Harnessing Energy From Biosolids

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Harnessing the energy available from biosolids has become increasingly important as fossil fuel reserves dwindle, the environmental impacts of obtaining fuels become more apparent, and economic drivers for renewable energy become more abundant.

Biogas is generated from the anaerobic digestion of wastewater solids. Improving the anaerobic digestion process with proper mixing, adequate heating, and more uniform feeding can all increase the amount of biogas generated. Harnessing energy from biosolids at wastewater treatment plants reduces greenhouse gases and has the potential to produce enough electricity for more than 4 million people.

Three case studies are presented: one case study of a system in operation, one under evaluation, and one in construction.

The first case study presents the commissioning and two years of operations of the first thermal hydrolysis process (THP) in North America, and provides unique insight to utilities that are considering using this technology to produce Class A biosolids, recover energy, and reuse the biosolids as high-quality material for topsoil.

While the first case study is for a new, large-scale facility, the second case study provides insight for smaller facilities that are considering expansion or enhancement of digester facilities at a medium-sized 25-dry-ton-per-day (dtpd) facility, which can provide a basis and understanding of how digester pretreatment improvements can increase biogas yield, thereby increasing energy recovery.

The third case study presents an economic and technical analysis of options for digester gas use and the initial construction of the selected facility, which receives high-strength organics, in addition to its own biosolids. The quantity and quality of the offsite organics results in more biogas than can be used by the existing power generation equipment, and it serves to describe the economics and technical feasibility of installing either additional power generation or installing gas cleaning equipment to produce line quality natural gas.

Case Study 1: DC Water Thermal Hydrolysis

The 370-mil-gal-per-day (mgd) average daily flow Blue Plains Advanced Wastewater Treatment Plant (BPWWTP) is operated by the District of Columbia Water and Sewer Authority (DC Water), and serves the metropolitan Washington, D.C., area. The facility has implemented a new biosolids processing facility, which has been operational since late 2014.

The facilities were executed as three different but interrelated projects: main process train (MPT), combined heat and power (CHP), and final dewatering facilities (FDF).The upgrades have reduced the volume of biosolids and provide a Class A product. The main process train includes sludge screening, predewatering, thermal hydrolysis, and mesophilic anaerobic digestion in four 3.8-mil-gal (MG) digesters. The main process train is followed by belt filter press dewatering and beneficial use of the Class A biosolids product. The digester gas is used to fire three 4.6-megawatt (MW) gas turbines in the new CHP facility that generates up to 10 MW net of power to the plant and steam for the thermal hydrolysis process. The new MPT and ancillary facilities are capable of processing up to 450 dtpd.

Thermal Hydrolysis Overview

Thermal hydrolysis is a proven anaerobic digestion pretreatment process that is well established in Europe and is quickly gaining popularity across the United States. In addition to the installation at DC Water (450 dtpd), thermal hydrolysis is in design or construction at other large water reclamation facilities (WRFs) in San Francisco (200 dtpd), Dallas (245 dtpd), and Virginia Beach, Va. At Hampton Roads (Va.) Sanitation District (92 dtpd), Franklin, Tenn. (25 dtpd), and Pontiac, Mich. (26 dtpd) are examples of smaller WRFs that are utilizing thermal hydrolysis to meet their long-term biosolids goals.

Thermal hydrolysis is a process by which sludge is heated under pressure, with the purpose of improving the availability of organic solids to make them more readily biodegradable. Thermal hydrolysis pretreatment of the sludge prior to digestion allows for a significant reduction in the size of the digesters by feeding at a concentration of 10 percent solids versus the 5 percent feed to a conventional digester, while ensuring adequate retention time to reduce sludge volumes and provide methane to feed a CHP. The THP process has been proven to result in Class A biosolids after digestion, and provides high volatile solids reduction (VSR) and high methane content in the resulting gas.

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Start-Up

The seeding process was initiated in late September 2014. Approximately 3 MG of pasteurized and digested biosolids were transported from the AlexRenew facility to BPWWTP and was added to the heated water in two of the digesters. This seed volume provided approximately 40 percent of the volume of these two digesters. Once a digester was full, thermally hydrolyzed sludge was introduced. This sludge was slowly added to the digester, based on volatile solids in the digester, starting at a rate of approximately 20,000 lbs volatile solids per day (7 percent of the volatile solids in the digester) to each of the first two digesters, and increasing approximately 3 to 5 percent per day. The feed rate was adjusted based on the digester performance. The pH, solids inventory, relative gas production compared to feed, and other parameters were monitored on a regular basis in order to determine if the feed should be increased, lowered, or suspended.

In addition to the typical parameters monitored in digesters, a bacterial colony sample collection was performed. While this information was not readily available for operational decisions, the bacterial colony analysis did provide detailed information on the colony shifts and acclimatization time, and helped troubleshoot performance issues with the digesters.

Acclimatization of the digesters was not instantaneous. Performance of the digesters during the first eight to 10 months of operations was reliable, but not optimal, as the methanogenic bacteria most comfortable with the thermally hydrolyzed sludge were becoming dominant. Throughout the acclimatization period, the performance of the thermal hydrolysis and digestion exceeded expectations. Methane concentration in the digester gas ranged between 60 and 65 percent methane, gas production was approximately 0.28 cu meter (m^3) per kilogram (kg) of chemical oxygen demand (COD) fed (4.5 ft^3 per lb of COD fed), and COD reduction was approximately 48 percent. The digesters required approximately 140 days to "washout" or consume the pathogenic bacteria to result in Class A biosolids; however, since mid-February 2015, all sludge has met Class A requirements for pathogen reduction.

Long-Term Operations

The goal of any digester is to reduce the mass of solids for downstream processing, which is monitored by analyzing the VSR in the digesters. The VSR is dependent upon several operational factors in the digesters. The most significant operational parameters are the ratio of primary solids to waste activated solids (WAS) and the solids retention time (SRT) in the digester; digesters fed with more primary solids will typically have higher VSR, as this material is more easily biodegradable. Digesters with longer SRT will provide increased VSR, since the more time available for digestion, the more volatile solids will be reduced. The digesters at DC Water are generally fed with 50 percent primary solids and 50 percent WAS. At normal operation throughput, a SRT of approximately 20 days was observed. Typical mesophilic digesters operating under these parameters will have a volatile solids removal generally between 38 and 50 percent.

Figure 1 presents the volatile solids in the raw solids, the digested solids, and the resulting VSR over the six-month analysis period. The data indicate an average of just over 81 percent volatile solids in the feed, an average of just under 57 percent in the digested solids, and a resulting volatile solids removal of just over 68.5 percent.

In addition to VSR, it is vital to understand the resulting biosolids and the end product that will be used. The ability to dewater biosolids effectively can have a direct effect on end use, hauling costs, and viability of further processing; the more water that can be effectively removed, the more options available for final biosolids disposition. In the case of DC Water, the biosolids have multiple outlets, including land application, soils blending, and curing, followed by use as a topsoil. The biosolids from the THP digestion process have been found to be very consistent, but "stickier" than typical biosolids, which has resulted in the lining of trucks with straw to reduce the time to unload.

Dewatering can be done by many different technologies, including, but not limited to, centrifuges, belt filter presses, screw presses, Fournier presses, and plate and frame presses; DC Water elected to utilize belt filter presses to eliminate the shear forces from centrifuges and reduce the risk of pathogen regrowth. Mesophilically digested biosolids can typically be dewatered between 18 and 25 percent total solids on belt filter presses. Figure 2 presents the results from operations at DC Water, which have demonstrated 30 to 32 percent total solids throughout the operating period. Polymer usage has been steady between 20 and 22 lb per dry ton throughout the operating period.

In summary, the experience at DC Water indicates that THP, followed by mesophilic di-

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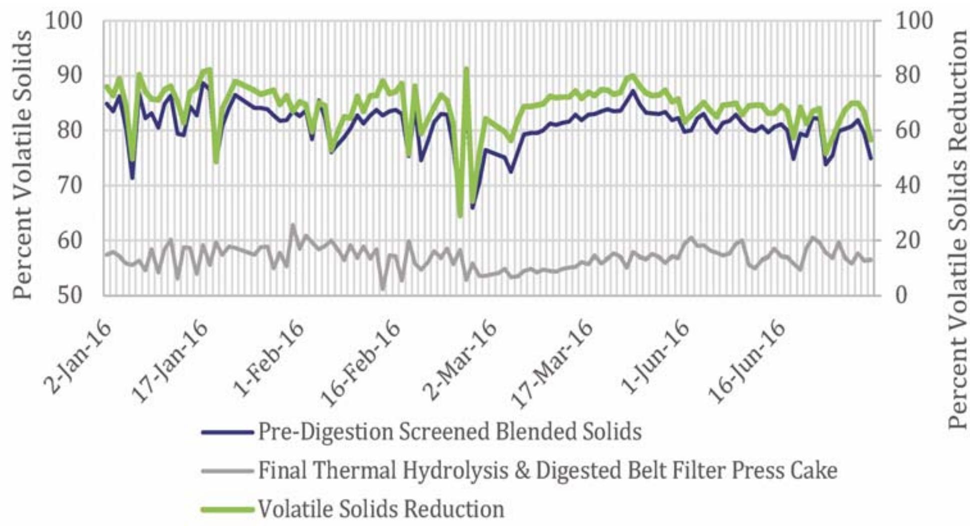

Figure 1. Volatile Solids Reduction

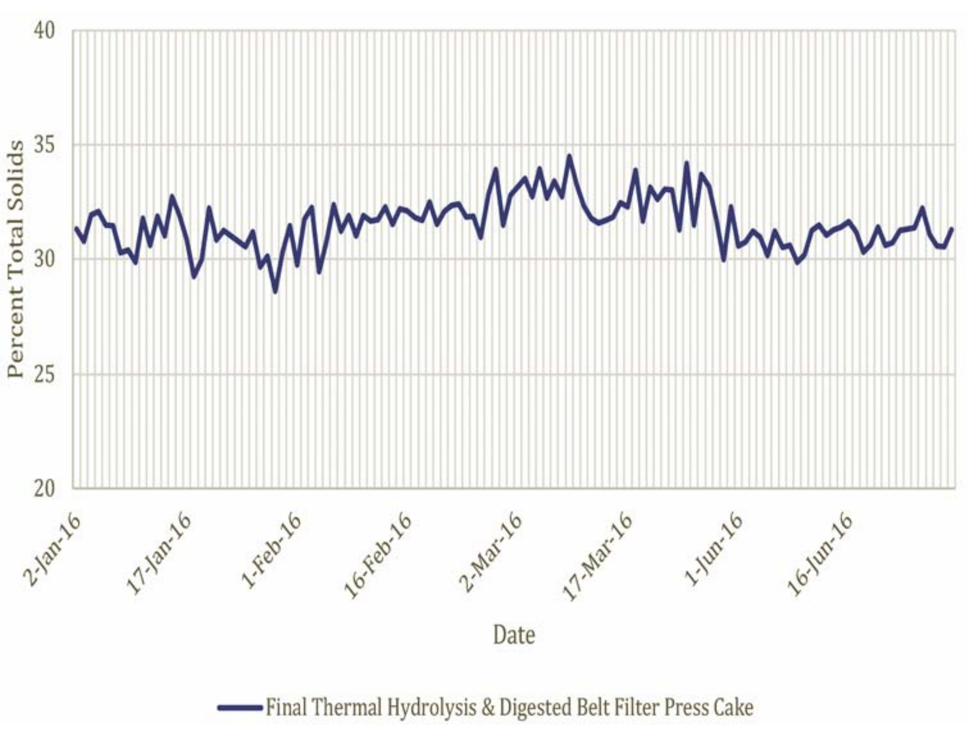

Figure 2. Dewatered Biosolids Concentration

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gestion, will provide a Class A biosolids that can be readily dewatered. Digester performance is improved at similar SRT; digesters can be highly loaded and are resilient to feed changes. The digestion process provides significantly increased VSR and resultant gas yield. The biosolids release water better than typical biosolids, resulting in significantly increased solids concentrations in dewatered biosolids.

Case Study 2: Metro Vancouver Digester Improvements Evaluation

The Lulu Island Wastewater Treatment Plant (LIWWTP) currently has two 5,300-m^3 anaerobic digesters that treat biosolids collected from primary sedimentation tanks and secondary clarifiers. As influent flows to the plant increase, Metro Vancouver (MV) would like to assess methods of deferring the construction of a third digester through the installation of a THP or digestion pretreatment technology that would increase the capacity of the existing digesters.

A study was performed that outlines the technologies available (and their merits) when compared to the project's goals. This long list of alternatives was screened at a high level, with the objective of selecting a short list of options evaluated at a greater level of detail.

The digesters are fed a mixture of gravity-thickened primary sludge and thickened waste secondary sludge. The volumetric primary-to-secondary sludge ratio is 60:40; the resulting mixture is approximately 4 percent total solids. Average flow is roughly 400 m^3/day and average digester throughput is about 16,000 kg/day. The LIWWTP does not have effluent discharge limits for nutrients such as nitrogen or phosphorus, and no nutrient removal takes place at the plant. Due to the long retention time and higher primary fraction of the solids, the digesters achieve an average VSR of about 60 percent. Post-digestion solids are dewatered to 25 percent total solids and transported to the interior of British Columbia for land application.

Gas generated from the digesters is compressed and used for mixing. The gas is then used for boilers that provide hot water for plant heating, and the remainder is flared. The split between the boilers and flares is typically about 50/50, but can vary with as much as 99 percent usage by the boilers in the winter, to 96 percent sent to the flares in the summer. There is an ongoing project at LIWWTP to condition the excess biogas that is currently flared and sell it to the local gas utility.

Table 1. Evaluation Criteria for Biosolids Treatment Technologies

Criteria		Description
Primary Attributes	Capacity Increase	The primary motivation for this study is an increase in digester capacity or performance.
	Net Biogas Availability	An increase in gas production is not necessarily an essential requirement, but net availability of biogas from the digesters for gas conditioning or other plant uses cannot decrease as a result of installing the selected process.
	One Solids Product	MV does not want more than one type of biosolids product produced from the solids treatment system at LIWWTP.
Secondary Attributes	Class A Solids	A Class A biosolids product is not a requirement, but would be seen as beneficial.
	Existing Installations	The number of existing, full-scale installations provides an indication of how established and proven a process is.
	Capital Cost	Cost will be used as an evaluation criteria, but only in relative terms to Digester Three.
	Footprint	The amount of space that the technology requires may affect future planning.
	Electrical Energy Draw	This will assess whether the technology requires more electrical energy to be drawn from the grid.
	Wet Tons Hauled	Some technologies would decrease the amount of wet tons hauled, representing an annual cost savings.
	Chemical Demand	Additional chemical demands
	Operational Complexity	Some technologies may require more highly skilled operations staff or increased observation and automation.
	Side Stream Impact	The liquid waste streams coming back to the head of the plant from dewatering could be affected by the technology implemented.

Evaluation Objectives

The primary objective of this study was to increase capacity of the existing digester facilities at LIWWTP, with a preference to defer the expenditure of constructing a third digester. The key drivers were:

- Increased digestion capacity from the existing digester system.
- No decrease in biogas production.
- A single biosolids product is produced (i.e., no mixture of cake types).

Additionally, MV would find producing Class A biosolids beneficial.

Evaluation

Biosolids technologies were evaluated based on the criteria presented in Table 1, which are split into primary drivers as acknowledged by MV, and additional attributes determined as desirable. The primary drivers are criteria that are required to be met for further consideration of a given technology, whereas the additional attributes will assist in comparing the feasible alternatives to each other. The evaluation at this stage was completed in terms of present sludge flow; future increases in flow will be taken into account in later phases of this study.

Eight alternatives were identified that could potentially meet the objectives of MV and were evaluated against all the criteria. Each alternative was evaluated based on the criteria presented in Table 1, and are summarized in Table 2. Alternatives that did not meet all of the primary drivers were not considered for further comparison, and are shaded out in the summary table. These alternatives were excluded, based mainly on a lack of significant capacity increase, as all alternatives could be operated to produce one solids product and none of them adversely affect gas production.

The remaining alternatives were compared based on all of the evaluation criteria. Because the plant's existing digesters provide a 25-day retention time and achieve 60 percent VSR, none of the alternatives will significantly increase VSR beyond this point. This means that gas production will only marginally increase; however, once the flow rate of sludge increases beyond what the existing digesters can treat at 60 percent VSR, these options will

Table 2. High-Level Summary of Alternatives Evaluation

	Digester Three	Thermal Hydrolysis	Anaergia Omnivore	CNP Pondus	Extended Thermophilic	Lystek	Acid-gas	Sonication	Conceptual Alternatives
Capacity Increase	50%	100%	100%	40%	25%	0%	25%	0%	0-15%
Net Biogas Availability	No Change	Decrease	No Change	Marginal Increase	Decrease	No Change	No Change	No Change	No Change
One Solids Product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Class A Solids	No	Yes	No	No					
Existing Installations in North America	Numerous	1	1	1					
Capital Cost	$53 million	Less than Digester Three	Less Than THP	Comparable to Anaergia					
Footprint	Largest	Medium	Small	Medium					
Electrical Energy Draw	Neutral	Increase	Neutral to Negative	Increase					
Wet Tons Hauled	Neutral	Decrease	Neutral	Data Inconclusive					
Chemical Demand	Neutral	Increase	Increase	Increase					
Operational Complexity	No Change	High	Medium	High					
Side Stream Impact	None	Medium	None	Low					
Recommendation to Carry Forward	Yes	Yes	Yes	No	No	No	No	No	No

become net-energy-production-positive because they increase the amount of gas produced per digester volume.

The three alternatives remaining were THP followed by digestion, recuperative thickening, and construction of a third digester, which is the base case. These alternatives were compared based on several evaluation criteria, including the ability to generate Class A biosolids, capital cost, number of operating facilities, footprint, electrical energy draw, wet tons hauled, chemical demand, operational complexity, and sidestream impact. Figure 3 presents the scoring of the different options.

Costs were analyzed for Digester Three and the two alternatives over a 20-year period. A summary is presented in Table 3.

Digester Three is the most expensive option, followed by THP (29 percent less expensive), and recuperative thickening utilizing Anaergia's Omnivore (83 percent less expensive). These net present values are mostly driven by large differences in capital cost. While the Omnivore solution exhibited the lowest capital cost, MV eliminated the Omni-

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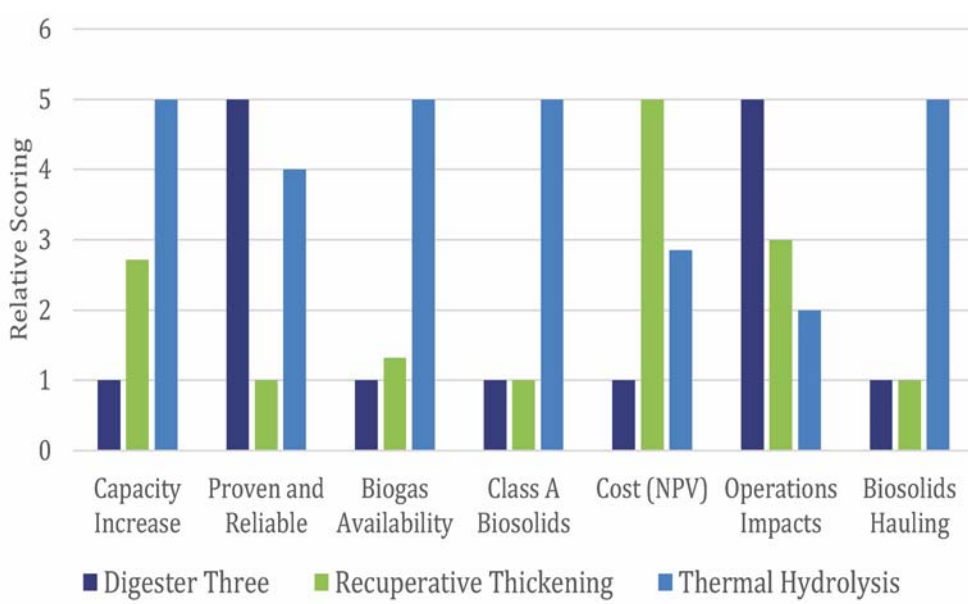

Figure 3. Metro Vancouver Evaluation Criteria Scoring

Table 3. Summary of Costs: Metro Vancouver Options

	Digester Three	Anaergia Omnivore	THP
Total Capital Cost	$53,000,000	$10,200,000	$33,762,000
Total Annual Cost (2016)	$708,000	$688,000	$1,108,000
Total Annual Revenue (2016)	$(765,000)	$(766,000)	$(948,000)
Total Annual Net Cash Flow (2016)	$52,943,000	$10,122,000	$33,922,000
Net Present Value	$51,928,000	$8,782,000	$35,607,000

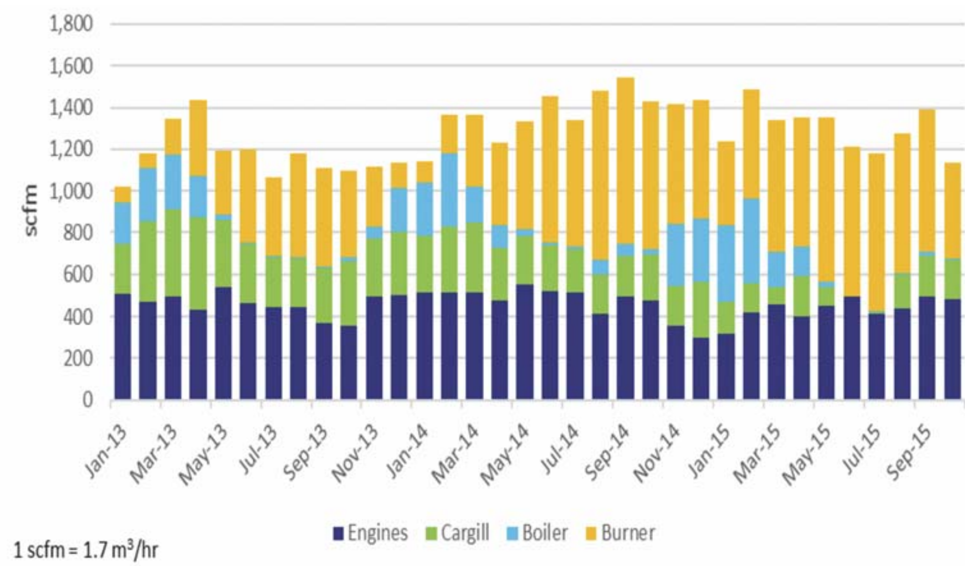

Figure 4. Des Moines Water Reclamation Facility Average Digester Gas Utilization per Month

Table 4. MidAmerican Energy Co. Pipeline Injection Standards

Component	Concentration
BTU Content	> 35 MJ/m^3 (970 BTU/scf)
Carbon Dioxide	< 3% by volume
Nitrogen	< 4% by volume
Total Inerts (N_2 + CO_2)	< 5% by volume
Oxygen	< 0.3% by volume
Water	< 80 kg/1,000,000 m^3 (5 lb/mmscf)
Hydrogen Sulfide	< 5.7 mg/m^3 (0.25 grain/Ccf)
Total Sulfur	< 460 mg/m^3 (20 grain/Ccf)
Volatile Organic Compounds	0 ppm
Inlet Pressure	> 1,032 kPa (135 psig)

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vore from further consideration due to the limited number of facilities in operation and the inability to improve the solids to Class A without additional requirements.

Based on project criteria defined by MV, the recommendation is implementation of a thermal hydrolysis system at LIWWTP in order to increase solids digestion capacity. This recommendation is based on detailed analyses as described and further investigation into specific issues affecting Metro Vancouver facilities.

Case Study 3: Des Moines Water Reclamation Facility (Digester Gas to Renewable Natural Gas)

The Des Moines Wastewater Reclamation Authority (WRA) operates a wastewater reclamation facility (WRF) to provide wastewater treatment services to the City of Des Moines and surrounding communities. A critical aspect of the service is the ability to continuously treat and manage the primary and secondary sludges generated by the wastewater treatment processes. Additionally, the WRA provides a vital service to local industries and neighboring communities by accepting and processing industrial waste sludges and other organic wastes (hauled wastes).

The primary and secondary sludges are blended with the hauled wastes, and the combined feed is processed in an anaerobic digestion system. Anaerobic digestion produces significant amounts of biogas, which is currently used as a fuel in WRA boilers and engines, in addition to being sold to a nearby industry (Cargill) for use in a process boiler.

Even with the uses of the biogas, the loading to the digesters with outside organics has resulted in such an increase in biogas production that the WRA was forced to flare a large percentage of this valuable resource. In addition, improvements to the digester complex completed in 2014 have allowed volatile solids loading to increase and biogas production to double. Due to the digester improvements, WRA has seen an increase in the amount of digester gas that must be flared because it cannot be used in the engines, boilers, or by the nearby industrial user.

Figure 4 shows the average monthly biogas utilization at WRF between January 2013 and October 2015. Digester gas is used year-round in the engines for power generation; boilers are generally fired in colder months when additional heating is required. Cargill's demand of biogas tends to be steady throughout the year, but excess production of gas must be flared in the waste gas burner. The WRA has seen an increased amount of gas flared since early 2014, which can likely be attributed to the digester improvements project and its effect on biogas production.

Pipeline Quality Standards

The recent upgrades to the anaerobic digestion facilities; increased import of fats, oils, and grease (FOG); and other organic wastes processed in the codigestion process have more than doubled WRA's biogas production, and this upward trend is expected to continue. The large volume of gas available provides an opportunity for WRA to generate revenue from this gas.

The WRA is moving ahead with plans to process up to 3,800 m^3/hr of anaerobically digested biogas into pipeline quality renewable natural gas (RNG). This approach offers the opportunity to generate revenue from the sale of RNG to the local utility, as well as revenue from the sale of renewable identification numbers (RINs) via compliance with the U.S. Environmental Protection Agency (EPA) renewable fuel standards for a D5 advanced biofuel credit.

The WRA plans to inject RNG into a nearby pipeline owned and operated by MidAmerican Energy Co. (MEC), a local utility. The nearby pipe is a 6-in. natural gas main line located approximately half a mile from the WRF and has a maximum allowable operating pressure of 125 pounds per sq in. gage (psig). Table 4 summarizes the standards for pipeline injection established by MEC.

The WRA is required to provide the following equipment for biogas injection:

- Install remote pressure control to allow biogas injection into MEC's system.
- Install pressure control and overpressure protection onsite.
- Install gas quality measurement equipment onsite and provide gas quality information to MidAmerican Gas Control.
- Install gas chromatograph, oxygen, hydrogen sulfide, and moisture analyzers.
- Provide MEC with a primary wireless and backup communication line to the gas quality equipment. The equipment must be compatible with MEC's gas control system and must be equipped with alarms that it can monitor.
- Install odorization equipment.

Once the gas chromatograph or other analyzer identifies a component that does not meet MEC's specifications, its protocol will automatically shut the valve and thereby prohibit gas from entering the pipeline. Thus, the gas pressure must be decreased and the gas must be returned to one of three places:

- Recycle off-spec product gas back to the inlet of the feed compressor and back through the pressure swing adsorption (PSA) system.
- Return off-spec product gas to the existing waste gas burners. The product gas pressure will be regulated down for combustion in the burners.
- Return off-spec product gas to the gas sphere to blend with the tail gas from the PSA. The product gas pressure will be reduced to ultimately be combusted in the thermal oxidizer.

If the product gas is too low in terms of British thermal unit (BTU) content or has too high of a concentration of carbon dioxide or hydrogen sulfide, it can be recycled back through the PSA system to increase the methane concentration and decrease the concentrations of the impurities.

If the product gas exceeds the oxygen specification, recycling through the PSA system will not reduce the oxygen gas quality; thus, this gas would either need to go to the waste gas burner or to the gas sphere to be combusted or oxidized.

Gas Cleaning

In order to appropriately clean the gas, three biomethane systems were evaluated, including liquid scrubbing systems, membrane scrubbing systems, and PSA. The three technologies were compared in terms of site layout; capital, operating, and life cycle costs; current installations; ease of operation; ease of maintenance; and system reliability. Advantages and disadvantages of each system were developed and compared. Pretreatment and post-treatment requirements were a critical decision factor.

As part of the evaluation, a bioenergy economic model was developed to evaluate and compare available technologies. The model calculates life cycle costs based on digester gas production, RIN values, and utility costs, while accounting for maintenance costs, capital investments, and opportunity costs (additional costs, assuming that the digester gas is no longer used in boilers and engines). Each economic factor has separate escalation factors allowing various sensitivity analyses to be considered.

Ultimately, WRA selected PSA as the technology for biomethane production because it does not require upstream or downstream biogas treatment, it's a proven and reliable technology with numerous installations in the U.S., it's a relatively easy system to operate and maintain, and it fits well within the design criteria outlined by the utility company and the biogas production at the facility.

Renewable Natural Gas Quality Monitoring

The WRA will own and operate gas quality monitoring equipment upstream of the injection point that includes a gas chromatograph, hydrogen sulfide analyzer, oxgen analyzer, and moisture analyzer. The pressure and temperature of the RNG will also be monitored; hourly averages of gas quality will be provided to the utility company to ensure compliance with the pipeline specifications.

If the gas does not meet the required specifications, it cannot be injected into the pipeline and must be recycled, stored, or flared. Additional laboratory sampling must be performed on a quartely basis. The laboratory analysis includes siloxanes, total silicon, total sulfur, halogens, carcinogens, and volatile organic compounds.

Digester Gas to Renewable Natural Gas Economics

Due to recent digester improvements at WRA, additional biogas is being produced, but is unable to be utilized. The WRA is proceeding with plans to process the anaerobically digested biogas into pipeline quality RNG. The project is highly economically feasible, especially with revenue from RIN sales through EPA's renewable fuel standards. The RNG will be injected into a nearby natural gas pipeline, owned and operated by MEC.

Conclusions

Rising energy and operating costs are ever-present challenges at wastewater treatment plants. At the same time, there are benefits to reducing greenhouse gas emissions and using renewable energy at these facilities.

Increased energy rates for natural gas and electricity have resulted in energy representing 25 percent or more of a facilty's operating budget, second only to labor. By harnessing the energy at wastewater treatment plants, plant managers can reduce energy costs, while simultaneously making progress toward improving the environment.

Harnessing the energy available in biosolids at wastewater treatment plants can reduce overall plant life cycle costs, while beneficially using valuable energy resources. Increased public awareness of, and desire for, green sustainable solutions encourages the environmental benefits of the beneficial use of biogas. While this beneficial use has been practiced for may years, recently, forward-thinking utilities have sought to implement beneficial-use projects, such as those described, and it is expected that this trend will continue, and even grow stronger, in the decades to come.