ENERGY RECOVERY FROM ANAEROBIC DIGESTION WHEN COMPARED TO CLOSE-COUPLED GASIFICATION

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Abstract

During the summer of 2010, the Washington Suburban Sanitary Commission (WSSC) began a study comparing biosolids management options for the Seneca, MD and Piscataway, MD Waste Water Treatment Plants with a focus on energy recovery from residuals through the methods of drying followed by gasification and anaerobic digestion with combined heat and power generation. Both plants currently manage their biosolids with lime stabilization and Class B beneficial use. The study was set up as a three phase approach consisting of identifying and screening technologies, performing a detailed economic and noneconomic analysis of the short listed options and finally developing a concept design report for the selected option. Samples from both plants were analyzed for both energy potential and digestibility leading to the finding that the Seneca sludge was not suitable for conventional mesophilic anaerobic digestion alone. Several drying and gasification alternatives were screened but only close coupled systems were short listed for further analysis. Several anaerobic digestion configurations and pretreatment technologies were also screened leading to a short list of conventional mesophilic anaerobic digestion at Piscataway WWTP; acid-gas phase digestion for both WWTPs; 2PAD™ technology for both WWTPs and a combined digestion facility at Piscataway with thermal hydrolysis pretreatment. A detailed economic analysis led to drying and gasification along with a regional thermal hydrolysis and anaerobic digestion being the most favored options for the two plants under study. Future work includes expanding the study to compare additional regional options in conjunction with other Commission three plants.

Key words

Anaerobic Digestion, Beneficial Reuse, Energy Recovery, Gasification, Thermal Hydrolysis, Solids Processing

Introduction

Energy recovery from residuals and biosolids is one option to offset energy usage and reduce carbon footprint in public and private utilities treating domestic wastewater. One established method of recovering energy from biosolids is to recover biogas from anaerobic digestion and produce energy using combined heat and power generation (CHP) technologies. Another method of recovering energy from biosolids is to use dried biosolids as fuel source for energy generation through the processes of gasification and energy recovery systems.

Biosolids gasification produces a synthetic gas also known as syngas with approximately one third of the energy content as compared to biogas, however, the byproduct of gasification is an inert ash with 90% less mass for disposition than a dewatered cake produced after an anaerobic digestion process. Typically, the syngas is used to dry the biosolids providing an energy neutral drying system; however, excess energy may be available depending on plant conditions. Biosolids energy recovery systems following gasification are newer technologies for the application of biosolids than is anaerobic digestion; however the demand to reduce energy costs and pressure on land application programs are paving the way for adapting dried biosolids gasification and energy recovery systems as a disposition method. The USEPA is encouraging green energy production and recovery, specifically through the use of anaerobic digestion to create digester gas that can be used in a CHP system. Using this, the Washington Suburban Sanitary Commission (WSSC) has obtained funding to assess the potential for installing green energy technologies at the Piscataway and/or Seneca wastewater treatment plants (WWTPs).

Comparing energy recovery via anaerobic digestion and combined heat and power (CHP) to drying followed by gasification and energy recovery started in August 2010 for two WSSC WWTPs; Seneca and Piscataway, MD. The goal of the study is to determine the best solution(s) for beneficial use of the plant's biosolids with a focus on tapping into the energy potential of biosolids. The study was structured to consist of a three phase approach to indentify and screen potential technologies, evaluate short listed options using both economic and non economic metrics and finally developing conceptual design reports of the selected alternative for each plant. In addition to studying individual plant approaches, regional solutions combining the sludges from both plants were also evaluated.

This paper presents the energy recovery potential from the screened alternatives and the amount of electricity that can be produced, where applicable. The paper also presents the 20 year life cycle cost (LCC) analysis for each alternative. Non-economic analysis including carbon footprint, odor potential, noise potential, process integration, and side stream recycle impact to enhanced nutrient removal treatment process is also presented for each alternative.

Background on Existing Facilities

The Seneca and Piscataway WWTPs are designed for 26 and 30 million gallons of wastewater per day (MGD) (4,100 and 4,730 m^3/h), respectively. The Seneca WWTP does not have primary settling tanks while Piscataway produces both primary sludge and secondary waste activated sludge (WAS).

Currently the solids handling facilities for Seneca WWTP include gravity belt thickeners (GBT), dewatering centrifuges, and lime stabilization to produce a Class B biosolids. The systems that were evaluated in the study were aimed at replacing the current Class B lime stabilization process. It was assumed that the existing centrifuges would remain and be used either upstream of the drying and gasification process or downstream of the digestion and CHP process.

The current solids handling facilities for Piscataway WWTP include scum separation, first stage sludge thickening, lime slurry addition and stabilization, second stage sludge thickening, and belt filter press dewatering to produce Class B biosolids. Like Seneca, the purpose of this study was to evaluate replacing the Class B lime stabilization process. Also, it was assumed the existing belt presses would remain and be used in a similar manner to the existing centrifuges at Seneca.

The design sludge loading from the Seneca and Piscataway WWTP's along with the proportions of Primary sludge and WAS for Piscataway is provided in Table 1 below.

Table 1: Solids production and projections for the Seneca and Piscataway WWTP's

Sludge Production	Seneca (dtpd)	Piscataway (dtpd)	Piscataway % Primary	Piscataway % WAS
Current daily average	11	15.5	44	56
Current peak month	15	23	46	45
Design daily average	18.5	22	48	52
Design peak month	24	33	53	47

Study Approach

The comparison of anaerobic digestion and CHP to drying/gasification and energy recovery was conducted through a three phase approach. At the time of writing this paper the first two phases are complete and the third phase is in progress. In addition, WSSC has also decided to evaluate some additional centralized regional plant options which will include loads from other WWTP's in the area such as Western Branch, Parkway, and Damascus.

The first phase consisted of identifying and screening potential technologies for digestion pretreatment, digestion, CHP, and technologies for drying, gasification and energy recovery. The second phase consisted of a detailed evaluation of the short listed alternatives using 20 years LCC analysis and non-economic metrics. The third and final phase will consist of generating a concept design report of the selected alternative for each plant.

During the first phase, the design team established design parameters, tested the biosolids characteristics and indentified and screened potential technologies available for consideration. First the plant flows and expected growth were determined to establish design loads under current, 20-year, and design build-out conditions. Digestibility and heat value characteristics of biosolids samples were determined with bench scale and laboratory analyses. The final part of phase one focused on screening available technologies suitable for each WWTP using both energy recovery methods.

The second phase of economic and non-economic evaluation was conducted to compare factors such as; 20 year lifecycle costs, carbon footprint, odor and noise potential, ability to integrate into the facility, and side stream treatment impacts. The project team formulated cost opinions for capital and O&M to estimate the 20 year LCC for each considered alternative, which along with the non-economic factors formulates the basis for identifying the best alternative for biosolids processing and energy recovery at each treatment plant. In addition to individual plant options, combined solutions were also evaluated to compare the economy of scale impact for a regional biosolids facility.

In conjunction with the on-going third phase, the commission has also decided to evaluate additional regional options in cooperation with other area plants. Work for evaluating the additional regional options is underway.

Close-Coupled Gasification

Gasification is an established process for converting organic materials to a fuel gas called synthetic gas or syngas, and has been practiced since the 1800s to generate fuel gas from coal and other biomass. Syngas is composed mainly of CO, CO_2, H_2 and CH_4 and has a low heating value of 120-150 British Thermal Units (BTU) per cubic feet (ft^3) which is approximately 25% of the heat value of biogas generated from anaerobic digestion. Although gasification is common in many industries, gasification of biosolids is still considered innovative as defined by the Environmental Protection Agency (EPA). One of the larger differences between traditional organic materials used as the fuel source in gasification and biosolids is the higher ash content of biosolids.

To effectively harness energy through gasification and energy recovery, most commercially available systems require dried biosolids with greater than 75% solids in granular form. Pelletization is not required for gasification; however, a certain degree of uniformity in the dried granular material along with low dust content is required. The required dryness depends on the technology. The energy required for drying is typically supplied by the gasification process. Energy can also be recovered from waste heat, such as a CHP system, if available onsite. Currently there are 17 installations of dryers with energy recovery worldwide with two located in North America.

There are two forms of recovering energy from syngas: two stage gasification and close-coupled gasification. In two stage gasification systems, syngas is cleaned to remove impurities, mainly tar, before feeding internal combustion engines to produce electricity and recoverable heat. The two-stage gasification technologies such as ones offered by Nexterra and Kopf were eliminated from consideration since they did not have full scale operating installations on Biosolids in North America. In close-coupled gasification, syngas is thermally oxidized to produce hot flue gas that can be cooled for energy recovery to offset fossil fuel for drying and power generation. Information describing close-coupled gasification is presented below.

Close-coupled gasification, shown in Figure 1, does not require syngas cleaning and instead the syngas is thermally oxidized. Syngas oxidation generates high temperature, approximately 1,800°F, flue gas which can be used for thermal heat recovery. The energy recovered from the flue gas can be used as the energy source to dry to the biosolids to the desired dryness and thus minimize or eliminate the need for fossil fuels (e.g., natural gas or fuel oil). The hot flue gas can also be used as an energy source for generating electricity through the use of steam turbines or an Organic Rankin Cycle engine. Electricity generation with close-coupled gasification is commonly practiced on other types of biomass; however, this system is not common for biosolids since it’s generally more economical to use the energy to offset the drying energy requirement. The close-coupled mode of energy recovery is considered commercially developed and is currently practiced in biosolids facilities in Buffalo, MN (Kruger/Veolia) and in Sanford, FL (MaxWest).

Energy and mass balances for gasification systems show that there could be sufficient energy in undigested dewatered sludge (depending on the heat content and the percent solids of the dewatered cake) to dry the material without the need for any auxiliary fuel. The gasification process is considered a good candidate for harnessing the energy from the dried biosolids and recycling this energy to dry the biosolids, producing energy efficient or an energy neutral drying processes. For anaerobically digested biosolids, some of the volatile material is consumed and converted to biogas which reduces the calorific value of the biosolids. Since the calorific value of digested biosolids is lower, a higher dewatered solid content is required to achieve an energy neutral drying and gasification processes.

The amount of fuel or biosolids to be processed, and the amount of excess energy in the hot flue gas generated, will dictate which form of CHP technology can be practically used to generate power and in some cases, low grade waste heat. Another factor which determines the appropriate type of CHP is the size of the facility and the goals for energy recovery. Small to medium facilities, with a goal of producing electricity may use a technology such as the Organic Rankine Cycle (ORC) with approximately 10-20% electricity efficiency to recover energy from excess flue gas generated. Larger facilities with similar goals may select high pressure steam turbines with approximately 15-38% electrical efficiency. There are practical economic and non-economic criteria which help determine the appropriate size and type of system.

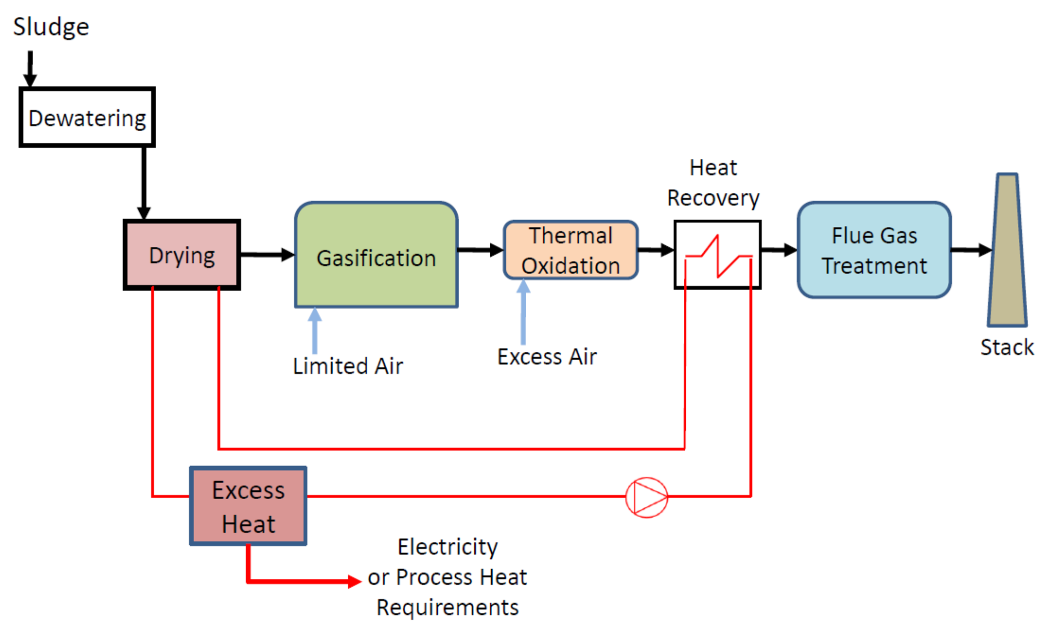

Figure 1: Close-Coupled Gasification System for Energy Recovery

Shortlisted Close-Coupled Gasification Technologies

For the drying followed by gasification options, only close-coupled gasification technologies were shortlisted since this is the only method currently practiced commercially in North America. The close coupled systems offered by MaxWest Environmental Systems Inc. and I. Kruger Inc. were the screened processes for the economic and non-economic evaluation of the second phase of the study. At the time of the study and writing this paper, both vendors have one full scale installation in the United States; Buffalo, MN (Kruger) and Sanford, FL (MaxWest). There are six energy recovery systems in Europe.

The Kruger BioCon™ ERS system is a package system that consists of a BioCon Belt Dryer, a reciprocating grate furnace, heat recovery equipment and emission control equipment. Energy for the belt drying process is supplied via the biosolids furnace.

The hot flue gas from the furnace is cooled in a heat exchanger that transfers heat to the belt drying air circulating through the dryer cabinet. The energy can be recovered either by an air-to-air heat exchanger, thermal oil to air heat exchanger or steam boiler, depending on site restrictions and desire to recover electricity. A generic process flow diagram of a Kruger BioCon and ERS system is provided in Figure 2.

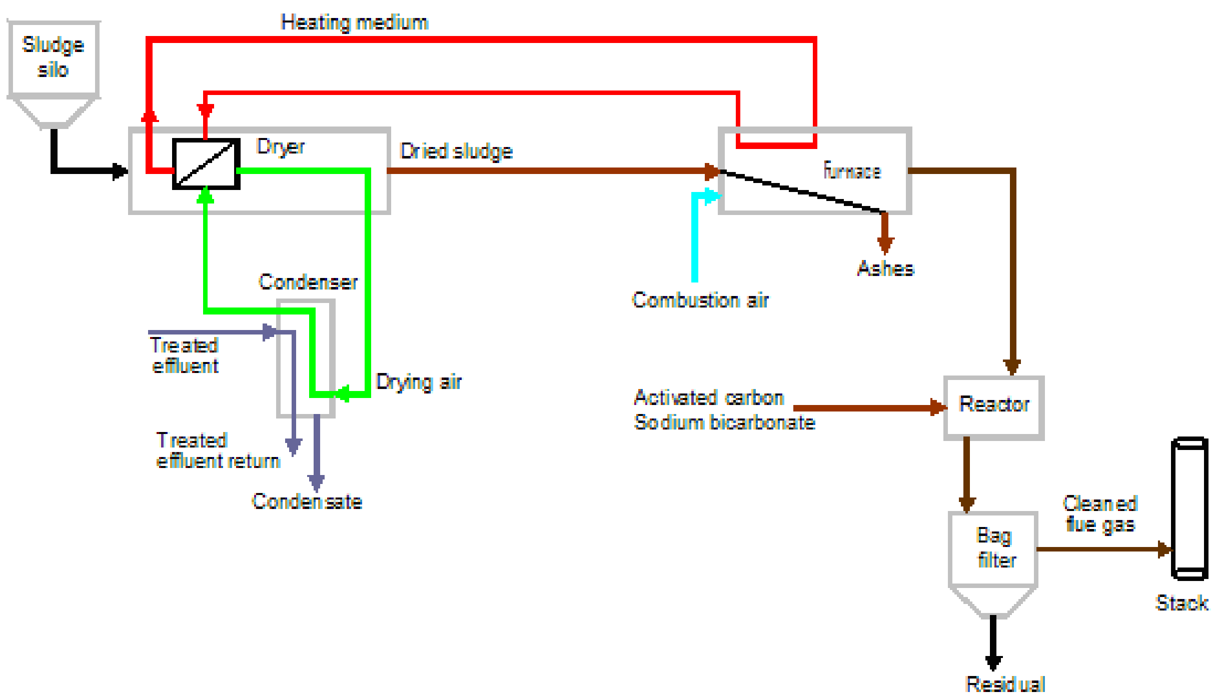

Figure 2: Generic Kruger BioCon ERS Process Flow Diagram

The reciprocating grate furnace is used to gasify and oxidize dried granular material produced from the drying process. These types of furnaces are commonly used for biomass worldwide but have been more commonly used in Europe for the application of biosolids when compared to the United States. Currently there are five installations in Europe and one in North America. The Kruger furnace operates under the principal of two stage combustion. The first stage or primary chamber occurs at the grates where under-fire or primary air is provided at 30-60% of the total air that is required for complete combustion. By starving the first stage of oxygen, gasification occurs, producing syngas. The second step occurs above the grates in the secondary chamber, where the syngas produced during the gasification step is combusted with excess air producing hot flue gas. The energy from the flue gas is recovered for the drying process and the flue gas is scrubbed before exiting out the stack.

The Max West system is similar to the Kruger system in that it is a package system that operates in the close coupled configuration using the energy recovery from the gasification and thermal oxidation process for upstream drying. The Max West System however separates the gasification and thermal oxidation processes into two separate unit operations as opposed to a combined furnace like the Kruger system.

The MaxWest Gasification system consists of the primary gasifier and the ash removal and storage system. The primary gasifier is a fixed bed, updraft reactor which is constructed of a refractory lined, steel unit in which primary gasification reactions take place in an induced draft environment (negative draw). Dried, processed biosolids are conveyed from the feedstock storage hopper into the gasification system feed bin located at the front end of each primary gasification cell where syngas is produced. The energy in the produced syngas is recovered through the use of a thermal oxidizer, a thermal energy diversion unit, the heat recovery system, and a cooling tower. The thermal oxidizer is a refractory lined, horizontal steel cylinder with injection ports for the admission of air to promote homogenous blending of the syngas prior to combustion. The syngas from the primary gasifier is combusted in a thermal oxidizer, which operates under an induced draft condition. The energy from the hot flue gas is recovered by a heat recovery heat exchanger and heats a thermal fluid, typically thermal oil. A secondary heat exchanger or economizer can also be added on the backend of the process to recover residual energy remaining in the flue gas before it is treated by the flue gas cooling tower and scrubbing system and vented out the stack.

The remaining inert, mineralized ash is removed from the bottom of the primary gasification unit through the use of a hydraulic, walking floor system. The ash is conveyed, through a hopper chute, to a drag or screw conveyance system and transferred to a disposal containment system.

Each gasification system vendor offers different project delivery methods. Max West only offers their system on a Design, Build, Own, Operate, Finance (DBOOF) model where Kruger is typically offered as either a Design, Bid, Build or Design, Build method.

Anaerobic Digestion Technologies

Several anaerobic digestion process configurations and digestion pretreatment technologies were screened. Conventional and advanced anaerobic digestion processes were considered. Digestion processes that can achieve Class A biosolids were also screened. The initial screening process was based on practiced amount of volatile solids reduction and thus amount of biogas that can be generated to convert to energy. Another consideration was ability to achieve Class A once in operation or be upgraded to Class A in the future.

The solids from the two plants digest differently based on bench scale digestion studies described later. Thus different digestion processes were shortlisted for each plant. The shortlisted digestion options for Piscataway included conventional mesophilic anaerobic digestion, acid-gas digestion, temperature phased acid-gas digestion (2PAD™). The shortlisted alternatives for Seneca included acid-gas digestion, temperature phased acid-gas digestion (2PAD™), and thermal hydrolysis after combining with Piscataway solids at Piscataway site. The following sections briefly describe these digestion processes.

Mesophilic Anaerobic Digestion

Mesophilic anaerobic digestion is one of the most proven processes for the stabilization of solids from municipal wastewater treatment. Conventional mesophilic digesters are typically operated at solids retention times of 10-20 days and at temperatures ranging from 90 to 105ºF. Feed solids concentrations are typically in the range of 3-6%. Volatile solids reduction (VSR) varies between 40% and 55%. The biosolids produced in mesophilic digestion typically has ammonia concentration in the range of 600-1,000 mg/L. The biogas produced can be treated for various energy recovery uses.

Acid-Gas Anaerobic Digestion

Acid-Gas (AG) anaerobic digestion consists of a highly loaded “acid-phase” digester followed by a more lightly loaded “gas-phase” digester. The concept is to provide separate, ideal environments for the acid-forming and the gas-forming microorganisms. The acid-phase is designed to provide pretreatment (primarily biological hydrolysis and acidification) and the gas-phase is designed for maximizing gas production. A typical AG digestion system has an acid-phase digester with a detention time of 1-2 days followed by a gas-phase digester with a detention time of about 10 days. Expected VSR is in the range of 45-65% with high levels (>1,000 mg/L) of ammonia in the recycle stream after dewatering. Key requirements are to produce a pH less than 5.8 and volatile fatty acids more than 6,000 mg/L, without using mineral acids in the acid-phase. Minimal amounts of methane gas, typically less than 6 percent of the total AG process, are produced in the acid-phase digester. This gas has a lower quality than what is produced in the gas-phase digester and usually contains less than 40% methane. The relatively short detention time of the acid digester can be maintained by allowing for varying volumes in the digester corresponding to variations in raw solids flow.

2PAD™ Anaerobic Digestion

One specific variation of the Acid-Gas Digestion process is the Two Phase Anaerobic Digestion process (2PAD™) offered by Infilco Degremont, Inc. (IDI) as shown in Figure 3. The IDI 2PAD™ system consists of an acid phased thermophilic digester and a methane gas phased mesophilic digester. The high temperature in the thermophilic digester destroys pathogens meeting EPA requirements for Class A biosolids.

In the 2PAD™ process, the influent biosolids are heated as they pass through a heat recovery exchanger. Following preheating, the residuals are fed to the thermophilic digester where they are held for two days. Temperatures in the thermophilic digester are maintained at 131ºF to maximize pathogen destruction. The effluent from the thermophilic digester is fed through the heat recovery exchangers to cool the biosolids before they are fed to the mesophilic digester at 95ºF for ten days. The heat recovered during cooling of the biosolids is used to partially heat the biosolids feed to the thermophilic digester. The 2PAD™ process is semi-batch with two to four sludge feedings per day to the system.

Thermal Hydrolysis with Mesophilic Anaerobic Digestion

Thermal hydrolysis (TH) is a sludge conditioning process that precedes anaerobic digestion to produce a Class A product and make biosolids more digestible. The TH process disintegrates cell structure/organic materials and dissolves naturally occurring cell polymers (a form of protein), into an easily digestible feed for anaerobic digestion. This process subjects dewatered sludge to high pressure and temperature through direct steam injection. The high solids concentration (9-10%) enables digestion volume to be on the order of half that of conventional digesters operating at 5% solids feed.

Traditionally thermal hydrolysis has occurred in a series of batch tanks (Cambi™ or Thelys™) but a newer continuous process (Exelys™) is under development by Veolia Water Solutions and Technologies. All thermal hydrolysis processes use high pressure steam and operate at approximately 330°F and 120-130 psi. The process generates biogas that can be used for electrical production and generates a high quality Class A product. There are more than 25 installations of batch thermal hydrolysis processes worldwide but only one demonstration unit of the continuous process is currently operating (Hillerod, DK).

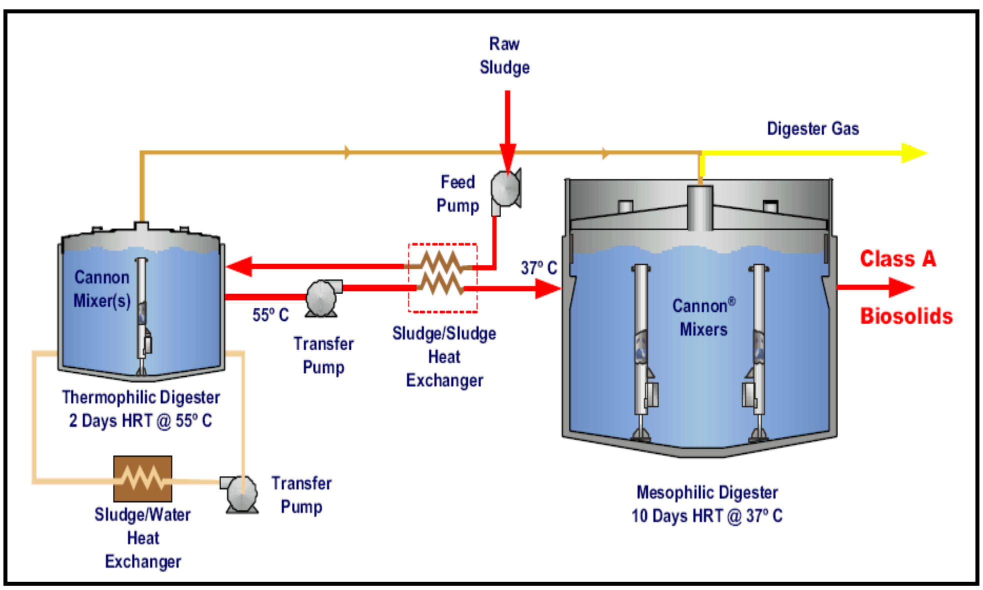

Figure 3: **Process Flow Schematic of a 2PAD™ system (From IDI's Literature)**

The most common thermal hydrolysis process in operation today is the Cambi system shown in Figure 4. In the Cambi process, dewatered biosolids are conditioned through three batch reaction steps. First dewatered biosolids are fed to a pulper where the biosolids are mixed with flash steam from the flash tank. The biosolids are pumped from the pulper to a reactor where live steam is injected and the solids are held for sufficient period for the hydrolysis reaction to occur. From the reactor, the hot, pressurized biosolids are fed to a flash tank where the pressure is reduced producing a flash steam that is recovered to pulp and heat the incoming raw dewatered cake. From the flash tank, the biosolids are diluted with pasteurized water to the desired solids content (typically 9-10% DS), cooled with heat exchangers, and fed to the anaerobic digestion process.

The Exelys process depicted in Figure 5 is a newer generation of thermal hydrolysis currently under development by Veolia. Unlike Cambi, which uses a series of batch tanks, Exelys is a continuous plug flow system. Dewatered biosolids and steam are continuously fed to a mixing and condensing system. The pressurized sludge is fed to a plug flow reactor with sufficient detention time for the hydrolysis reaction to occur. From the plug flow reactor the solids are cooled and diluted with pasteurized water to feed the digesters at the desired solid content and temperature. The reaction conditions, temperature and pressure, are similar to the Cambi process.

Options for Combined Heat and Power

Anaerobic digestion produces biogas that can be utilized in a range of fuel combustion equipment. The most optimal design to use this fuel is through the co-production of heat and power, otherwise known as a combined heat and power plant (CHP). In the CHP of this size, the biogas is typically combusted in a reciprocating internal combustion engine or in a combustion turbine. The hot exhaust gas is then passed through a heat exchanger to generate hot water or steam to be utilized in a process, such as heating anaerobic digesters. In many instances, lube oil heat and jacket water heat is also extracted to increase the recovered heat.

Multiple gas cleaning and pre-treatment systems were also evaluated. The digester gas pretreatment technology selection was coordinated with the CHP technologies chosen for further evaluation. The most appropriate technologies include iron sponge for sulfide removal, and activated carbon or chemical scrubbing for siloxane removal. Gas purification for pipeline or vehicle fueling as an alternative to CHP was not recommended in this evaluation.

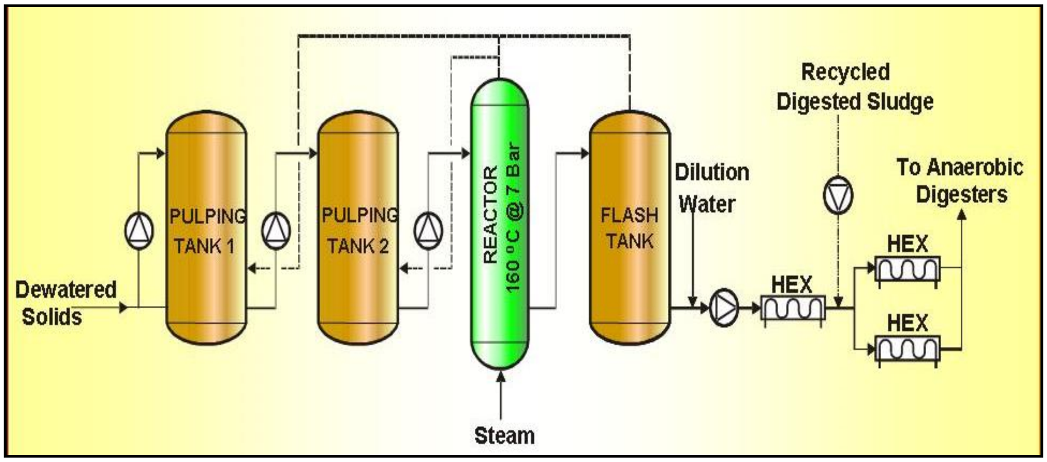

Figure 4: Process Flow Schematic of a Cambi Thermal Hydrolysis System (Cambi Literature)

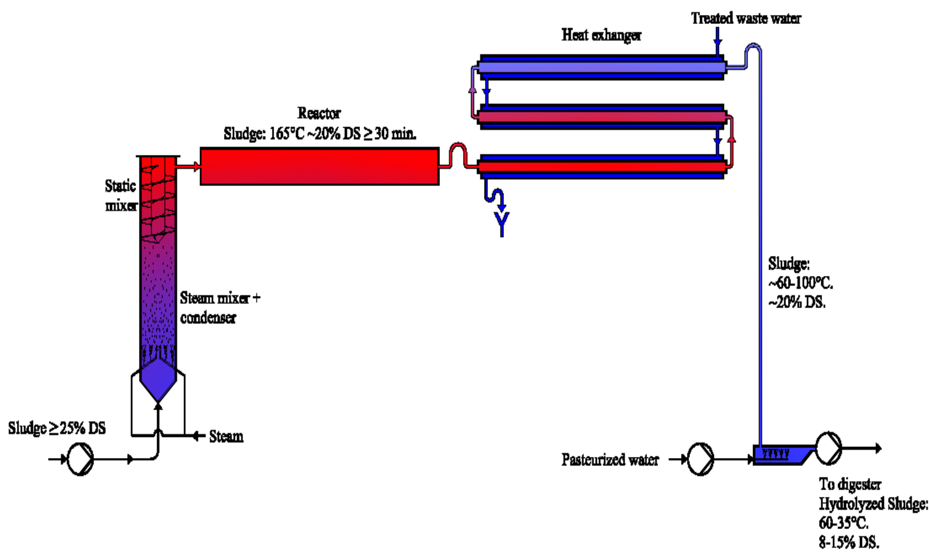

Figure 5: Process Flow Schematic of an Exlyse Thermal Hydrolysis System (Veolia Literature)

Four CHP technologies were evaluated; reciprocating engines, gas turbines, microturbines and fuel cells. Based on the projected range of gas volumes, it was determined that gas turbines are not suitable as they are mostly used for much higher gas volumes so they were eliminated from the evaluation. Fuel cells were also eliminated due to the limited number of installations and anticipated higher costs when compared to other technologies. Based on the initial screening, reciprocating engines and microturbines were recommended for further development as alternatives for the CHP system.

Solids Characterization and Digestibility

In order to predict the performance of gasification or anaerobic digestion, samples of sludge from both plants were collected for laboratory and bench scale analysis. Sludge samples from both Seneca and

Piscataway WWTPs were shipped to Hazen Research Fuel Laboratory in Golden, CO for Proximate and Ultimate analysis. Samples were also sent to Virginia Polytechnic Institute and State University in Blacksburg, VA (Virginia Tech) to evaluate the digestibility of the biosolids.

Proximate and Ultimate Analysis

A proximate analysis provides the gravimetric fraction or weight fraction of moisture, volatile matter, fixed carbon and ash. An ultimate analysis is a gravimetric analysis that provides the percentage weights of specific atomic species as opposed to compounds. The information provided by the proximate and ultimate analysis are used by the gasification or combustion system manufacturer to select components suitable for optimal operating conditions and designing the fuel and ash handling systems. The proximate and ultimate analysis for Seneca and Piscataway are provided in Table 2 and Table 3 below.

Table 2: Proximate Analysis (dry basis)

Source	Ash (%)	Volatile (%)	Fixed Carbon (%)
Seneca WWTP	24.17	66.94	8.89
Piscataway WWTP	22.30	70.39	7.31

Table 3: Ultimate Analysis Results (dry basis, wt %)

Source	Carbon %	Hydrogen %	Nitrogen %	Sulfur %	Ash %	Oxygen %
Seneca WWTP	41.33	5.66	5.57	0.86	24.17	22.41
Piscataway WWTP	43.20	4.79	3.29	1.09	22.30	24.33

The higher heating value (HHV) provides a measure of the heat energy available within the feed materials. The results are presented on a dry solids basis. The higher the HHV, more energy is available for release from the process. If gasification and drying are combined, higher HHVs would mean either less auxiliary fuel (natural gas) is required to sustain the process or there is potential to generate excess energy beyond what is required for drying. However, when looking at combined drying/ gasification systems, the efficiencies of all of the processes need to be considered (gasification, oxidation, heat transfer, dewatering, and drying efficiencies), to make this determination.

Comparing the measured HHV to the calculated or theoretical values according to the modified Dulong method provides surprisingly good convergence, meaning that the two results are close to the same value. The results of this analysis are provided in Table 4 below. The HHVs for both Seneca and Piscataway are in line with typical non-digested WWTP solids and allow drying and gasification to be good candidate technologies for processing the solids.

Table 4: Higher Heating Value (dry basis)

Source	HHV (BTU/lb)	Calculated/Theoretical HHV (BTU/lb)	Difference (actual vs. calculated)
Seneca WWTP	7686	7702	-0.21%
Piscataway WWTP	7920	8087	-2.1%

Digestion Potential

Two sets of samples from both plants were also provided to Virginia Tech for batch digestion testing. Batch digesters were set up in triplicate using seed sludge from a local anaerobic digestion plant (Peppers Ferry WWTP). A second set of samples was provided and 75% of the contents of the first phase digesters was wasted and replaced with new sludge. The intent was that the first phase would be used both for data and to confirm that the biomass was acclimated to the sludge from WSSC. A summary of the digestion results are presented in Figure 6 below.

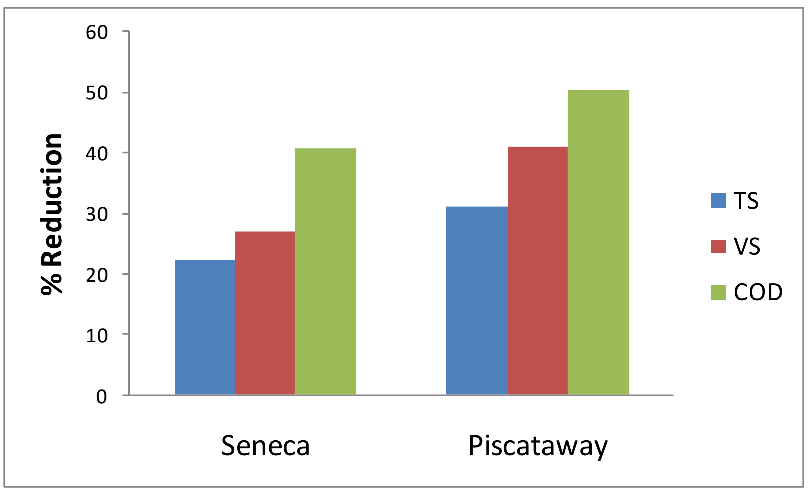

Figure 6: Batch Digestion Testing Results

The batch tests show that the sludge from Seneca digests poorly, however, the sludge from Piscataway digested fairly well. Since Seneca consists of only waste activated sludge (WAS), the result is expected and within the range of expected values for WAS. Piscataway, however, contains primary sludge so the digestibility was significantly better; however, it was a little lower than expected for a mixture of primary and waste activated sludge. The lower digestion values for the Piscataway sludge could be due to using alum in the clarification process. Available aluminum ion has been shown to bind proteins in waste water and sludge making the protein unavailable during anaerobic digestion.

Batch digestion reflects a single sludge sample so it is limited in the data it can provide since sludge at a WWTP can vary from day to day and week to week. A more complete data analysis would require digestion over several detention times, typically several months of operation once the digester is at steady state. Although limited, the batch digestion data provided useful information for predicting the performance of a full scale system.

Energy Recovery Comparison

The screened drying and gasification alternatives were individual BioCon and ERS systems at each plant and a combined MaxWest Facility at Piscataway. MaxWest did not offer individual plant systems as an option as each was a smaller system than they wanted to propose.

Screened anaerobic digestion processes for economic and non-economic evaluation included conventional mesophilic anaerobic digestion (MAD) at Piscataway WWTP; acid-gas phase digestion for both WWTPs; and 2PAD™ technology for both WWTPs. A regional digestion facility at Piscataway for both plants using thermal hydrolysis pretreatment was also selected for further evaluation. Based on the results of the batch digestion testing, conventional anaerobic digestion was not considered appropriate for Seneca.

Energy recovery potential from all short listed technologies was performed. Evaluations have shown that electricity production potential from anaerobic digestion at each plant ranges from 600-850 kW. Drying followed by gasification showed no auxiliary energy is needed for the drying process without electrical potential for Seneca using the close-coupled method of energy recovery. For, Piscataway, however, since primary sludge was produced, excess energy yielding up to 260 kW of electricity could be produced using the Organic Rankin Cycle technology. Increasing the cake solids from the existing dewatering technology at each plant from 20% to 30% using electro-dewatering to generate additional waste heat was also evaluated, however, the power costs for the enhanced dewatering equipment outweighed the electrical production potential so it was not considered for further evaluation.

Furthermore combined drying/gasification by MaxWest and combined anaerobic digestion proceeded with thermal hydrolysis were considered assuming they would be located at Piscataway. For the combined option using thermal hydrolysis as a biosolids pretreatment process prior to anaerobic digestion, approximately 1.3 to 1.6 MW of power could be produced. One of the largest advantages of including a combined digestion system with thermal hydrolysis pretreatment is that the solids can be hauled as dewatered cake as opposed to a liquid sludge which significantly minimizes the hauling costs and number of trucks required. Electrical production with a combined gasification facility offered by MaxWest was also examined; however, it was not economical or recommended by the vendor so was excluded from the evaluation.

Figure 7 shows the electrical production potential comparing individual plant alternatives to a combined digestion facility with thermal hydrolysis. Based on this figure it is evident that a regional facility with thermal hydrolysis allows for the highest electrical production potential, however, energy is consumed in pre-dewatering at Seneca and hauling Seneca sludge.

Economic Evaluation

The life cycle cost analysis (LCC) was developed to compare the treatment alternatives from a cost perspective. The analysis was based on calculating the present worth value for the total cost (capital and O&M) of each alternative assuming 20 year life cycle period.

Capital Costs were developed as the opinion of probable construction cost for each of the shortlisted alternatives. The probable construction costs were based on preliminary layouts of the new facilities and vendor quotes for major equipment. The construction costs reported here are considered accurate to +/- 35%.

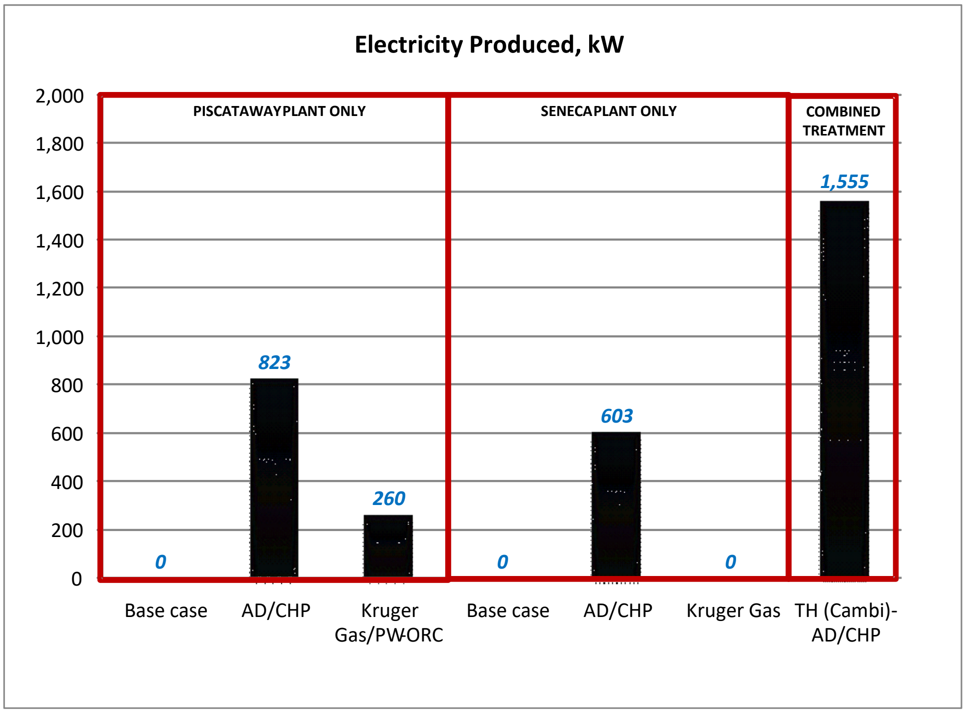

Figure 7: Summary of Electrical Production Potential from different processing

The annual O&M cost estimates for each alternative were calculated for the years 2010 and 2030 to set the basis for the life cycle cost analysis. The O&M costs were categorized under the following components; energy, transportation of solids, land application, chemical demand and labor (including both operation and equipment maintenance). The O&M costs for the years in between 2010 and 2030 were interpolated assuming a linear increase in cost from 2010 to 2030. The appropriate escalation rates were applied to each category. The discounted rate was applied to the escalated value to determine the discounted values for each year. The present worth value for the O&M cost was determined by summing all discounted values for all the years from 2010 through 2030.

For the options with anaerobic digestion, reciprocating engines were selected as the preferred CHP system since they showed the lower 20 year LCC when compared to microturbines. The costs for the reciprocating engines were used in the digester system options LCC.

The capital cost for each alternative, including CHP capital cost, was added to the present value for the O&M cost to determine the overall present value for each option. Table 5 presents the calculated present worth value for each category under each option and the total present worth value for each option.

Table 6 shows LCC estimates for the combined options and compares the options to the individual plant solutions at both plants. Since conventional mesophilic digestion was not considered viable at Seneca it is not shown below. Also, a solution of gasification at Seneca and acid-gas digestion at Piscataway was included to show the potential for different solutions at each plant.

Based on this cost analysis, gasification via BioCon and ERS and regional thermal hydrolysis with anaerobic digestion and CHP were shown to be most cost effective alternatives. Other criteria are considered in addition to the cost analysis; including mainly carbon footprint and potential electricity production, which are discussed in the following sections. Individual digestion plant options were found to be the least economical.

Table 5: LCC for Individual Plant Alternatives

		Baseline		**MAD**		**Acid-Gas**		**2PAD**		**Gasification (BioCon+ERS)**	
		Pisc[(a)]	Sen[(b)]	Pisc	Sen	Pisc	Sen	Pisc	Sen	Pisc	Sen
Capital Cost	$MM	6	7	34	-	38	29	43	38	28	28
O&M	$MM	62	56	30	-	27	40	27	41	27	36
TOTAL PW	***$MM***	**68**	**63**	**64**	**-**	**66**	**69**	**70**	**80**	**55**	**64**
TOTAL PW	***($/DT)*** [(c)]	**530**	**540**	**500**	**-**	**510**	**590**	**550**	**690**	**430**	**550**

[(a)] Piscataway WWTP
[(b)] Seneca WWTP
[(c)] treatment ($) per dry ton

Table 6: LCC Comparing Combined Options to Individual Systems at Both Plants

		Individual plants combined					**Regional Options**	
		Baseline	Acid-Gas	2PAD	Gasification (BioCon+ERS)	Gasification (BioCon) at Sen + Acid-Gas at Pisc	Thermal Hydrolysis (Cambi)	Gasification (Max West)
Capital Cost	$MM	13	67	81	57	66	57	-
O&M	$MM	118	68	69	63	63	68	124
TOTAL PW	***$MM***	131	134	150	119	130	125	124
TOTAL PW	***($/DT)***	538	550	614	489	532	513	510

Non-Economic Evaluation

In addition to the economic analysis, the systems were also evaluated and ranked based on factors such as; ease of operation and maintenance, impact of sidestreams on the Enhanced Nutrient Removal (ENR) process, sustainability, product quality, odor and noise. The operation and maintenance were quantified in terms of cost and ultimately captured in the economic analysis, however certain qualitative factors are also taken into account such as requirements for maintaining a Title V air emissions permit for drying and gasification systems or using high pressure steam for the thermal hydrolysis systems. The digestion options would place a large nutrient load back on the ENR process so additional side stream treatment processes were included in the capital costs and additional chemical costs and aeration requirements were accounted for in the LCC.

The sustainability of both the digestion processes and drying and gasification processes are quantified by the greenhouse gas emission. For product quality, the digestion options produce a dewatered cake of Class A or Class B quality depending on the process configuration and inclusion of digester pretreatment technology. The drying and gasification processes produce an inert ash with significantly less mass for disposal either to a landfill or for beneficial reuse such as concrete or road production. All options should minimize odor and noise to levels that are not major deciding factors.

Carbon footprint Estimates

Another parameter that was important to the commission was the carbon footprint of the plant. CO_2-equivalent (CO_2e) emissions were evaluated as an indication of sustainability for each alternative using 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Local Government Operations Protocol (LGOP) for the quantification and reporting of greenhouse gas emissions inventories (published in May 2010) were used in addition to IPCC guidelines.

The carbon footprint calculations included emissions from electricity, natural gas, transportation, and chemical uses. The boundaries set for the carbon footprint analysis included direct emissions from the plant such as fossil fuel and digester gas combustion as well as chemical addition at the plant. The scope for the carbon footprint analysis also included indirect emissions resulting from the plant operations such as electricity purchased for running equipment, emissions associated with hauling chemicals to the plant or biosolids from the plant as well as the emissions associated with the manufacturing of chemicals.

Emissions from the CHP processes and gasification process were estimated, along with the emissions from methanol addition to the wastewater for dewatering filtrate side stream treatment. However, all of these are of biogenic origins, and the IPCC excludes biogenic CO_2 from the Inventory. The emissions from the biogas used to produce CHP and any emissions from drying/gasification are excluded since these emissions are biogenic, however emissions from incomplete CH_4 combustion were estimated and accounted for. Use of natural gas to supplement fuel to CHP is also included in CO2e estimates. The denitrification reaction that occurs in the side stream treatment process is a naturally occurring reaction with the byproduct being CO_2, so it is also treated as a biogenic source.

Figure 8 summarizes the CO2e estimates for the regional thermal hydrolysis option in comparison to the individual sludge treatment at both plants. All digestion and gasification alternatives show significant savings and reduction in carbon footprint when compared to the baseline process of lime stabilization. The digestion technologies, however, have the lowest carbon footprint and actually provide a negative carbon footprint overall. The low carbon footprint is realized by the generation of electricity from a biogenic fuel source, biogas.

Summary

At this phase of the study, both drying/gasification/ERS and a combined digestion/CHP system with thermal hydrolysis appear to be the most favored options from a life cycle cost analysis standpoint. Drying following by gasification offers the most mass reduction and when conducting sensitivity analysis for the options it appeared to be most stable against consumables, hauling and land application factors. However anaerobic digestion with thermal hydrolysis has the highest electrical production potential, and lowest CO2e potential, which are important factors for WSSC. The limited number of drying and gasification installations along with air permitting issues and impact of the new Sewage Sludge Incineration regulations are points of concern with WSSC. Anaerobic digestion with thermal hydrolysis pretreatment, the other favored option, also contains an obstacle in that there are currently no thermal hydrolysis systems installed or operating in North America, although there are > 25 systems worldwide. Also all thermal hydrolysis systems require high pressure steam and are privately operated.

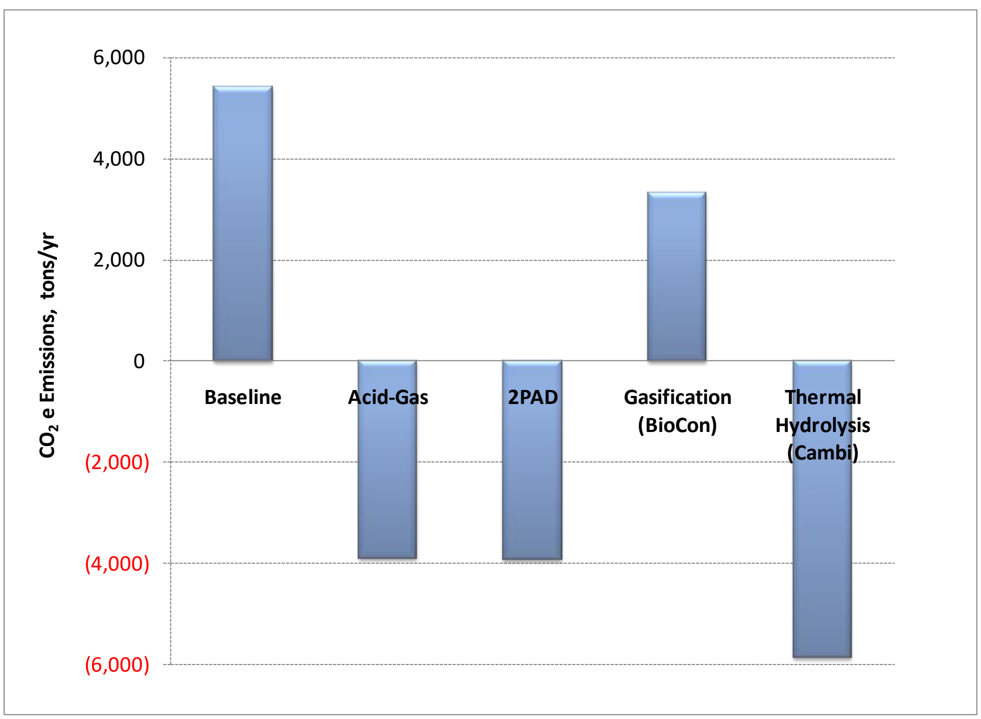

Figure 8: CO2e Comparison for the Evaluated Alternatives for Both Plants

WSSC has decided to continue to evaluate other centralized and regional options based thermally hydrolyzed anaerobic digestion, including solids from Western Branch, Parkway, and Damascus WWTPs. The additional options currently being evaluated include:

- Centralizing biosolids processing at either Western Branch or Piscataway serving all WSSC WWTPs,
- Regional biosolids processing at Piscataway excluding Western Branch
- Regional biosolids processing at Western Branch serving Parkway, Piscataway, Western Branch,
- Regional biosolids processing at Seneca serving Damascus & Seneca
- Merchant biosolids processing at Blue Plains serving all WSSC WWTPs

Resutsl of this evaluation were not available at the time of presenting this paper.