Waste Not, Watt Not: Considerations for Codigestion and Cogeneration Implementation

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With rising energy costs and evermore stringent regulatory limits, utilities are looking for options to reduce operating costs and to create additional sources of revenue, while meeting new energy challenges. A traditional method of achieving these goals at wastewater treatment facilities in the United States and across the world is mesophilic anaerobic digestion, where wastewater solids (both raw, primary, and biological treatment, or secondary sludges) are consumed by microorganisms at relatively high temperatures (>95°F). Anaerobic digestion reduces sludge quantities and produces biogas, which can have greater than 60 percent methane content and can be used in lieu of natural gas to create heat and electricity.

Cogeneration, or combined heat and power (CHP), is the thermodynamically efficient use of a fuel source to simultaneously generate electricity and recover useful heat. The electricity and heat produced via cogeneration can be used to offset the cost of electricity and natural gas purchased from local utilities. In the context of a wastewater treatment facility, biogas produced from the anaerobic digestion of primary and secondary solids will provide fuel for an engine to generate onsite electricity and reusable heat, which is often subsequently used to heat the anaerobic digesters. Figure 1 presents an example process flow diagram for cogeneration.

While utilizing the biogas produced by anaerobic digestion can offset energy consumption at a wastewater treatment facility and be a potential source of revenue, there is a limit to the amount of energy that can be produced from municipal wastewater sludges alone. In an effort to increase biogas production, many utilities have started utilizing codigestion, which includes the addition of high-strength waste (HSW) sources to supplement the digestion process.

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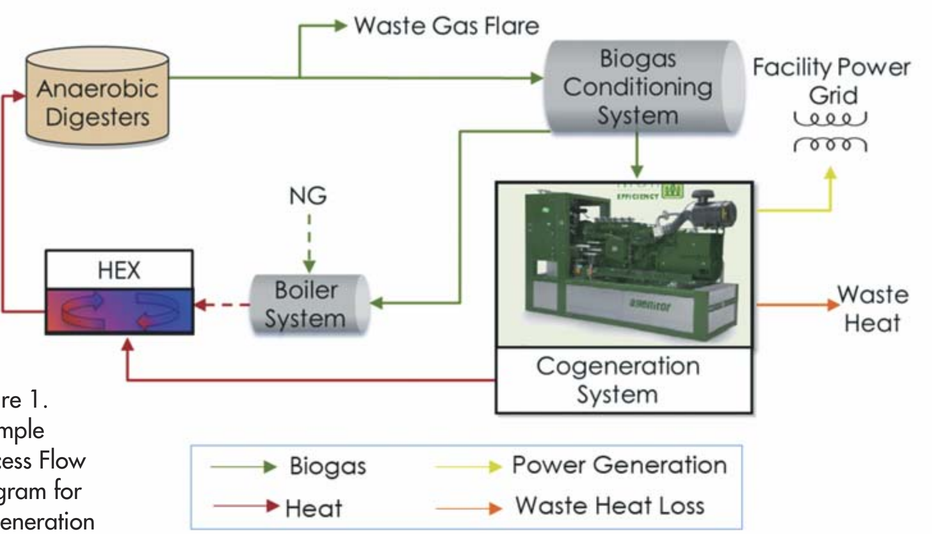

Figure 1. Example Process Flow Diagram for Cogeneration

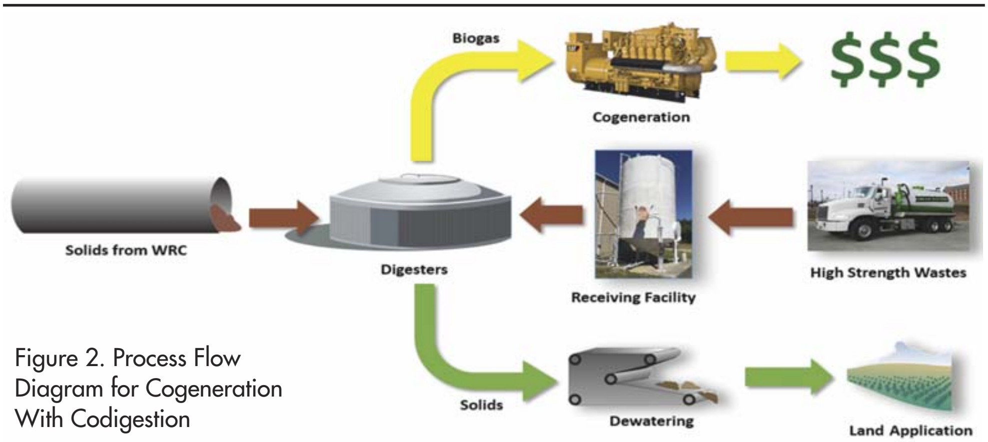

Figure 2. Process Flow Diagram for Cogeneration With Codigestion

Codigestion, in terms of wastewater treatment, is the process of feeding locally collected HSW to the facility's anaerobic digesters in order to increase overall biogas production. Codigestion with HSW can result in a neutral, beneficial, or detrimental effect on the digestion process, depending on the characteristics of the HSWs introduced to the system.

The addition of HSW increases the volatile solids loading (VSL) into the digester, which in turn can increase the amount of biogas that is produced. An increased volume of biogas provides fuel for operation of larger cogeneration units, thereby increasing electricity production, improving heat-capture opportunities, and pushing the facility closer to net neutral energy usage. In addition to increasing biogas production, codigestion, in some cases, can improve the digestion process, thus yielding higher volatile solids reduction (VSR), improved nutrient balance, and more effective utilization of the digester volume. Benefits to the utility and surrounding community are realized by diversion of waste from the sewer system or landfills, as well as providing revenue from tipping fees. Figure 2 presents the process flow diagram for anaerobic digestion at a facility that practices cogeneration, supplemented by codigestion.

In general, sources of HSW exist within the confines of urban areas and are the byproducts of food and beverage industries. Fats, oil, and grease (FOG) are typical food wastes produced by restaurants and other food processing businesses. Certain nonfood-producing industries may also generate HSW, but these wastes typically aren't compatible with codigestion due to constituents such as metals or other biological inhibitors. In all cases, sources of HSW should be individually characterized and evaluated for toxicity to the digestion process in order to avoid biological upsets and reduced biogas production. The HSWs should also be evaluated for biomethane formation potential to better understand the prospective benefits of different waste sources.

Implementing a Codigestion Program

Codigestion efforts across the U.S. utilize a variety of sources, such as FOG from restaurant grease traps, solid preconsumer and post-consumer food waste, and food processing wastes. Certain types of waste require greater pretreatment and screening for removal of undesirable contents, including, but not limited to, trash, excess water, eating utensils, and seashell grit. Some utilities have partnered with waste haulers and other third-party collectors, waste managers, and preprocessors of HSW to broaden their options for receiving a consistent supply of anaerobic digester feed. Figure 3 is a high-level summary of the preliminary steps in the process of identifying potential HSW sources.

Figure 3. General High-Strength Waste Source Identification Steps

Sources of High-Strength Waste

Each HSW source should meet, at a minimum, the following criteria prior to being considered for implementation in a codigestion system:

1. No known toxic constituents (heavy metals, extreme pH, sanitary chemicals, biocides)
2. High-potential biogas production (high chemical oxygen demand [COD] and/or volatile solids [VS])
3. Prescreened and homogenous waste (remove trash and grit, avoid large chunks of material)
4. Reliable quantity and consistent supply from HSW producer
5. Proximity of HSW source to the treatment facility and accessibility for HSW collection
6. Beneficial diversion of HSW from sanitary sewer and/or landfills

Criteria 1 and 2 are important in determining the respective biogas yield of various waste streams, in addition to whether or not a waste stream will cause upsets to the anaerobic digestion process. Criterion 3 addresses undesirable materials present in certain HSWs, which could lead to excessive maintenance and potential performance issues for tanks and process equipment. Some HSW streams are relatively free of debris and do not require screening (food and beverage processing byproducts), whereas other HSWs (solid food waste, grease trap waste) typically contain components of concern, such as trash, utensils, broken plates, etc. Several haulers currently operate their own pretreatment facilities with sorting, screening, and/or dewatering capabilities, while others do not. The latter unscreened wastes should not be accepted at the facility unless a screening process is included as part of the HSW receiving station design. A screening facility at the HSW receiving station would increase both capital and operation and maintenance (O&M) costs, but would also allow for acceptance of a wider variety of hauled material.

Table 1 presents the Th-COD (g-O2/g), or the theoretical maximum COD per gram of waste component, for major macromolecules and waste types. This value indicates the comparative ranking of methane production potential from various HSWs. Fatty acids (which correspond to FOG waste streams) provide a highly beneficial anaerobic digester feed substrate due to a large methane yield, and have proved a successful HSW source for many codigestion facilities. Fatty acids at excessive concentrations, however, can also inhibit key microbial organisms, while sugary waste (carbohydrates) at excessive concentrations can result in system acidification. For these reasons, a combination of sources is often best for overall process performance. Actual performance will require bench-scale or full-scale testing to determine individual compatibility and co-compatibility of wastes with the facility's biosolids in a codigestion process.

Criteria 4 and 5 focus on the cost-effectiveness, logistical soundness, and long-term potential use of each HSW source. The HSW producers under consideration should include relatively large, well-established industries or haulers located within a reasonable distance to the treatment facility to assist with the economics of hauling wastes.

Criterion 6, waste diversion (either hauled HSW diverted from landfills or diversion of discharged HSW from collection systems), is a priority due to potential ancillary benefits, including:

- Reduced collection system odors and corrosion
- Reduced need for sewer cleaning
- Reduced solid waste footprint in landfills
- Reduced energy and chemical consumption for treatment at the treatment facility

Various municipalities across the U.S. have also enacted restrictive legislation to reduce landfilling of food or organic waste, in particular. This trend includes efforts within the food and beverage industry to improve operational sustainability, while partnering with municipalities to find cost-effective options for waste disposal and recovery.

Another consideration for diversion of HSW from the sewer system is surcharge fees, which are applied to permitted HSW dischargers. These fees generate annual revenue for the municipality, and any reduction in revenue must be included in the cost-benefit evaluation for certain HSW streams. The reduction in surcharge fees must be compared to the benefits of energy recovery, as well as anticipated reductions in the cost of wastewater treatment operations and collection system infrastructure maintenance (including corrosion, sewer blockages from FOG material, etc.). Often, the majority of the diverted HSW will come from physically separated and hauled waste streams, which should not significantly impact industrial sewer surcharge revenue since these materials are usually not discharged and can be hauled directly from the producer's facility.

Locating High-Strength Waste Sources

Once the criteria for acceptable HSW have been established, several methods can be used to identify and locate suitable HSW sources.

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One alternative is investigating different sources utilizing database searches via the Standard Industrial Classification (SIC) system or the North American Industry Classification System (NAICS), which are standards used by federal statistical agencies for classifying business establishments. These two systems were created for taxation purposes, but can provide a general idea of the type of businesses in the area that may generate HSWs, such as bakeries, breweries, food manufacturing, and restaurants.

The aforementioned industrial surcharge fees charged by many municipalities can provide another tool for locating waste streams high in COD or biological oxygen demand (BOD). Industrial dischargers are often required to have pretreatment permits, and can therefore be quickly identified via the municipality's permit administrator. Identifying these sources is the first step for potentially diverting waste from the sewer system and eliminating it from the treatment plant's liquid treatment process. Many industrial dischargers are expressing a willingness to participate in energy recovery projects to potentially reduce their discharge fees, while promoting sustainability.

Contacting waste haulers has also proven beneficial in implementing a codigestion program because many of them contract with multiple waste producers, including smaller producers that may not have sufficient volume to be targeted as an individual waste source. Waste haulers can often be identified via the state registry or through municipal FOG programs, which seek to mandate FOG capture prior to sewer discharge.

Some waste haulers remove the FOG from grease traps and transport it to processing facilities where it is processed and dewatered; other waste haulers transport byproducts of food and beverage manufacturing, such as off-spec syrup for soft drinks. Many of these haulers pay tipping fees at the respective FOG processing facility, landfill, or other disposal location for their waste and are eager for an alternate, less expensive disposal method. The municipality may receive these wastes directly or make an agreement with the waste processing facility to accept waste only after it has been screened and/or partially dewatered. This is especially a consideration for unscreened FOG sources, since this material can be high in VS and easily biodegradable, which is highly beneficial for codigestion.

During an evaluation of available sources, it is important to remember that there are several competing recipients of high-value HSW, including biofuel manufacturers, fat rendering facilities, and some composting operations.

Pilot System and Laboratory Studies

As treatment processes and biosolids differ from facility to facility, so does the interaction of the sludge with different HSWs. For this reason, it is important to perform laboratory studies with different solids-to-HSWs ratios to determine ideal combinations. Once the best waste ratios are determined, tests can be performed to maximize the waste biodegradability and the kinetics of the codigestion process. While laboratory-scale testing generally involves small samples tested under ideal conditions, a larger-scale pilot evaluation should be conducted to verify that the digestion performance will not be compromised when larger quantities of waste are introduced into the digester system. The pilot system can also aid in determining the VSR and projecting biogas production for cogeneration.

Performing bench-scale testing and laboratory analyses are critical to understanding the expected performance of the wastes in an anaerobic digester. Utilizing waste characterization and bench-scale testing, experienced engineers and engineering professors who work on biogas projects can provide guidance to assist with financial projections for codigestion/cogeneration projects. The bench-scale evaluation should include a detailed work plan for waste collection and characterization, batch studies for HSW codigestion performance, and digester operation simulations for the plant's sludges, as well as waste combinations to simulate synergistic effects.

Bench-scale study objectives include:

- Identify waste sources for further study for potential use in codigestion.
- Collect and characterize wastes: pH, total solids (TS), VS, COD, volatile fatty acids (VFA), N (nitrogen) species, etc.
- Perform ultimate digestibility tests to quantify potential methane production and biological inhibition.
- Digestibility tests can include several combinations of HSW, with blended primary and secondary sludges, to better understand synergistic effects.

Dr. Spyros Pavlostathis, with the school of civil and environmental engineering at the Georgia Institute of Technology, conducted a recent evaluation for the City of Atlanta that analyzed seven wastes selected from the metropolitan Atlanta area for potential use as substrates for codigestion. Of those seven wastes, three were selected for additional evaluation utilizing a bench-scale study with digester sludge from one of the city's facilities. The study selected the wastes for further analysis based, in part, on the following:

- Total gas production (methane and carbon dioxide)
- COD and VSR
- COD CH_4 / $COD_{initial}$ (g/g) - methane production (COD equivalent) for each gram of COD substrate
- Extent of waste digestion or degradation of waste components, i.e., high degradation suggests minimal inhibition

The three wastes selected (two FOG/food hauling wastes and one syrup from soft drink production) are being analyzed individually and as mixtures for codigestion effectiveness and gas production. The bench-scale study is currently in its final steps and will give the city guidance for the final selection of wastes, as well as projected gas production for a potential codigestion/cogeneration project.

Digester Performance Considerations

Several design and operational components must be considered prior to implementing a codigestion/cogeneration project. The main objective of the anaerobic digestion process is treating biosolids using an adequate solids retention time (SRT) to reduce pathogens and destroy VS. If there is sufficient process volume available for digestion, any excess volume may be used to accommodate the codigestion of

Table 1. Substrate Versus Biomass Yield and Gas Composition

Waste Component	Molecular Formula	Th-COD ($g-O_2/g$)	Biomass Yield (g-VSS/g-COD consumed)	Gas Composition	
				CH_4%	CO_2%
Fat (Fatty Acids)	$C_{16}H_{32}O_2$	2.875	0.030	72	28
Municipal Sludge	$C_{10}H_{19}O_3N$	1.990	0.054	70	30
Proteins	$C_{16}H_{24}O_5N_4$	1.500	0.040	69	31
Carbohydrates (Sugars)	$C_6H_{12}O_6$	1.067	0.138	48	52

(Source: from Anaerobic Codigestion of Municipal Sludge and High-Strength Waste, A Path to Net Bioenergy Production. Spyros G. Pavlostathis, Georgia Institute of Technology; 2015)

FOG and/or other HSWs; however, operators must be careful not to overload the digestion process with high concentrations of COD and VS from HSW sources. The literature reports criteria for digester organic loadings (VS) ranging between 0.1 and 0.3 lbs-VS/ft^3/day. While this recommended loading criteria has been validated, research has shown that loading rates exceeding this have been implemented successfully for codigestion, and additional studies are being completed.

It has been shown in some cases that a variety of wastes and feed sources can stabilize the microbial populations within the digesters for relatively large organic loadings. The organic loading rate of the wastes can be evaluated during bench-scale testing to determine the upper limits that a particular digestion process can accommodate from individual wastes or mixtures of wastes. Of course, full-scale testing will verify bench-scale results to help fine-tune process operations and digester performance.

Other digestion process considerations include variations of mesophilic/thermophilic and acid-phase digestion, and total gas production provided by these processes. Several physical, thermal, and chemical process technologies are also available that enhance biogas production by pretreating solids prior to digestion, such as lysis, hydrolysis, pulsed electric field, etc. These technologies have been utilized successfully, but their implementation value must compare the additional capital and O&M investment required versus increased biogas/energy production and solids reduction.

Cogeneration Considerations

Biogas is predominantly methane (CH_4) produced as a byproduct of the anaerobic digestion process. The biogas can be used to produce heat and electricity, or as a renewable supply gas for natural gas offset. Anticipated biogas production is dependent on several factors, including projected solids quantities, projected FOG and HSW quality and quantity, and industry standard calculations for biogas production. Prior to the utilization of the biogas, the quality of the gas must be determined through sampling and analysis to determine the level of gas treatment required for a specific use. Table 2 indicates the generally expected quality of the biogas, including lower heating value and contaminants.

While other constituents represent only a small fraction of the biogas makeup, various levels of treatment must be provided, depending on the gas usage and equipment, such as boilers, dryers, and engines. At a minimum, the biogas will need moisture removal and some compression prior to utilization in a cogeneration system. If hydrogen sulfide (H2S) or siloxane content is at higher concentrations than the cogeneration system engine manufacturer recommends for its systems, then additional gas cleaning processes will need to be included to protect these assets.

Prior to incorporating a cogeneration system, design and operational considerations should include:

- Digester gas production and quality of biogas. How much biogas is available and how much additional gas can be produced with codigestion?
- Electrical, and industrial and commercial, infrastructure requirements for connected loads to proposed generator equipment.
- Present worth of electrical power and heat offsets compared to capital and O&M costs of a proposed codigestion/cogeneration project.
- Cogeneration engine-type selection comparing efficiencies (electrical and thermal), equipment costs, O&M, gas treatment requirements, and turndown capabilities.
- Economical site layout and configuration to ensure access and proximity to existing plant systems (hot water boilers and heating loops, digesters gas systems, electrical, and other infrastructure).
- Emissions and air permitting requirements.

Table 2. Typical Biogas Constituents

Constituents	
Methane (CH_4)	60-65%
Carbon Dioxide (CO_2)	30-35%
Other (Moisture, Hydrogen Sulfide (H_2S), Siloxane, etc.)	~ 5%
Lower Heating Value (Btu/ft^3 Biogas)	500-600

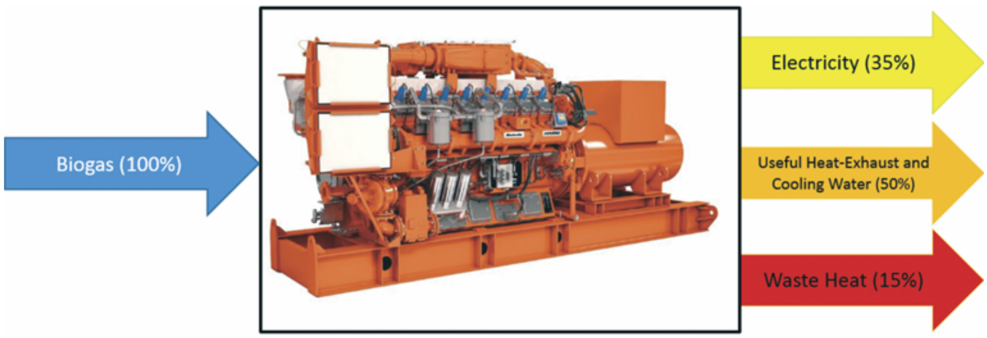

Figure 4. Example Energy Balance Through a Cogeneration System With Approximate Energy Recovery Percentages

Energy Production

Once the quantity of biogas is estimated via bench-scale pilot studies and through the review of previous work and the literature, the amount of electricity and heat that can be recovered and utilized at the facility can be calculated. The engineer should always include realistic downtime of the cogeneration system to accommodate routine maintenance and unscheduled downtime, usually assuming 85 to 90 percent system runtime for a conservative financial evaluation.

Cogeneration system sizes, such as internal combustion (IC) engines, are determined based on their electrical output potential and the biogas available for combustion. The IC engines can range from 32 to 36 percent efficiency or greater, depending on the engine design. As the gas is burned, the engine's exhaust heat can be recovered and used in heating applications, such as digester or building heating. Additional heat can also be recovered via the engine's cooling jacket water.

A general rule of thumb for IC engine sizing includes operating the engine at or near its full capacity to optimize its efficiency. If the engine is sized too large relative to the biogas production, it will need to operate at less than 100 percent power if longer runtimes are desired. Running an engine at a reduced output does not

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take advantage of the engine's best operating efficiency range, which is usually near full power. In addition, engines that are sized too large, without gas storage, must often be turned on and off periodically, which contributes to maintenance of, and wear on, the engine. However, the kilowatt-hour (kWh) production per runtime period is higher for full-power operation (even for intermittent operation) and requires less periodic routine maintenance compared to continuous operation at a lower output capacity. This is due to the routine maintenance costs and overhauls for engines, which are based on hours of runtime. For example, if an engine is operated constantly at a reduced power, the maintenance cost is higher because the engine will need routine maintenance more often (more hours of runtime) than an engine that runs at full power, but less hours.

When sizing a cogeneration facility, it is important to work closely with reputable engine manufacturers to understand engine efficiencies, as well as periodic maintenance contracts, which are usually based on hours of runtime. This information will allow the design engineer to provide optimally sized equipment for a longer life cycle and lower maintenance costs. In addition, expansion of the system should be considered to provide for future wastewater flows and/or addition of HSWs. Expansion should also consider future infrastructure, such as new digesters, electrical loads, and emergency power needs.

The electricity that is generated can be interconnected with the facility's power grid and used to reduce purchased electricity from the local utility. Some facilities have decided to include continuous operation of the generator system, supplying the facility with a constant source of electricity. Other facilities have decided to store biogas and only operate their generator system during peak pricing hours when electricity rates are highest. Due to the shorter runtime, a larger engine can be utilized during peak hours if gas storage is available, when rates are sometimes double or triple. If enough HSW is accepted at the facility, and with proper operation of the digestion system as well as efficient operation of the overall facility, electrical cost offsets can be between 40 and 60 percent.

Revenue Potential

A significant capital investment is needed to construct and operate a codigestion and cogeneration facility. The codigestion facility will require HSW storage tanks (heated for FOG material), screening equipment (depending on HSW suppliers), a secondary containment area, and waste grinders, as well as mixing and transfer/feed pumps. The cogeneration facility includes the engine generator, an enclosure for the generator or building, and gas conditioning/cleaning equipment, as well as the electrical interconnection switchgear and heat recovery systems. Even with the associated capital and O&M costs, the revenue and offset savings can often have a payback within the lifetime of the project and produce a savings for the municipality. Of course, savings will depend on the local costs for power and natural gas. Nonquantifiable benefits for these systems include resiliency for the facility in the form of power production capability, and sustainability via reduction in greenhouse gases and energy recovery.

There are three potential sources of savings and revenue that can be realized through codigestion and cogeneration:

- The *electrical power* produced by the cogeneration system corresponds to direct savings through the offset of electricity purchases from the local utility. The higher the price of electricity in the area, the higher the potential is to payback the initial capital investment and start yielding savings.
- The *natural gas offset* for digester heating via the cogeneration system's waste heat recovery. The engine's exhaust heat and cooling water can be used in lieu of, or can supplement, a gas-fired boiler system. Unlike electricity, the actual savings from the offset of natural gas usage is dependent on the facility's heating requirements, which can fluctuate widely. During warmer months, significantly less natural gas is required to heat the boilers than during winter months.
- In addition to energy-related cost savings, the opportunity to collect *revenue from HSW tipping fees* can also assist in offsetting life cycle system costs, and provide an annual revenue stream for the codigestion and cogeneration facility. Hauled waste tipping fees can be charged by weight or by volume to dispose of waste materials at landfills and comparable disposal sites. Throughout the U.S., codigestion facilities vary in their tipping fee charging practices. Although tipping fees across the country typically range from $0.03 to $0.12 per gal for HSWs, values towards the lower end of the range are most realistic for system start-up or facilities in competitive waste disposal environments. As an example, the City of Fort Worth initially chose not to charge tipping fees at its HSW receiving station in order to attract large quantities of the best available waste.

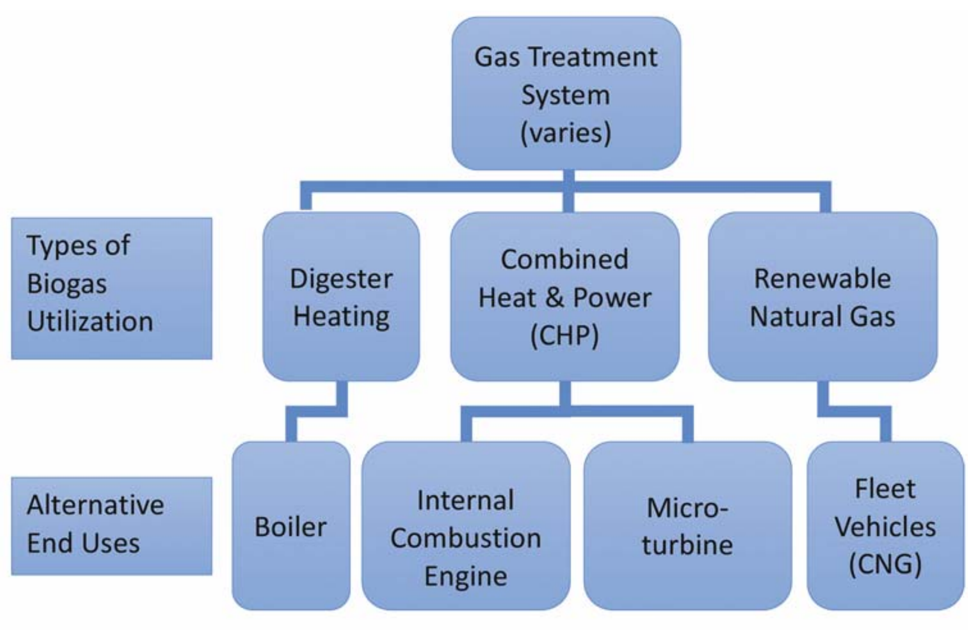

Figure 5. Biogas Utilization Alternatives and Uses

Biogas Utilization

For a facility that generates biogas and is looking at codigestion and/or cogeneration, a biogas utilization study is recommended to understand how much gas can be produced, and also how that biogas will be best utilized. To ensure that the biogas is utilized in the most beneficial way, an evaluation should consider the following:

- Gas production quantities, both current and projected
- Biogas characterization analyses (more than just one sample or "snapshot") to understand the true extent of gas treatment needed
- Biogas quality changes due to the addition of outside waste sources (codigestion)
- Various options for gas usage (engines, boilers, building heat, compressed natural gas)
- Triple-bottom-line evaluation (don't forget that there are social and environmental benefits to be considered)
- Biogas storage for flexibility of operation
- Appropriate process and thermodynamic efficiencies for energy/heat production and recovery, e.g., from biogas to power and heat (especially though heat exchanger equipment)

Success Stories

East Bay Municipal Utility District - Oakland, Calif.

The East Bay Municipal Utility District (EBMUD) main wastewater treatment plant (WWTP) in Oakland, Calif., is a 55-mil-gal-per-day (mgd) facility that treats wastewater from seven cities. The City of Oakland has established a zero-waste goal to implement 100 percent recycling of municipal solid waste (MSW), of which 11.9 percent is food waste. The EBMUD partnered with local haulers in 2004 to collect pretreated post-consumer food waste to add to the facility's digesters. A bench-scale pilot study was conducted to evaluate the anaerobic digestibility of the "cleaned" food waste product from EBMUD's food waste recycling facility.

Collected food waste is preprocessed by the hauler using screens, magnets for removal of metals, and a hammer mill to remove contaminants and reduce the size of the nonhomogeneous waste components. This process is similar to typical pretreatment for composting operations and other recycling efforts. The food waste is then delivered and diluted in an underground slurry tank prior to undergoing additional processing at the WWTP's food waste recycling facility, where staff developed a patented method to isolate the desirable uncontaminated food waste pulp.

At full scale, the food waste recycling facility accepts up to 40 tons of food waste per day (two truckloads) and can process flows up to 250 gal per minute (gpm). Bench-scale analysis determined that the processed pulp has a COD between 85,000 and 222,000 mg/L. Volatile solids destruction (VSD) for the pulp is approximately 80 percent, versus 50 to 60 percent for the wastewater solids. Results indicate that the normalized energy benefit per dry ton of food waste applied is 730–1,300 kWh, compared to 560–940 kWh per dry ton of municipal wastewater solids.

In 2010, cogeneration (36,900 megawatt-hours [MWh] produced) met 90 percent of the facility's electricity needs and saved approximately $3 million in electricity costs. After adding a new turbine in 2012, EBMUD became a net electricity producer utilizing cogeneration, in addition to solar and hydropower installations. The U.S. Environmental Protection Agency (EPA) provided funding for the bench-scale food waste evaluation.

Village Creek Water Reclamation Facility - City of Fort Worth

The Village Creek Water Reclamation Facility (WRF) is a 166-mgd facility in Arlington, Texas. The facility operates 14 mesophilic anaerobic digesters and installed two 5-megawatt generator sets in 2001 to facilitate cogeneration implementation. A duct burner and heat recovery steam generator were also installed; however, the biogas production from the WRF's digesters (including additional gas piped from the City of Arlington landfill) was initially insufficient to meet the demands of the energy recovery equipment.

A mass balance around the digester system was used to determine that codigestion could be implemented in six of the facility's 1.25-mil-gal (MG) digesters to provide sufficient energy to supply the generators with enough fuel for efficient operation.

The HSW producers in the City of Fort Worth requested an alternate method of disposal for their waste streams. Initially, interested industries were looking to dispose of waste batter from a corn dog plant, glycerin from a biodiesel production plant, dissolved air flotation skimmings, expired soda, and many other production wastes. The city decided to select a few, high-volume providers, rather than a wide variety of sources, to ensure simplicity and consistency in the waste stream. The first truckloads received were from Liquid Environmental Solutions (grease trap waste; COD between 100,000–150,000 mg/L), followed by South Waste (grease processing), DELEK biodiesel residuals, and Coca-Cola bottling recycle streams. The city also chose to divert scum from the WRF's natural-gas-fired grease incinerator for use as a codigestion substrate. Additional waste sources were recruited through the city's pretreatment program and more have approached the city on their own due to the program's well-known benefits.

The WRF only accepts wastes with a sufficiently low viscosity to allow for the use of centrifugal chopper pumps. The facility also only accepts wastes that do not require pH adjustment or chemical additions. As a result of sanitization chemicals that are often present in food processing wastes (notably, quaternary ammonium salts), separate batch tanks were installed as part of the receiving station to allow for isolation and/or dilution of potentially toxic wastes.

Received HSW COD concentrations range from 85,000–200,000 mg/L. Peak-month delivery to date is 185 loads and the approximate flow rate percentage of HSW entering digesters 9 through 14 is 3 percent. Between January and September of 2013, biogas production in these six digesters was 98 percent greater than the conventional digesters, contributing to an overall increase in biogas production of 30 percent for the WRF.

One issue encountered with system implementation involved spreading weekday deliveries evenly over the seven-day week. Another issue involved the high delivery temperature (130°F) of grease-processing waste, which initially damaged the HSW flow meter lining and caused deflection in the polyvinyl chloride piping. The quality (temperature, toxicity, strength, etc.), as well as the delivery schedules of the wastes, must be considered when vetting the HSW providers.

Conclusion

Codigestion and cogeneration projects may not be the best fit for all municipalities; however, energy costs will eventually rise, and with a greater emphasis on sustainability and resiliency, energy recovery projects will continue to become more prevalent. In addition, as technologies for engines and biogas treatment systems continue to advance, related equipment will become more efficient and less maintenance-intensive. For any energy recovery project, a thorough business-case evaluation will need to consider several items as noted, including triple-bottom-line concepts to make sure that the investment is sound from several perspectives: financial, social, and environmental. When evaluating HSWs for potential use in a codigestion process, well-planned and well-executed laboratory work and bench-scale studies are essential for identifying the value of available wastes. If implemented properly, an energy recovery project can be a cost-effective approach to offsetting energy costs or begin the path to energy net neutrality, while allowing all stakeholders to realize the benefits.