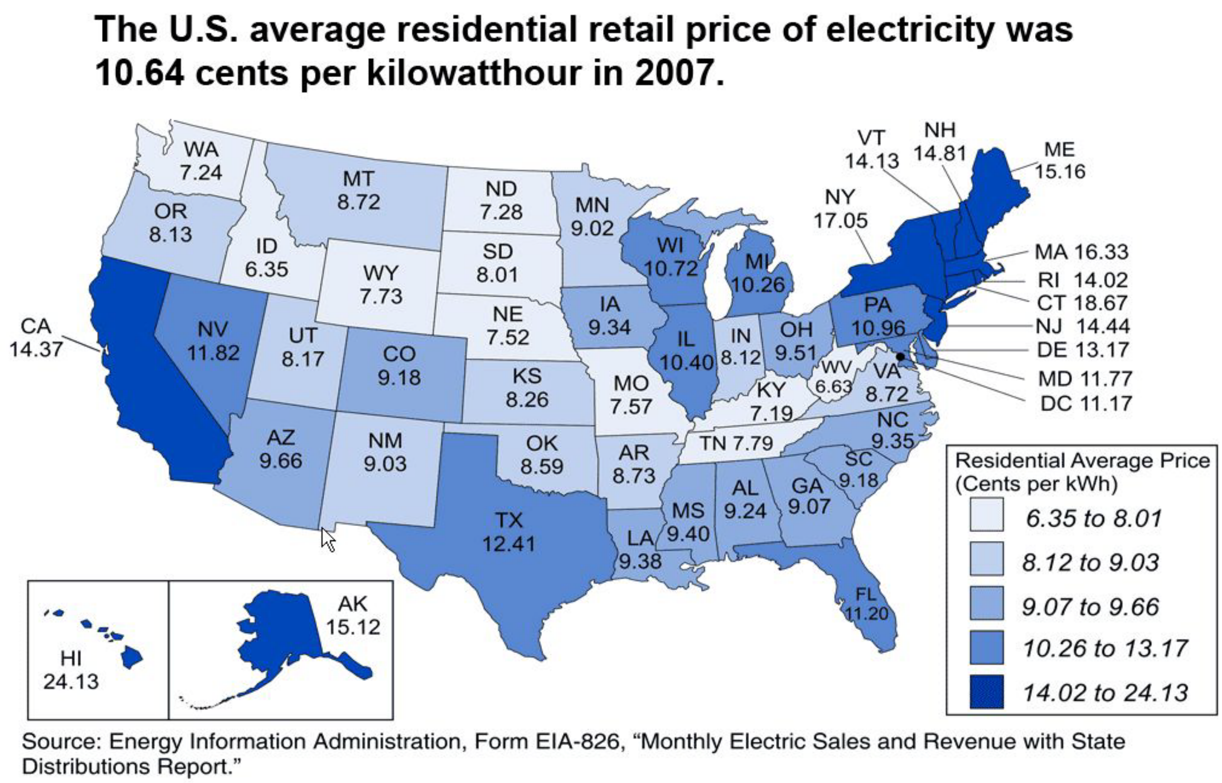

Figure 3-6: US Average Residential Electricity Retail Price in 2007

Digesters not only involve a large initial capital investment but also, as Bert Waybright explained, require competent management. "The digester is almost like a living animal and needs

[30] Waybright, Bert, interview by Benton Cassie. *Questions about Mason Dixon Anaerobic Digester* (February 9, 2010).

to be treated as such" [31]. Poor design, selection of materials or feeding can negatively affect the output of the digester. A reduced gas production would in turn generate lower digester outputs, and less energy flow.

[31] Waybright, Bert, interview by Benton Cassie. *Questions about Mason Dixon Anaerobic Digester* (February 9, 2010).

Figure 3-7: Aerial View of Mason Dixon Farms in Gettysburg, PA (Source: Google Earth)

3.4 The South Shropshire Biodigester

The South Shropshire Biodigester began operation in March 2006 in Ludlow, England in Shropshire County. The Biodigester was funded by the Department of Food and Rural Affairs (DEFRA) and Advantage West Midlands under DEFRA's New Technologies Demonstrator Program. The plant was built and operations contracted to Greenfinch Ltd. (Greenfinch).[32] Table 3-3 shows the technical data for the South Shropshire Digester Plant.

Table 3-3: South **Shropshire Digester Plant** *Technical Data*

South Shropshire Digester Plant Technical Data	
Digester Size (Two digesters)	900 m^2 (1100 yd^2)
Gas Storage Tank Internal Surface Area	150 m^2 (180 yd^2)
Time in Digester	25 – 30 days
Operating Temperature	42°C (108°F)
Source: http://www.biogasregions.org/doc/shining_examples/40.pdf, 04/01/10	

For the first nine months of operations, the plant digested both kitchen and garden waste. However, the garden waste contained such a large amount of non-organic materials including plastics and metals that it was not longer accepted. Operating costs were lower and biogas production was higher with when garden waste was no longer accepted as feedstock. The plant generates over 1,500 MWh a year of electricity, which is generated from the methane produced during the digestion process. The plant consumes approximately ten percent of the biogas generated to fuel the digesters and power their plant. The biogas that is not consumed is converted into electricity and sold back to grid, which reduced electricity costs in the surrounding communities.[33] Table 3-4: South Shropshire Digester Production Data shows the production data for the South Shropshire Biodigester.

[32] "South Shropshire Biodigester, Ludlow," *Biogas Regions Shining Example,* SevernWye Energy Agency, http://www.biogasregions.org/doc/shining_examples/40.pdf, 04/01/10.
[33] "South Shropshire Biodigester, Ludlow," *Biogas Regions Shining Example,* SevernWye Energy Agency, http://www.biogasregions.org/doc/shining_examples/40.pdf, 04/01/10.

Table 3-4: South Shropshire Digester Production Data

South Shropshire Digester Production Data	
Source-Separated Kitchen Waste	5,000 tonnes/year (5500 tons/year)
Fertilizer Output	150 hectares (370 acres)
Biogas	880 tonnes/year (970 tons/year)
Generated Thermal Energy	2,600 MWh/year
Generated Electrical Energy	1,500 MWh/year
Source: http://www.biogasregions.org/doc/shining_examples/40.pdf, 04/01/10	

The solid waste that is left over after the digestion is sold as bio-fertilizer. When compared to fossil fuel based fertilizer, the bio-fertilizer is less expensive and has higher oxygen and nitrogen content. The nitrogen that occurs as a result of anaerobic digestion is more degradable than added nitrogen or nitrates, and therefore more readily available for absorption.[34]

Table 3-5: Typical Nutrient Value of Bio-Fertilizer

Typical Nutrient Value of Bio-Fertilizer	
Nitrogen	4-5 kg/m^3 (7-8.5 lbs/yd^3)
Potassium	1-2 kg/m^3 (2-3.5 lbs/yd^3)
Potash (Potassium Carbonate)	1-2 kg/m^3 (2-3.5 lbs/yd^3)
Magnesium	2 kg/m^3 (3.5 lbs/yd^3)
Source: http://www.biogengreenfinch.co.uk/farming/biofert.asp, 04/01/10	

The South Shropshire Biodigester is the first digester in the world to offer a commercial food waste pick up program, “Food Recycling Round.” Greenfinch has partnered with F&R Cawleys Ltd. (Cawleys), a local recycling company. Cawleys offers food waste pick up six days a week to restaurants and food processing plants in the surrounding counties as part of their Zero Landfill program.[35]

3.5 Vermont Studies

Daniel L. Scruton, a Senior Agricultural Development Coordinator of the Vermont Agency of Agriculture, Food and Markets, produced a feasibility study in the State of Vermont with

[34] “Bio-fertiliser,” Biogen, http://www.biogengreenfinch.co.uk/farming/biofert.asp, 04/01/10.
[35] “Commercial Services,” Biogen, http://www.biogengreenfinch.co.uk/food_waste/commercial_services.asp, 04/01/10.

anaerobic digestion on farms. 16 farms responded to be studied. 2 of these farms were too small to contain digesters but the others got further information on anaerobic digestion. After further information was provided four farms dropped out because they concluded their farm was not practical for digestion[36].

Two farms were investigated to see the potential for making hot water from biogas. One farm had 35 cows and wanted a hot water heating system. The other farm had 75 cows and wanted hot water heating for the barn and house. An analysis was done and it was concluded that the manure was too dry. It was also not cost effective to change the manure handling; storage and spreading that would be needed for the digester.

An economic analysis was done to 7 farms to see whether it would be feasible to handle anaerobic digestion. Out of the seven farms, four of these farms had less than or equal to a seven year payback[1]. This is considered a reasonable cash flow. The other 3 farms had more than a 9-year payback.

After the initial feasibility study was complete, it was suggested that digesters would not be feasible for farms under 500 cows and if the electricity rate charge is under 10 cents per kWh. It was suggested that net metering could be an economic solution, which warrants further analysis.

[36]Environmental Protection Agency. "Vermont's Experience With the Adoption of Anaerobic Digestion On Farms ." *Environmental Protection Agency.* November 28, 2007. http://www.epa.gov/agstar/pdf/conf07/scruton.pdf (accessed April 20, 2010).

4.0 Possible Places

Anaerobic digestion has been successfully utilized in many locations around the world. This section of the paper will discuss several locations that currently are not utilizing anaerobic digestion. The locations discussed have been selected as operations that would benefit from anaerobic digester. This section will also discuss reasons why these places do not use anaerobic digestion.

4.1 Upper Blackstone Water Pollution Abatement District

The Upper Blackstone Water Pollution Abatement District (UBPAD) is located in Millbury, MA. The UBWPAD treats wastewater from the following communities in Massachusetts: Auburn, Cherry Valley Sewer District, Holden, Millbury, Rutland, West Boylston, Worcester, Oxford, Paxton, Shrewsbury and Sutton. The UBWPAD also treats septic and sludge from these and other surrounding communities. The plant was built in 1976 and designed to process 56 million gallons a day (mgd) of waste water. Over 90% of pollutants are removed from the wastewater through the process of activated sludge. Table 4-1 shows the average daily flow for the plant in 2007.[37]

Table 4-1: UBWPAD Influent/Effluent Flows

Influent/Effluent	Unit	Value
Average Daily Flow	mgd	32.2
Average Raw Biochemical Oxygen Demand (BOD)	mg/L	151
Average Final Carbonaceous BOD (CBOD)	mg/L	4.2
BOD Overall Removal	tons	7,195
BOD Removal	%	97
Average Raw Suspended Solids (SS)	mg/L	134
Average Final SS	mg/L	6.2
SS Overall Removal	tons	6,238

[37] http://www.ubwpad.org, 04/14/10.

SS Removal	%	95
Source: "FISCAL YEAR 2007 PERFORMANCE SUMMARY," www.ubwpad.org, 03/25/2010.		

Table 4-2 shows the energy and cost information for the UBWPAD in 2007. From this information it was determined that the UBWPAD spends nearly $45,000 dollars a day and $16 million dollars a year to process solid waste and operate solid waste incinerators. Due to the current configuration of the buildings around the incinerators, it is not currently possible to capture waste heat.

Table 4-2: Energy and Cost Information for UBWPAD, 2007 Fiscal Year

Energy and Cost Information	Units	Value
Electricity Used	KWH	16.2 million
Natural Gas Used	CF	69.1 million
Solids to Incinerator	tons/year	51,990
Solids to Incinerator	tons/hour	6.2
Solids Processing Cost	$/ton	300
Source: "FISCAL YEAR 2007 PERFORMANCE SUMMARY," www.ubwpad.org, 03/25/2010.		

Due to the high operating costs, the UBWPAD would benefit from having anaerobic digesters. However there are several factors that prohibit the UBWPAD from building anaerobic digesters at this time. Anaerobic digestions systems are a costly investment and due to recent renovations to the UBWPAD to improve water quality in the Blackstone River, building the digesters would not be economically feasible. Another factor prohibiting the UBWPAD from building digesters is limited space. The current location of the facility does not allow space to build digesters. If the plant were to build digesters, current facilities would either have to be relocated or nearby property would have to be acquired.

Figure 4-1: Aerial view of the Upper Blackstone Water Pollution Abatement District in Millbury, MA (Source: www.wbwpad.org)

4.2 Hereford, TX

Hereford, Texas is proclaimed as the "Beef Capital of the World." As of a 2008 census there were approximately 15,000 residents that live in the community and the town is just over 5.5 square miles in size. The town was named after the Hereford cattle that the early ranchers had herded. The town is also known as the "town without a toothache," because of a high fluorine content in their drinking water supply.

As a ranching community Hereford, Texas has at any given time more than a million head of cattle. As the population grew in Hereford the waste generated from the cattle became a problem and the town is now looking for solutions to the growing problem. Annually, tens of millions of tons of manure is generated from the massive herd. The large stores of manure pose environmental impacts and negative health impacts to the 15,000 residents of the community. The town tried to use the manure for electricity, fertilizer and pellets for wood burning stoves. These solutions to the overgrowing problem were working for the town until peanut farmers in New Mexico used local sources for their fertilizer and the pellets were found to create a large amount of ash which was not appealing from a commercial perspective. And the local power company stated that they did not need the excess electricity that would be generated from the burning of the manure. The decomposing manure can generate intense heat and pose a fire hazard. The dried out manure can create large amounts of dust as well as a noxious smell. The ranchers also need to control the flies that are attracted to the large piles because these flies can carry diseases that could pose a health problem to the residents.

In 2006 Hereford, Texas thought they found the answers that they were looking for. Panda Energy International Inc., a large Energy supplier of ethanol that is a leader in using renewable energy sources for fuel to produce the synthetic gas, planned to build a large facility that would produce 100 million gallons of ethanol a year. The town would provide 382 acres to Panda Energy for the site of the plant. Giving the manure to the plant would save each rancher hundreds of thousands of dollars a year in expenses that come from hauling the manure away. The plant would generate revenue for the town as well as full time jobs to run the plant and would stimulate the construction economy in the area. A picture of the site in Hereford, Texas is shown below in Figure 4-2. The energy producer would use the manure as a fuel source that would generate the heat needed to produce ethanol from corn. With over a million head of cattle and each one producing around 13 pounds of waste per day 6300 tons of manure is produced every day and annually this equates to 2.3 million tons of manure. According to Robert W. Carter, Chairman of the Board and Chief Executive Officer of Panda Energy International Inc., statement in a newspaper article about the Texas plant that the company would need 1500 tons of manure a day to run the facility.[38] Every year the energy company would need 550,000 tons of manure to operate for its projected goal.

[38] The Wall Street Journal. (2006, January 24). Cows in Hereford Are All Fixed Up About Ethanol Plant. Retrieved April 24, 2010.

Figure 4-2: Panda Energy International Facility in Hereford, TX
(Source: http://www.bbc.co.uk/worldservice/news/2009/06/090623_ethanol_wt_sl.shtml, 04/10/10)

Corn is fermented, processed, distilled, and then heated to produce the gasoline substitute known as ethanol. During the production process of the corn a residue known as "distiller's grain" is generated which can be shipped back to the farmers as feed for the cattle and additives for the soil which benefits all parties involved. The ranchers are providing the energy company with the manure free of charge which would save farmers hundreds of thousands of dollars every year in disposal cost. There are several ethanol producing plants in Texas but the one slated for construction in Hereford would be one of only a few that would use manure as a fuel source. The energy plant is projected to cost $120 million dollars to build and will be one of the biggest ethanol producing plants in the country. Due to contractor disputes and cost overruns Panda Energy International Inc. decided in 2008 that it would not be able to continue funding the project and the plant is not functional. "In 2004, approximately 3.57 billion gallons of ethanol were used as a gas additive in the United States, according to the Renewable Fuels Association (RFA). During the February State of the Union address, President George Bush urged Congress to pass an energy bill that would pump up the amount to 5 billion gallons by 2012. UC Berkeley geo-engineering professor Tad W. Patzek thinks that's a very bad idea."[39] Paztek believes that ethanol is not a viable solution because of the cost to produce the synthetic gas.

If the ethanol plant uses fossil fuels for an energy source, more non-renewable resources are used in the production of the renewable resource. "According to the U.S. Department of Agriculture, ethanol is blended in about 50 percent of the nation's gasoline supply. Ethanol yields 1.64 units of energy for each unit of energy it took to produce. That compares to just 0.8 units of energy from gasoline. In 2007, ethanol use in the U.S. reduced C02-equivalent greenhouse gas emissions by approximately 10.1 million tons, equal to removing more than 1.5 million cars from America's roadways. Also, ethanol reduces tailpipe carbon monoxide emissions by as much as 30%, toxics content by 13% (mass) and 21% (potency), and tailpipe fine particulate matter (PM) emissions by 50%. The American Lung Association of Metropolitan Chicago credits ethanol-blended reformulated gasoline with reducing smog-forming emissions by 25% since 1990". Table 4-3 illustrates the amount of ethanol produced and the amount of material used during a ten year period from 1997 to 2007. Producing a gas substitute is a responsible and a manageable solution to eliminate the dependence on fossil fuels but the production process has to be revised to ensure that the process does not use more energy to farm and harvest the materials needed.

---

[39] Science Daily. (2005, April 1). Study: Ethanol Production Consumes Six Units Of Energy To Produce Just One. Retrieved Apri l 24,2010, from http://www.sciencedaily.com/releases/2005/03/050329132436.htm

Table 4-3: Ethanol Use

Year	Ethanol Produced	Grain Used
1997	1.3 billion gallons	481 million bushels
1998	1.4 billion gallons	526 million bushels
1999	1.47 billion gallons	566 million bushels
2000	1.63 billion gallons	628 million bushels
2001	1.77 billion gallons	706 million bushels
2002	2.13 billion gallons	996 million bushels
2003	2.8 billion gallons	1.1 billion bushels
2004	3.4 billion gallons	1.3 billion bushels
2005	3.9 billion gallons	1.4 billion bushels
2006	4.9 billion gallons	1.8 billion bushels
2007	6.5 billion gallons	2.3 billion bushels

Source: "Kansas Ethanol, Clean Fuel from Kansas Farm, U.S. Ethanol Facts," http://www.ksgrains.com/ethanol/useth.html, 04/24/2010.

Using Anaerobic Digestion to process animal waste to create fuel for heating purposes, cooking, cooling and generating electricity is not beneficial on a commercial scale. The cost to handle and transport the gas for use on a large scale would not be cost effective. The methane that is produced during the process has more of an impact on the atmosphere that carbon monoxide. The process could be beneficial to a small number of farms across the country where the fuel produced can be used to run the farm. Capturing and using the gas reduces the amount of toxins that are released into the atmosphere. Recycling the waste and capturing the fuel and using it to operate the farm can eliminate the need for conventional fuels. The energy savings can justify the cost of the equipment needed for the process. Careful analysis needs to be done on an individual basis to determine if the upfront cost is worth the risk.

Table 4-4: Energy Content of Common Fuels

Table 4-4: Energy Content of Common Fuels			
Propane	92,000 Btu/gal	**Diesel fuel**	138,000 Btu/gal
Natural Gas	1,000 Btu/ft^3	**No. 2 fuel oil**	138,000 Btu/gal
Electricity	3,414 Btu/kWh	**Coal**	25,000,000 Btu/ton
Source: Barker, James C. 2001. Methane Fuel Gas from Livestock Wastes: A Summary. North Carolina State University Cooperative Extension Service, Publication #EBAE 071-80. 4/24/2010. http://attra.ncat.org/attra-pub/anaerobic.html#table3			

Table 4-4 above compares the energy content of biogas to other energy sources. Using the energy content in for the biogas produced from anaerobic digestion per animal can be determined. The energy amount is illustrated in Table below. In a place a like Hereford, Texas that has 1 million cattle at any one time the gross energy content produced is 16,600,000,000 Btu per head per day and a net energy that uses 35% to operate the digester of 10,700,000,000 Btu per head per day. In a article "Lifestyle Project" by Karin B. Kirk and John J. Thomas which has been published to the Journal of Geoscience Education the average sized home of four has a total energy content usage of 263,500,000 Btu per year. [40]

[40]Journal of Geoscience Education which is published by the National Association of Geoscience Teachers. (2003, November). "Lifestyle Project" by Karin B. Kirk and John J. Thomas. Retrieved Apri l 24,2010, from http://www.skidmore.edu/~jthomas/lifestyleproject/index.html

Table 4-5: Energy Content of Bio-Gas from Various Animals

Table 2. Energy Content of Bio-gas from Various Animals				
	Swine (per head)	**Dairy (per head)**	**Beef (per head)**	**Poultry (layers) (per bird)**
Animal weight (lbs.)	135	1,400	800	4
Expected Energy Content				
Gross energy content (Btu/head/day)	2,300	27,800	16,600	180
Net energy content (Btu/ head/day) (uses 35% of gross to operate digester)	1,500	18,000	10,700	110
Source: Barker, James C. 2001. Methane Fuel Gas from Livestock Wastes: A Summary. North Carolina State University Cooperative Extension Service, Publication #EBAE 071-80. 4/24/2010. http://attra.ncat.org/attra-pub/anaerobic.html#table3				

Table 4-6: Bio-gas Net Returns from Various Animals

Table 3. Bio-gas Gas Net Returns from Various Animals				
	Swine	**Dairy**	**Beef**	**Poultry (layers)**
Electricity Equivalent	**----- per head per year -----**			
kWh (20% combined generating efficiency)	32	385	230	2.5
Value (@ $.085/kWh)	$2.76	$32.73	$19.55	$0.21
Natural Gas Equivalent				
Mcf	0.55	6.60	3.90	0.04
Value (@ $11.04/Mcf)	$6.07	$72.89	$43.07	$0.44
Propane (LP Gas) Equivalent				
Gallons	6	72	43	0.45
Value (@ $2.00/gallon)	$12.00	$144.00	$86.00	$0.90
No. 2 Fuel Oil Equivalent				
Gallons	4	48	28	0.3
Value (@ $2.00/gallon)	$8.00	$96.00	$56.00	$0.60
Source: Barker, James C. 2001. Methane Fuel Gas from Livestock Wastes: A Summary. North Carolina State University Cooperative Extension Service, Publication #EBAE 071-80. Updated to 2006 prices by NCAT. 4/24/2010. http://attra.ncat.org/attra-pub/anaerobic.html#table3				

Using the above table North Carolina State University Cooperative Extension Service calculated net returns per animal for biogas energy and is displayed above in table 4-6.

5.0 Discussion

This section will compile all the information that has been covered in this paper so far and discuss the implications. This section will also discuss other applications for anaerobic digestion and other water to energy methods that exist.

5.1 Pros and Cons of Anaerobic Digestion

Anaerobic digestion has an array of benefits that can help to create a sustainable society. A wastewater treatment plant using anaerobic digestion generates less biological sludge compared to a conventional plant; which in consequence, reduced the amount of sludge sent to landfills and incinerators. Due to the closed environment required for anaerobic digestion, nearly all pathogens are removed from the sludge generated. The digestion is so effective at removing pathogens that the solid waste product can be used as fertilizer.

Capturing biogas is both environmentally and economically beneficial. Methane is a potent greenhouse gas and thus capturing it can reduce greenhouse gas emissions. The biogas can also help to reduce dependence on fossil fuels. Electricity and methane created from digestion can be sold to create revenue for the plant or the owning organization and provide inexpensive energy for the community.

Anaerobic digestion systems require a large capital investment. Even with incentives from the EPA and other government organizations, many digesters will not be built due to lack of initial capital investment.

Another complication with anaerobic digestion is the generation of potentially explosive biogas. Gas outputs must be carefully monitored to ensure that the digesters are functioning properly and that no gas is escaping. Anaerobic digestion is a safe process if all the necessary safety precautions are taken. Anaerobic digesters require an organized and competent operator. Digesters must be fed and monitored continuously. If the operator does not follow the specific operations, then gas output could be affected or damage could be caused to the equipment, which is the case for incompetent workers.

Another issue is obeying to the land use laws and utility companies. According to Bert Waybright, you must contact your local power company and fight through everything they require to connect at their speed[41]. People who want to build digesters will have to go through a complicated process to comply with the utility companies.

5.2 Other Applications of Anaerobic Digestion

This project has studied the use of anaerobic digestion using municipal solid waste and manure from animals. Anaerobic digestion can break down organic material and create biogas which is a synthetic fuel. Organic material that can undergo the digestion process can include food-waste and plant material.

5.2.1 Food Waste

Every year millions of tons of food waste are thrown away and end up in landfills. Restaurants generate large amounts of waste everyday along with a significant amount generated from the average sized family. Because the material is no toxic very little treatment will need to done on the by-product before the gases are released into the atmosphere. For a small scale operation using food-waste to create a bio-fuel can be beneficial. One who would choose to use the material can cooperate with area restaurants and local citizens to set up a waste collection

[41] Waybright, Bert, interview by Benton Cassie. *Questions about Mason Dixon Anaerobic Digester* (February 9, 2010).

system that could allow for free hauling of food waste for the owners and families. This could also benefit the digester owner by allowing for energy cost savings of fossil fuels. Some preliminary processing of the waste would need to be done to breakdown the material for proper consistency of the process.

5.2.2 Wood Waste

Organic compounds are decomposed by bacteria in the anaerobic digestion process. Wood material and plant material are organic materials that can be used as a bio-fuel for the production of energy. The process could be beneficial to operations in logging communities and crop farming communities where the waste can be transformed. Like food waste the production generates very little toxic by-products due to their non-toxic nature. And there would need to be very little preliminary treatment to undergo digestion.

5.3 Other Waste to Energy Methods

This project has studied one waste to energy methods so far. This section will give a brief description of other methods that can produce energy from waste. The goal of this section is not investigate the efficacy and efficiency of these processes, but to acknowledge that anaerobic digestion is not the only waste to energy method. Because pyrolysis and gasification occur with little oxygen and are under pressure the two processes can be seen as the same and some of the characteristics of the process are the same.

5.3.1 Pyrolysis

Pyrolysis is a process in which organic material is burned in a low oxygen, high heat and high pressure environment. The organic material with chemically decompose releasing methane, carbon monoxide and hydrogen. The process can take hazardous organic materials such as human and animal waste that went through anaerobic digestion and generate usable gases. Below a pyrolysis schematic is illustrated in Figure 5-1. The process requires that any inorganic materials be removed from the processed material. Because there is no direct contact with the flame much of the environmental and health impacts and environmental impacts from the residuals are almost eliminated. The pyrolysis production can directly been in connection with gas powered turbines and engines acting as the fuel for power generation. The heat generated from the drying process can be used to heat water and create steam that can also be used in the production of energy. And if the gas is stored in fuel cells the electricity can be more efficient. Nitrogen and carbon based gases that are harmful to the environment can be greatly reduced.

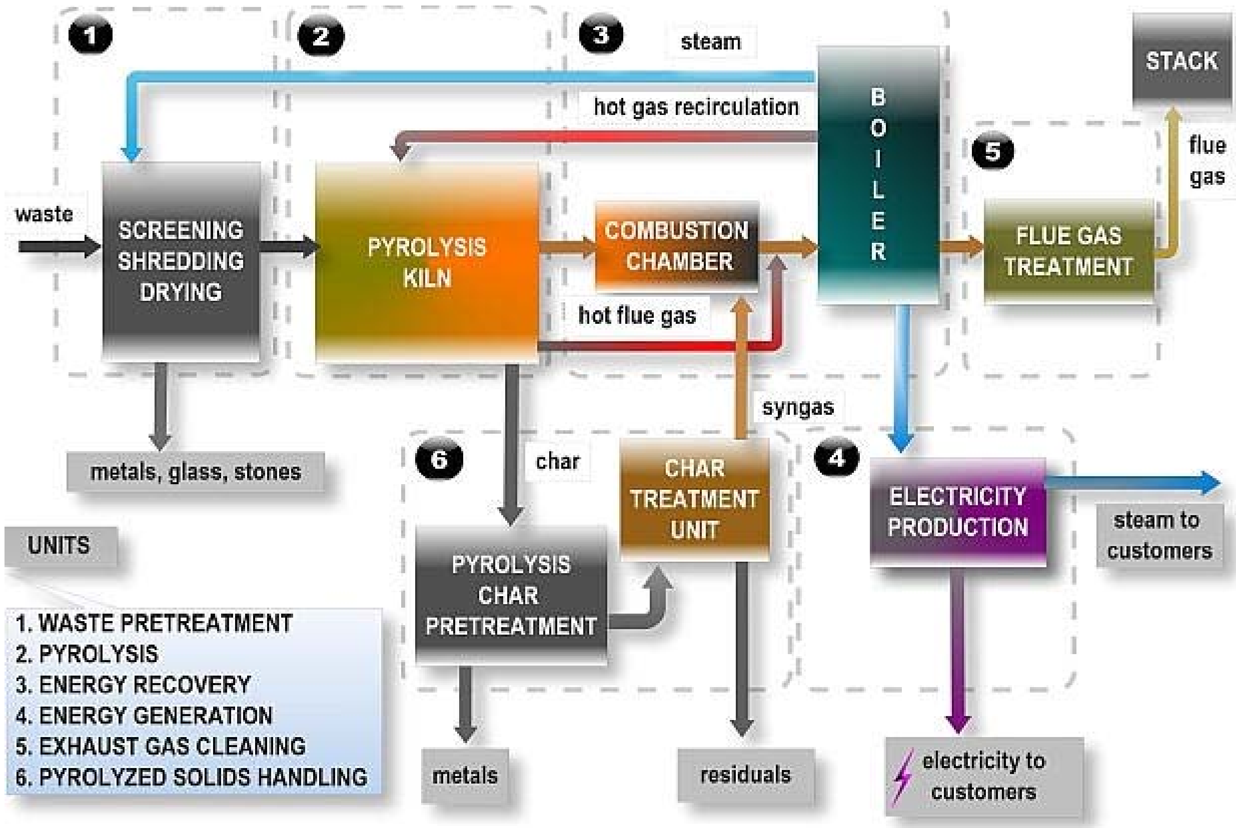

Figure 5-1: Pyrolysis of Solid Municipal Waste (Source: www.splainex.com/waste_recycling, 03/21/10)

5.3.2 Gasification

Gasification is a process that that converts organic material into synthetic gas. This gas can then be used to generate electricity. Further refining of this synthetic gas can produce chemicals, fertilizers, liquid fuels, a synthetic natural gas and hydrogen. The gasification process has been in the electricity industry for over 35 years. Gasification of municipal waste, house hold garbage and commercial waste has been used in the United States since the 1970's. Low value feed-stocks, which are crops or products like used vegetable oil, can be turned into synthetic fuels. The low value feed-stocks can be converted into high-value products that are reliable and clean energy sources. The production of synthetic materials reduces the dependence on non-renewable resources. A schematic of a gasification process is illustrated below in Figure 5-2.

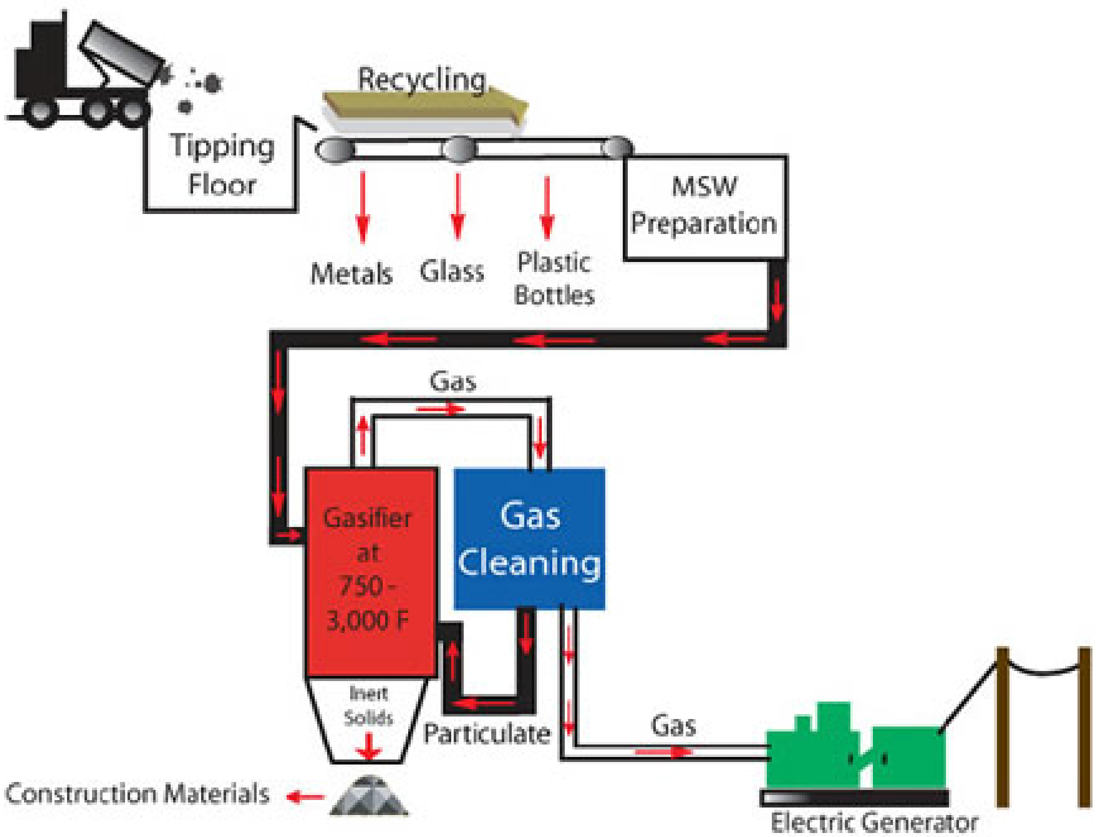

Figure 5-2: Schematic of MSW Gasification and Power Generation Plant
(Source: www.altenergymag.com/emagazine.php?issue_number=09.06.01=zafar)

Solid waste gasification is not possible on a large scale basis because the technology to remove the toxic material out of the waste does not exist. With the presence of air in the incineration process solid waste will burn. The burning of the waste creates toxic chemicals that are expensive to treat before being released into the atmosphere. “In 1960 mass burn incinerators burned 30% of the municipal waste in the United States. By 1988 this total had dropped to 13%

because of air pollution problems".[42] Although gasification shares many of the same environmental impacts as incineration, the process removes recyclable materials for further processing and the toxins in the by-product can be processed and almost eliminated.

[42] Waste Gasification: Impacts on the Environment and Public Health, 4/24/10, http://www.bredl.org/pdf/wastegasification.pdf

6.0 Conclusions

Anaerobic digestion provides an economical sustainable energy source. It will not be practical if the source of the manure isn't big enough. The installation of an anaerobic digestion system involves a large capital investment, which is the biggest issue, but will save money on energy costs in the future. For example, Upper Blackstone won't build anaerobic digesters because they don't have enough space. They would have to tear down some building, which is an additional expense and the capital cost for everything would be too expensive. These are the key requirements in order to gain a profit.

Cow manure, food waste and wastewater effluent provide a reliable and inexpensive feed stock for anaerobic digestion. In the past, problems have arisen on handling and disposal of these waste products, which can be a potential public health hazard. The use of anaerobic digestion not only reduces landfill waste and provides a safe means of storage and handling, but the process also removes many pathogens, allowing these materials to be recycled as fertilizers or for other purposes.

Even though all waste is not created equal (refer to Figure 2-2 on page 6), materials such as cow and pig manure, which yield relatively small amounts of biogas compared to fats or greases, are still economical feedstock. One benefit to cow and pig manure digestion is the mass quantities in which they are produced. According to the USDA in 2002, there were nearly 100 million cows in the United States and a single cow can produce over one hundred pounds of manure a day; that is potentially 500,000 tons of manure a day. Anaerobic digestion also provides a means to dispose of waste, while creating capital (energy, fertilizer, etc.).

Anaerobic digestion systems can be cost prohibitive. The systems are also living systems that require proper maintenance and operations. Even with the given negations, anaerobic digestion is economical to society with maintenance it met.

Obeying the land use laws and utility companies can be a challenge, especially for people in the U.S. The U.S. is more of a "fast-paced" nation, wanting everything done as fast as possible. Going through the complications of complying with the state and utility companies can be time consuming and tedious.

Anaerobic digestion is sustainable, economical and practical if the design, and maintenance is optimal. Anaerobic digestion offers solutions to the U.S.'s and the World's environmental problems, energy problems and excess waste problems. With growing awareness of the environment, energy security, and technology, it would be advantageous for the United States government to offer grants and incentives to companies and organizations that would construct digesters.

Appendices

A.1 Average Residential Electricity Costs in the United States (2008)

Average Residential Electricity Costs in the United State (2008)				
Census Division State	**Number of Consumers**	**Avg. Monthly Consumption (kWh)**	**Avg. Retail Price (Cents/kWh)**	**Avg. Monthly Bill (Dollar and cents)**
New England	6,125,483	630	17.70	$111.48
Connecticut	1,452,080	731	19.55	$142.79
Maine	695,368	521	16.20	$84.47
Massachusetts	2,647,529	618	17.68	$109.30
New Hampshire	594,180	616	15.68	$96.66
Rhode Island	430,152	589	17.45	$102.85
Vermont	306,174	581	14.48	$84.06
New Jersey	3,409,806	711	15.66	$111.44
New York	6,897,087	592	18.30	$108.41
Pennsylvania	5,231,696	861	11.35	$97.75
Illinois	5,098,579	765	11.07	$84.62
Indiana	2,733,128	1,036	8.87	$91.94
Michigan	4,290,313	666	10.75	$71.58
Ohio	4,891,891	910	10.06	$91.50
Wisconsin	2,579,776	710	11.51	$81.71
Iowa	1,325,990	884	9.49	$83.94
Kansas	1,203,021	928	8.88	$82.41
Minnesota	2,279,850	817	9.74	$79.55
Missouri	2,686,746	1,098	8.00	$87.83
Nebraska	794,548	1,023	7.87	$80.46
North Dakota	318,760	1,113	7.51	$83.68
South Dakota	363,517	1,010	8.27	$83.56
Delaware	391,810	942	13.93	$131.23
DC	215,355	734	12.79	$93.83
Florida	8,478,405	1,120	11.65	$130.52
Georgia	4,034,752	1,148	9.93	$113.96
Maryland	2,178,595	1,038	13.84	$143.69
North Carolina	4,146,430	1,120	9.52	$106.61
South Carolina	2,068,598	1,198	9.89	$118.40
Virginia	3,169,282	1,173	9.62	$112.75
West Virginia	863,650	1,135	7.06	$80.15
Alabama	2,110,859	1,271	10.40	$132.16
Kentucky	1,928,082	1,191	7.94	$94.64
Mississippi	1,238,408	1,231	10.39	$127.95
Tennessee	2,685,425	1,302	8.91	$116.02
Arkansas	1,308,810	1,107	9.27	$102.69
Louisiana	1,919,826	1,252	10.28	$128.77
Oklahoma	1,633,265	1,115	9.09	$101.39

Texas	9,418,077	1,130	13.04	$147.32
Arizona	2,528,405	1,095	10.27	$112.47
Colorado	2,173,458	679	10.13	$68.80
Idaho	654,545	1,087	6.99	$76.01
Montana	461,600	843	9.13	$76.95
Nevada	1,054,691	953	11.93	$113.68
New Mexico	841,329	632	10.01	$63.24
Utah	924,826	792	8.26	$65.36
Wyoming	252,986	896	8.21	$73.56
California	12,941,717	587	13.81	$81.10
Oregon	1,616,598	1,026	8.49	$87.16
Washington	2,789,188	1,086	7.54	$81.89
Alaska	678,306	641	25.98	$166.46
Hawaii	268,638	661	16.55	$109.31
U.S. Total	124,937,469	920	11.26	$103.67
Source: http://www.eia.doe.gov/cneaf/electricity/esr/table5.html, 04/01/10.				

A.2 Operational Agricultural Anaerobic Digesters in the United States

Source: "Anaerobic digesters sorted by operational status and state," http://www.epa.gov/agstar/operational.html, 04/01/10.

Farm/Project Name	Project Type	City	State	Year Operational	Farm Type	Population Feeding Digester	Biogas Generation Estimate (ft3/day)	Biogas End Use(s)	Installed Capacity (kW)	Methane Emission Reductions (metric tons CH4/yr)	Methane Emission Reductions (metric tons CO2E/yr)
Blakes Landing Dairy	Farm Scale	Marshall	CA	2004	Dairy	362	14,832	Electricity	75	78	1,639
Bob Giacomini Dairy	Farm Scale	Point Reyes	CA	2009	Dairy	300	20,000	Cogeneration	80	76	1,593
Bullfrog Dairy	Farm Scale	Imperial	CA	2008	Dairy	3,300		Electricity	300	834	17,519
Cal Poly Dairy	Farm Scale	San Luis Obispo	CA	1998	Dairy	175		Electricity	30	44	929
CAL-Denier Dairy	Farm Scale	Galt	CA	2008	Dairy	900	33,627	Electricity	65	190	3,983
Castelanelli Bros. Dairy	Farm Scale	Lodi	CA	2004	Dairy	3,214	89,148	Electricity	180	599	12,588
CottonWood Dairy	Farm Scale	Atwater	CA	2004	Dairy	5,000	300,000	Cogen.; Boiler/Furnace	700	1,264	26,544
Fiscalini Farms	Farm Scale	Modesto	CA	2008	Dairy	2,513	162,400	Cogeneration	720	254	5,343
Hilarides Dairy	Farm Scale	Lindsay	CA	2004	Dairy	1,500	756,000	Electricity; Vehicle Fuel	750	91	1,918
Langerwerf Dairy	Farm Scale	Durham	CA	1982	Heifer	750	30,000	Cogeneration	60	38	791
Lourenco Dairy	Farm Scale	Tulare	CA	2006	Dairy	2,640	53,250	Flared Full Time		351	7,364
Meadowbrook Dairy	Farm Scale	El Mirage	CA	2004	Dairy	2,000	87,000	Electricity	160	13	279
Strauss Family Dairy	Farm Scale	Marshall	CA	2004	Dairy	200	2,000	Cogeneration	25	25	525
Tollenaar Holsteins Dairy	Farm Scale	Elk Grove	CA	2008	Dairy	1,895	113,582	Cogen.; Boiler/Furnace	250	345	7,248
Vintage Dairy	Farm Scale	Riverdale	CA	2008	Dairy	5,000		Pipeline Gas		1,264	26,544
Christensen Hog Farm	Farm Scale	Lamar	CO	2008	Swine	5,500		Flared Full Time		182	3,826
Cushman Dairy	Farm Scale	North Franklin	CT	1997	Dairy	600	42,500	Electricity	80	43	909
Freund Farm	Farm Scale	East Cannan	CT	1997	Dairy	250	14,000	Boiler/Furnace Fuel		52	1,100
Suwannee Farms	Farm Scale	O'Brien	FL	2009	Beef						
University of Florida Dairy Research		Hague	FL	2000	Dairy	500		Boiler/Furnace Fuel	30	119	2,507
Wright Whitty Davis Farms, Inc.	Farm Scale	Baxley	GA	2006	Dairy	1,135	58,000	Elec.; Boiler/Furnace Fuel	200	259	5,433
Amana Farms, Inc.	Farm Scale	Amana	IA	2008	Beef	4,000	1.8 M	Cogeneration	2,600	128	2,679
Boland Farm	Farm Scale	Williamsburg	IA	1998	Swine	3,000			0	104	2,181
Top Deck Holsteins	Farm Scale	Westgate	IA	2002	Dairy	700		Cogeneration	130	53	1,112
Bettencourt's Dry Creek Dairy	Farm Scale	Hansen	ID	2008	Dairy	6,000		Cogeneration	2,250	538	11,295
Dean Foods Big Sky Dairy	Farm Scale	Gooding	ID	2008	Dairy	4,700		Cogeneration	1,500	421	8,848
Apex Pork	Farm Scale	Rio	IL	1998	Swine	8,900		Cogeneration	40	119	2,497
Hillcrest Dairy	Farm Scale	Elmwood	IL	2002	Dairy	1,400		Cogeneration	320	306	6,436
Hunter Haven Farms, Inc.	Farm Scale	Pearl City	IL	2005	Dairy	650		Cogeneration	270	54	1,124
Scheidairy Farms	Farm Scale	Freeport	IL	2005	Dairy	650		Electricity	120	54	1,124
Bos Dairy	Farm Scale	Fair Oaks	IN	2005	Dairy	3,600		Electricity	1,050	287	6,018
Fair Oaks Dairy - Digester 1	Farm Scale	Fair Oaks	IN	2004	Dairy	3,500		Electricity	800	279	5,851
Fair Oaks Dairy - Digester 2	Farm Scale	Fair Oaks	IN	2008	Dairy	10,500		Flared Full Time	800	279	5,851
Herrema Dairy	Farm Scale	Fair Oaks	IN	2002	Dairy	3,750		Cogeneration	800	299	6,269
Hidden View	Farm Scale	Fair Oaks	IN	2007	Dairy	3,500		Flared Full Time	950	279	5,851
Windy Ridge Dairy	Farm Scale	Fair Oaks	IN	2006	Dairy	7,000		Flared Full Time		557	11,702
USDA-Beltsville ARS facility		Beltsville	MD	1994	Dairy	150	13,000	Electricity	15	13	263
den Dulk Dairy	Farm Scale	Ravenna	MI	2007	Dairy	1,000		Cogeneration		67	1,415
Geerlings Hillside Farms Overisel	Central/Region	Hamilton	MI	2008	Swine	16,000	241,096	Elec.; Boiler/Furnace Fuel	130	175	3,671
Green Meadows Dairy	Farm Scale	Elsie	MI	2007	Dairy	3,200		Electricity	800	216	4,527
Scenic View Dairy - Fennville	Farm Scale	Fennville	MI	2006	Dairy	3,650	324,000	Cogen.; Pipeline Gas	800	578	12,140
Scenic View Dairy - Freeport	Farm Scale	Freeport	MI	2008	Dairy	3,050		Elec.; Boiler/Furnace Fuel	1,600	559	11,748
Willow Point Dairy	Farm Scale	Orleans	MI	2007	Dairy	2,750		Flared Full Time		185	3,890
Haubenschild Farms	Farm Scale	Princeton	MN	1999	Dairy	900	70,000	Cogeneration; Electricity	155	63	1,319
Jer-Lindy Farms	Farm Scale	Brooten	MN	2008	Dairy	290		Cogeneration	37	15	317
Northern Plains Dairy	Farm Scale	St. Peter	MN	2003	Dairy	3,000		Cogeneration	260	209	4,398
Riverview Dairy	Farm Scale	Morris	MN	2009	Dairy	6,500				454	9,529
West River Dairy	Farm Scale	Morris	MN	2009	Dairy	5,000				349	7,330
Premium Standard - Valley View Farm	Farm Scale	Green City	MO	2006	Swine	107,000		Boiler/Furnace Fuel		3,922	82,358
Brinson Farms	Farm Scale	Prentiss	MS	2005	Broiler	270,000		Cogen.; Boiler/Furnace	75	6	133
Piney Woods School	Farm Scale	Piney Woods	MS	1998	Swine	145		Electricity	5	5	115

Huls Dairy	Farm Scale	Corvallis	MT	2008	Dairy	350	36,000	Elec.; Boiler/Furnace Fuel	50	72	1,522
Barham Farms	Farm Scale	Zebulon	NC	1997	Swine	4,000	28,000	Flared Full Time		74	1,557
Black Farms	Farm Scale	Lillington	NC	2008	Swine	6,000		Flared Full Time		222	4,656
Butler Farms	Farm Scale	Lillington	NC	2008	Swine	8,280		Flared Full Time		306	6,425
Murphy Brown LLC - Kenansville Farm	Farm Scale	Faison	NC	2008	Swine	10,500		Boiler/Furnace Fuel		78	1,630
Vestal Farm	Farm Scale	Kenansville	NC	2003	Swine	9,792	41,879	Cogen.; Boiler/Furnace	30	362	7,598
Danny Kluthe Farm	Farm Scale	Dodge	NE	2005	Swine	8,000	35,000	Cogeneration	80	106	2,228
NMSU / Gonzalez Dairy	Farm Scale	La Mesa	NM	2008	Dairy						
AA Dairy	Farm Scale	Candor	NY	1998	Dairy	600	42,868	Cogeneration	130	39	826
Aurora Ridge Dairy	Farm Scale	Aurora	NY	2009	Dairy	1,800		Electricity	500	118	2,477
Boxler Dairy	Farm Scale	Varysburg	NY	2009	Dairy						
Cayuga Regional Digester Bioenergy	Central/Region	Auburn	NY	2007	Dairy	1,255	215,616	Cogeneration	625	82	1,727
Coyne Farm	Farm Scale	Avon	NY	2008	Dairy	1,400		Flared Full Time		282	5,913
Crescent Duck Farm	Farm Scale	Aquebogue	NY	2006	Duck	800,000		Electricity		633	13,287
EL-VI Farms	Farm Scale	Newark	NY	2004	Dairy	1,500		Boiler/Furnace Fuel		71	1,483
Emerling Farms	Farm Scale	Perry	NY	2006	Dairy	1,200		Cogeneration	230	75	1,568
Fessenden Family Dairy	Farm Scale	King Ferry	NY	2008	Dairy	800		Electricity	500	161	3,379
Lamb Farms	Farm Scale	Oakfield	NY	2010	Dairy	2,000		Electricity	450	402	8,447
New Hope View Farm	Farm Scale	Homer	NY	2001	Dairy	850		Cogen.; Boiler/Furnace	70	171	3,590
Noblehurst Farms	Farm Scale	York	NY	2003	Dairy	1,300	72,000	Cogeneration	130	77	1,623
Patterson Farms	Farm Scale	Auburn	NY	2005	Dairy	1,760	173,300	Cogeneration	250	88	1,849
Ridgecrest Dairy	Farm Scale	Genoa	NY	2008	Dairy	1,650		Flared Full Time		332	6,969
Ridgeline Farm	Farm Scale	Clymer	NY	2001	Dairy	525	325,000	Cogeneration	130	34	722
Sheland Farms	Farm Scale	Adams	NY	2007	Dairy	555	36,000	Cogeneration	125	36	764
Sunny Knoll Farm	Farm Scale	Perry	NY	2006	Dairy	1,800	111,400	Cogeneration	230	102	2,145
Sunnyside Farms	Farm Scale	Scipio Center	NY	2009	Dairy	6,100		Cogeneration	1,600	936	19,651
SUNY at Morrisville		Morrisville	NY	2007	Dairy	505	23,320	Cogeneration	50	29	612
Swiss Valley Farms	Farm Scale	Warsaw	NY	2009	Dairy	850	132,000	Electricity	300	56	1,170
Twin Birch Dairy	Farm Scale	Skaneateles	NY	2003	Dairy	1,900	100,000	Elec.; Boiler/Furnace Fuel	120	97	2,034
Will-O-Crest Farm	Farm Scale	Clifton Springs	NY	2008	Dairy	1,050		Flared Full Time		211	4,435
Bridgewater Dairy, LLC	Farm Scale	Montpelier	OH	2008	Dairy	3,900	429,000	Cogeneration	800	296	6,219
Miedema Dairy	Farm Scale	Circleville	OH	2008	Dairy	1,000		Flared Full Time		106	2,234
Quasar Energy Group - Wooster	Central/Region	Wooster	OH	2010	Dairy			Elec.; Boiler/Furnace Fuel	400		
Wenning Poultry Farm	Farm Scale	Ft Recovery	OH	2008	Layers	600,000		Cogeneration	600	714	14,992
Seaboard Foods Wakefield Farm	Farm Scale	Turpin	OK	2002	Swine	26,500				241	5,060
Bernie Faber Dairy (CalGon Dairy)	Farm Scale	Salem	OR	2002	Dairy	350		Cogeneration	100	91	1,903
Tillamook_1 (2 digesters)	Central/Region	Tillamook	OR	2003	Dairy	2,000		Cogeneration	250	518	10,874
Tillamook_2 (last 2 digesters)	Central/Region	Tillamook	OR	2008	Dairy	2,000		Cogeneration	300	518	10,874
Brookside Dairy	Farm Scale	Homer City	PA	2006	Dairy	400	33,000	Cogeneration	85	30	639
Brubaker Farms	Farm Scale	Mount Joy	PA	2007	Dairy	900	72,827	Cogeneration	160	68	1,438
David High	Farm Scale	Selinsgrove	PA	1998	Swine	1,200		Cogeneration	22	15	315
Dovan Farms	Farm Scale	Berlin	PA	2006	Dairy	400	44,214	Cogeneration	100	30	639
Four Winds Farm	Farm Scale	Ulysses	PA	2006	Dairy	650	40,930	Cogeneration	140	45	942
Hillcrest Saylors Farm	Farm Scale	Rockwood	PA	2007	Dairy	1,150	49,054	Cogeneration	130	69	1,452
Mains Farm	Farm Scale	Newville	PA	2006	Dairy	600		Cogeneration	90	46	959
Mason Dixon Farms	Farm Scale	Gettysburg	PA	1979	Dairy	2,300		Cogeneration	600	489	10,268
Oregon Dairy Farm	Farm Scale	Lititz	PA	1983	Dairy	250	19,000	Cogeneration	45	53	1,116
Penn England Farm	Farm Scale	Williamsburg	PA	2006	Dairy	800	50,000	Cogeneration	130	61	1,278
Pine Hurst Acres	Farm Scale	Danville	PA	2004	Swine	4,400	11,200	Electricity	47	55	1,156
Reinford Farms	Farm Scale	Mifflintown	PA	2007	Dairy	800	1,931	Cogeneration	130	61	1,278
Rocky Knoll Swine Farm	Farm Scale	Lancaster	PA	1985	Swine	1,000	60,000	Cogeneration	130	35	734
Schrack Farms	Farm Scale	Loganton	PA	2006	Dairy	1,430		Cogeneration	200	82	1,726
Wanner's Pride-N-Joy Farm	Farm Scale	Narvon	PA	2007	Dairy	400	60,561	Cogeneration	160	30	639
Midwest Dairy Institute	Farm Scale	Milbank	SD	2006	Dairy	2,400		Boiler/Furnace Fuel; Elec.	375	183	3,833
Broumley Dairy Farm	Farm Scale	Hico	TX	2008	Dairy	980	47,000	Cogeneration		243	5,102
Huckabay Ridge / Microgy	Central/Region	Stephenville	TX	2008	Dairy	10,000	2.8 M	Pipeline Gas		64	1,352
Premium Standard 1	Central/Region	Dalhart	TX	2002	Swine	108,000		Electricity	2,000	4,130	86,733
Premium Standard 2	Central/Region	Dalhart	TX	2002	Swine	10,000		Electricity	160	382	8,031
Circle Four Farms	Central/Region		UT	2005	Swine	194,000	1.2 M	Methanol		5,971	125,381
Wadeland Dairy	Farm Scale	West Weber	UT	2004	Dairy	1,200	70,000	Cogeneration	150	121	2,551
Martin Farms	Farm Scale	South Boston	VA	1994	Swine	3,000	12,000	Electricity	25	55	1,154

Blue Spruce Farm, Inc.	Farm Scale	Bridport	VT	2005	Dairy	1,100		Electricity	240	67	1,409
Foster Brothers Farms	Farm Scale	Middlebury	VT	1982	Dairy	380	37,500	Electricity	125	23	487
Gervais Family Farm	Farm scale	Bakersfield	VT	2009	Dairy	950		Electricity	200	58	1,217
Green Mountain Dairy, LLC	Farm Scale	Sheldon	VT	2007	Dairy	1,050	115,500	Cogeneration	300	64	1,345
Maxwell Farm /	Farm Scale	Coventry	VT	2008	Dairy	750		Electricity	225	46	961
Montagne Farm	Farm Scale	Swanton	VT	2007	Dairy	1,200	132,000	Cogeneration	300	73	1,537
Pleasant Valley Farms	Farm Scale	Berkshire	VT	2006	Dairy	1,950	220,000	Cogeneration	600	119	2,498
Westminster Farms	Farm Scale	Putney	VT	2009	Dairy	1,200		Cogeneration	225	73	1,537
Farm Power Northwest, LLC	Central/Region	Mount Vernon	WA	2009	Dairy	1,200		Electricity		109	2,279
G DeRuyter & Sons Dairy	Farm Scale	Outlook	WA	2007	Dairy	3,500	438,356	Cogeneration	1,200	316	6,646
Qualco Energy/Quil Ceda Power Corp.	Central/Region	Tulalip	WA	2008	Dairy	2,000	203,000	Cogeneration	450	525	11,020
Vander Haak Dairy	Multiple Farm	Lynden	WA	2005	Dairy	750	137,000	Cogeneration	450	68	1,424
Bach Digester, LLC	Farm Scale	Dorchester	WI	2010	Dairy	1,250		Electricity	300	259	5,441
Baldwin Dairy	Farm Scale	Baldwin	WI	2006	Dairy	1,050		Boiler Fuel; Flare	200	218	4,571
Central Sands Dairy, LLC	Farm Scale	Nekoosa	WI	2008	Dairy	3,500		Electricity	1,200	240	5,041
Clover Hill Dairy, LLC	Farm Scale	Campbellsport	WI	2007	Dairy	1,250	115,500	Cogeneration	300	259	5,441
Crave Brothers Dairy Far	Farm Scale	Waterloo	WI	2007	Dairy	1,900	223,000	Cogeneration	633	101	2,126
Double S Dairy	Farm Scale	Markesan	WI	2004	Dairy	1,100		Cogeneration	200	228	4,788
Emerald Dairy	Farm Scale	Emerald	WI	2006	Dairy	1,600		Pipeline Gas		332	6,965
Five Star Dairy Farm	Farm Scale	Elk Mound	WI	2005	Dairy	850		Cogeneration	775	176	3,700
Gordondale Farms	Farm Scale	Nelsonville	WI	2002	Dairy	850	93,501	Cogeneration	140	58	1,224
Green Valley Dairy	Farm Scale	Krakow	WI	2007	Dairy	3,400		Cogeneration	1,200	705	14,800
Grotequt Dairy Farm, Inc.	Farm Scale	Newton	WI	2009	Dairy	2,400		Cogeneration	600	165	3,457
Holsum Dairy - Elm Road	Farm Scale	Hilbert	WI	2007	Dairy	4,000	363,000	Cogeneration	1,200	274	5,761
Holsum Dairy - Irish Road	Farm Scale	Hilbert	WI	2004	Dairy	4,000		Cogeneration	700	274	5,761
Lake Breeze Dairy	Farm Scale	Malone	WI	2006	Dairy	2,550		Cogeneration	600	175	3,673
Maple Leaf Dairy	Farm Scale	Cleveland	WI	2010	Dairy	2,000		Cogeneration	1,200	415	8,706
Maple Leaf West	Farm Scale	Cleveland	WI	2010	Dairy	4,000		Electricity		829	17,412
Norm-E-Lane, Inc. (NEL)	Farm Scale	Chili	WI	2008	Dairy	2,000	242,000	Cogeneration	500	415	8,706
Norswiss Farms	Farm Scale	Rice Lake	WI	2006	Dairy	1,240	2.9 M	Electricity	850	257	5,398
Pagels Ponderosa Dairy	Farm Scale	Kewaunee	WI	2009	Dairy	4,000		Electricity	800	274	5,761
Quantum Dairy	Farm Scale	Weyauwega	WI	2005	Dairy	1,700		Cogeneration	300	352	7,400
Statz Brothers, Inc.	Multiple Farm	Sun Prairie	WI	2009	Dairy	2,000		Cogeneration	600	137	2,881
Sunrise Dairy	Farm Scale	Suring	WI	2005	Dairy	810		Cogeneration	250	168	3,526
Vir-Clar Farms	Farm Scale	Fond du lac	WI	2004	Dairy	1,200		Cogeneration	350	82	1,728
Volm Farms	Farm Scale	Kewaskum	WI	2009	Dairy						
Wild Rose Dairy	Farm Scale	LaFarge	WI	2005	Dairy	880		Electricity	775	60	1,267
Wyoming Premium Farms 1	Central/Region	Wheatland	WY	2003	Swine	5,000		Electricity	80	27	557
Wyoming Premium Farms 2	Central/Region	Wheatland	WY	2004	Swine	18,000		Electricity	160	190	3,999

Source: “Anaerobic Digesters sorted by operational status and state, “ United State Environmental Protection Agency, http://www.epa.gov/agstar/operational.html, 04/10/10.