Energy Reduction in Wastewater Treatment Plants

Irene Okioga, University of North Carolina at Charlotte, USA
Yesim Sireli, University of North Carolina at Charlotte, USA
Tiffany Storms, University of North Carolina at Charlotte, USA

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Abstract
For wastewater treatment plants (WWTPs) that incorporate anaerobic digestion, which one significant way of capturing this energy is through combined heat and power (CHP). This study, first, compiles wastewater CHP data from available online databases and other available online sources in order to obtain a database that is complete and concise for analysis. Then, it verifies the accuracy of data presented by EPA CHPP and compare methodology for obtaining CHP potential in WWTPs against actual values. And, finally, it develops a reference for WWTPs to use for selecting energy targets for CHP systems.

Keywords: Wastewater treatment, combined heat and power, energy reduction.

Introduction

According to the Water and Environment Research Federation (WERF, August 2011) wastewater and biosolids have 10 times as much stored energy as that which is needed for treatment. For wastewater treatment plants (WWTPs) that incorporate anaerobic digestion, which is the biological breakdown of organic matter in the absence of oxygen, one significant way of capturing this energy is through combined heat and power (CHP). CHP, also known as cogeneration, is a form of distribution generation (DG) which involves the process of simultaneously generating heat and electricity from a unit fuel source such as biogas, natural gas or fuel oil. In WWTPs, biogas, which primarily contains a mixture of approximately 40% carbon dioxide and 60% methane, is produced as a byproduct of anaerobic digestion. Biogas can be combusted to provide heat, electricity or both when used directly in engines for combined heat and power. This fuel can also be cleaned to be used in the same way as natural gas or further compressed and processed into compressed natural gas (CNG) for use as vehicle fuel. WWTPs that utilize anaerobic digestion can therefore be considered as potential generators of renewable energy. Since the anaerobic digestion process takes place continuously during the wastewater treatment process, biogas is also produced continuously, allowing for constant electricity and heat production.

According to Brown and Caldwell (2010), use of biogas alone from anaerobic digestion in WWTPs can offset up to 40% brown energy consumption through the production of CHP, which, according to WERF (2012), is the most common application of biogas in WWTPs. The energy potential can further be increased by the addition of nonhazardous high-strength wastes (HSW), such as fats, oil, and grease (FOG). However, despite the opportunity WWTPs have of producing renewable energy through CHP systems, according to the Environmental Protection Agency Combined Heat and Power Partnership (EPA CHPP, 2011), more that 20% of the WWTPs with anaerobic digestion in the United States do not utilize CHP. One factor that has slowed the growth of CHP in the wastewater industry is lack of a strong baseline data of biogas generation in WWTPs and a lack of guidance for setting energy targets based on biogas production. In 2012, WERF and the New York State Energy Research and Development Authority (NYSERDA) published a report based on a survey study they undertook in 2011 with more than 200 respondents, to determine the barriers WWTPs face in implementing CHP Systems and indentify ways to overcome these barriers. In line with the recommendations from the survey study, which includes efforts to fill the information gaps that exist, this study attempts to compile, summarize and simplify data that quantifies CHP energy potentials and installations at WWTPs in the USA, in order to facilitate selecting achievable CHP energy goals and targets.

This study recognizes that there are other studies that have had similar goals and therefore builds on those related studies. In 2007, EPA CHPP published a guide entitled "Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities", which was later update in 2011. In addition to providing information for assessing energy potential for CHP at WWTFs that have anaerobic digesters, the guide also provides basic WWTP CHP data and such as the number of WWTP utilizing digester gas for CHP in the USA, the total CHP electrical capacity by state and potential CHP capacities. However, according to the North East

Biosolids and Residuals Association (NEBRA, 2012), "industry experts" have found that the data included in the report is both incomplete and with error. In July 2011, the Water Environment Federation (WEF) sought ways to improve the data available to WWTPs through initiating and funding The National WWTP Biogas Data Project, "Preparation of Baseline of the Current and Potential Use of Biogas from Anaerobic Digestion at Wastewater Plants". The project was awarded to a team comprising of InSinkErator, NEBRA and Black & Veatch. Data captured in this phase includes: facility name, location and contact information wastewater flows; type of digestion and CHP technology used, application of biogas generated, indication if outside waste is fed to digester; whether electricity is generated and if is fed to the grid. The database is currently available online through the biogasdata.org website. Though the database currently does not have information such as the biogas production at each plant, CHP capacities and estimated energy production that WWTPs planning for CHP systems may deem useful, it is anticipated that such information will be provided in the second phase of the project. In order to obtain CHP capacities that are currently not included in biogasdata.org, the study used an online database maintained by ICF international for the data compilation - www.eea-inc.com/chpdata/index.html. In addition to listing CHP capacities at various industries in the USA including WWTPs, the ICF international database also indicates the CHP prime mover (type) and the fuel type as not all the industries included in the database use biogas.

The objectives of this study can be summarized as follows:

1. To compile wastewater CHP data from available online databases and other available online sources in order to obtain a database that is complete and concise for analysis.
2. Verify the accuracy of data presented by EPA CHPP and compare methodology for obtaining CHP potential in WWTPs against actual values.
3. Develop a simplified reference for WWTPs to use for selecting energy targets for CHP systems.

Methodology

The US EPA Combined Heat and Power Partnership (CHPP, 2011) estimates that approximately 26 kilowatts (kW) of electricity and 2.4 million British Thermal Units (MMBtu) of thermal energy can be produced for every 1 million gallons per day (mgd) of wastewater treated. The electric production and thermal energy (heat) recovery was estimated by the CHPP based on modeling the fuel produced and needed by a typically sized digester (20 ft. deep and 40 to 60 feet in diameter), operating under mesophilic temperatures (temperatures between 95°F and 100°F), and with a loading rate of 9.1 mgd.

Though there are various types of CHP prime movers, the CHPP report only considered those most commonly used at WWTPs, namely: microturbines, reciprocating engines (rich burn and lean burn) and fuel cells as indicated in Table 1. Gas turbines, steam turbines, and combined cycle systems are mostly used for wastewater flows greater than 100 mgd (Spellman, 2013). The Electric Production and Heat Recovery per mgd were obtained using the average values of the mentioned most commonly used prime movers in WWTPs. The Electric Production (Btu/day) may be calculated by multiplying Electric Efficiency with the Energy Potential of biogas (Btu/day).

The Energy Potential of biogas may be obtained using the formula below:

$EP = (HHV)VBiogas$ *(Equation 1)*

Where
EP = Energy Potential (Btu/day)
HHV = Higher Heating Value
VBiogas = Volume of Biogas

Heat Recovery (Btu/day) can be obtained by dividing the Electric Production (Btu/day) by the Power to Heat Ratio of the respective prime mover. The electric efficiency data and power to heat ratios shown in Table 1 were obtained from manufacturers' data.

Additional heat for nondigester heating uses such as space heating and hot water available from CHP systems can be calculated as the difference between Heat Recovery and Digester Heat Load (Btu/day).

The Digester Heat Load can be obtained by summing the Heat Requirement for digesting sludge and that lost through wall, floor and roof heat transfer.
Heat Requirement values can be approximated using the formula below:

$Q_1 = W_f C_p (T_2 - T_1)$ *(Equation 2)*

Where
Q_1 *= Digester heat requirement (British Thermal Units/day or Btu/d)*
W_f *= Volatile Organic feed load removed (Pounds per day or lb/d)*
C_p *= Specific Heat of Sludge (Btu/lb/ºF)*
T_2 *= Reactor Temperature (ºF)*
T_1 *= Temperature of sludge entering digester (ºF)*

Heat loss may be approximated using the formula below:

$Q_2 = UA(T_2 - T_1)$ *(Equation 3)*

Where
Q_2 *= Heat Loss (Btu/d)*
U = Heat-transfer coefficient (Btu/hr.ft2.ºF)
A = Surface area of digester over through which heat loss occurs (ft2)
T_2 *= Reactor Temperature (ºF)*
T_1 *= Surrounding Temperature (ºF)*

Based on the relationship between wastewater flow and potential electricity from CHP systems, it is apparent that the higher the plant flow, the greater the electricity potential. According to CHHP (2011), the greatest 'economic potential', defined as one having a payback period less than or equal to 7 years, are realized for larger plants with flows equal to or higher than 30 mgd.

Further, a study conducted by the Electric Power Research Institute (EPRI, 2012), shows that the electricity intensity (kilowatt hour per million gallon – kWh/mg) for larger WWTPs remains fairly constant as can be seen in Figure 1, indicating that further benefits, in terms of percentage savings from CHP systems, can be realized by larger plants. Nevertheless, smaller plants can boost their biogas production, by adding nonhazardous high-strength wastes (HSW), such as fats, oil, and grease (FOG), or where feasible, incorporating thermophilic digestion systems in the treatment process.

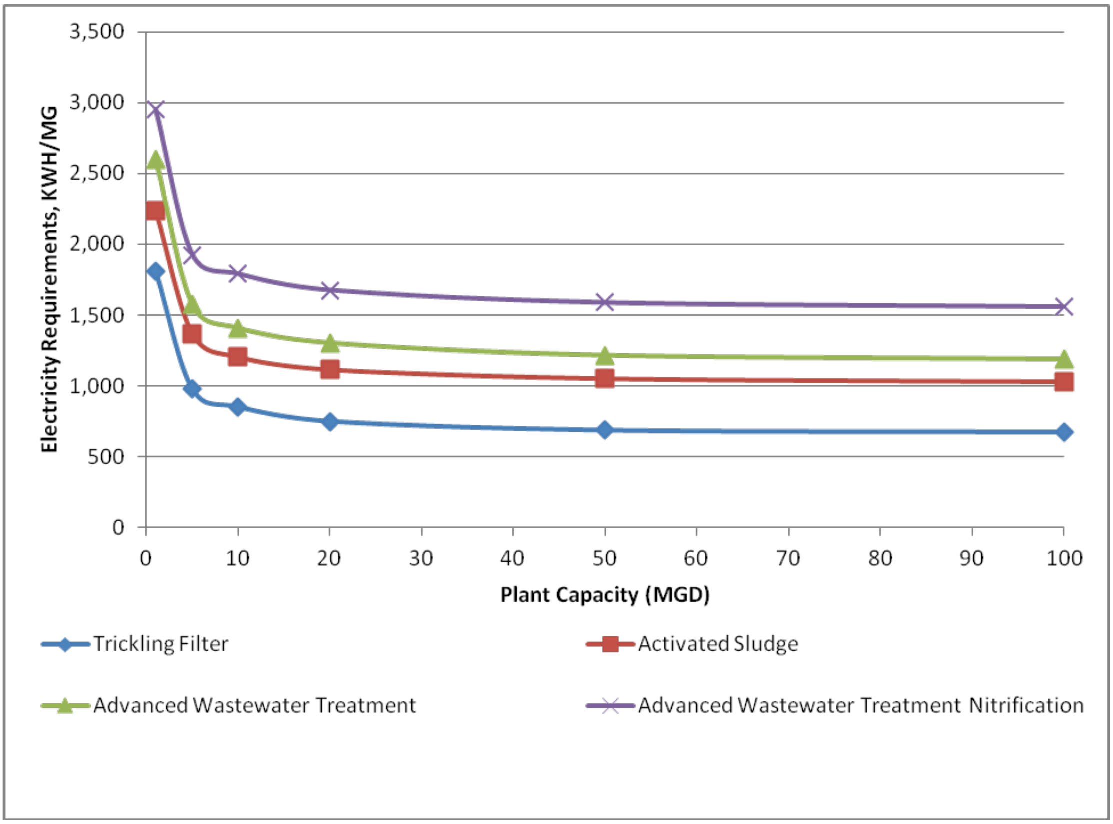

Figure 1: Electricity Demand for Wastewater Treatment by Size of Plant and Treatment Type – Plants.Source: EPIC (2012)

Energy Reduction Goals and Target Setting for CHP from Individual WWTP Case Studies

WWTPs may have several energy related goals and performance indicators which may include, but are not limited to, reduction in brown energy consumption and increase in renewable energy sources, reduction in energy cost, reduction of peak load demand, and reduction in greenhouse gas emission in treatment processes as well as in utility vehicle use.

Recognized as a leader in energy efficiency in the wastewater Sector, the Sheboygan WWTP implemented a 300 Kilowatt (kW) capacity Combined Heat and Power (CHP) system and is an example of a facility that implemented CHP to reduce energy consumption, with the ultimate goal of becoming a net-zero or energy neutral facility. The plant, which has a treatment capacity of about 18 million gallons per day (mgd), is currently able to achieve between 70% and 90% energy sufficiency from its CHP system, resulting in an annual savings of approximately $78,000 from the electricity generated and approximately $60,000 based on heat generated (ACEE, 2011).

The Gloversville Johnstown Joint WWTP in New York is an example of a facility that highly benefited from energy cost savings due to installation of CHP systems. The plant was expanded in 1992 to 13 MGD in order to treat both domestic wastewater (30%) and industrial wastewater (70%) from fishing and leather and tanning industries in the cities of Gloversville and Johnstown. Through the early 2000s, after the leather and tanning industries within the service areas closed down, the Gloversville Johnstown Joint WWTP experienced a reduction in revenue and excess capacity at the facility. The implementation of a CHP system made it possible for the facility to reduce operating costs and control their financial situation. The current location of the WWTP and its proximity to dairy processing facilities further enabled the facility to incorporate dairy waste into its processing stream thus generating more biogas and energy, as well as utilizing the unused treatment capacity. The WWTP is able to produce between 90% and 95% of the electricity required to operate the facility though a 700 kW capacity CHP system (Cogeneration and On-site Power Production, 2011).

The Des Moines Wastewater Reclamation Authority is an example of a facility that implemented CHP in order to reduce electrical peak demand load (peak shaving).
In addition to minimizing the amount of natural gas used for process heat by over 100% and electricity usage by more than 40%, the Delhi Charter Township WWTP, Michigan was also upgraded to include CHP systems in order to reduce fuel associated with transporting biosolids, based on the reduced digest rate volume.
There are numerous case studies in literature that focus on selecting achievable energy goals for water and wastewater treatment facilities.

According to US EPA (2008), even though various case studies exist as pointed out above, there are no standard energy objectives and targets that can be directly selected to suit individual plants that plan to implement energy improvement programs. This study compiled and analyzed actual CHP data that can be used in lieu of individual case studies for selecting achievable CHP energy goals and targets. The actual data analyzed was compared to calculated electrical potentials obtained by methodology developed by the U.S. Environmental Protection Agency Combined Heat and Power Partnership (October 2011).

A list of wastewater treatments plants in the USA that utilize biogas was developed from an online database, http://www.biogasdata.org . The database was created through a collaborative effort by InSinkErator, NEBRA, and Black & Veatch with funding from Water Environment Federation (WEF), and contains wastewater treatment plants within the U.S.A that operate anaerobic digestion systems as of 2013. The information that was obtained from this database included the type of anaerobic digestion prime mover, average plant flow and plant capacity. WWTPs that do not produce electricity from the biogas (no CHP systems) were eliminated. A second online database, developed by ICF International (former Energy and Environmental Analysis, Inc.), and accessible from http://www.eea-inc.com/chpdata/ was used to obtain the CHP capacity of the wastewater treatment plants considered.

The WWTPs were then categorized according to flows ranging from 1 to 5 mgd, 5 to 10mgd, 10 to 20 mgd, 20 to 50 mgd and 50 to 100 mgd and the actual CHP electrical capacities evaluated to identify outliers in each range. The outliers were eliminated using standardized z-scores, calculated using the category averages and standard deviations. This methodology assumes that the data is somewhat normally distributed. For each range, a value was considered an outlier if its standard z-score was greater than ±2.5.

The 95% confidence range of electrical capacities were then calculated using the remaining data to obtain corresponding electrical capacities for each range. Electrical capacities based on actual data as well as those approximated using a factor of 26 KW per mgd of average plant flow, were plotted on the same graph for a visual comparison (Figure 2). Where average flow data was not available, the plant flow capacities were used to estimate electrical capacities for comparison with actual values. Error bars were used to represent the 95% confidence interval selected for the analysis. The error bars in Figure 2 represent the difference between the average values in each range and the upper or lower limits.

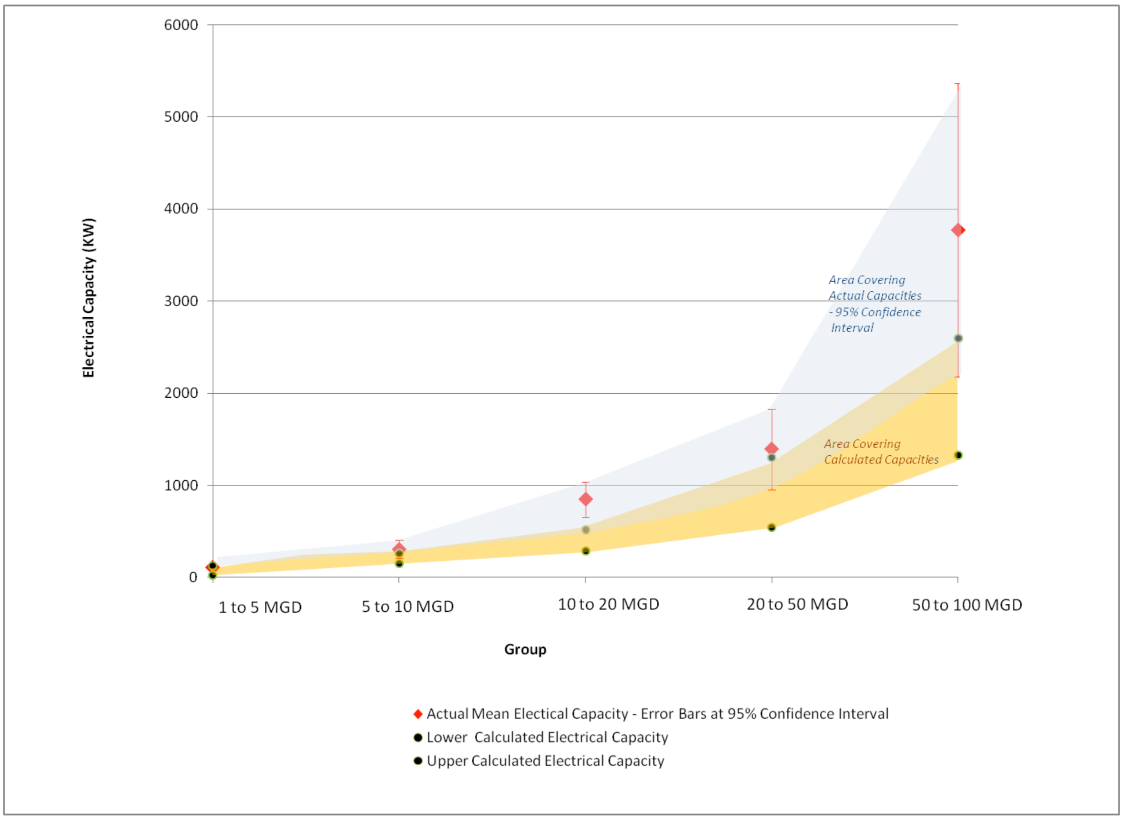

Figure 2: Wastewater Flow against Actual and Calculated Electrical Capacities

Conclusions

As can be seen in Figure 2, for flows ranging between 1 to 10 mgd, calculated electrical potentials are comparable to the actual capacities based on a 95% confidence interval. The methodology developed by CHPP (2012) for approximating electrical potential is therefore applicable for such flows. However, as the flows increases, actual calculated capacities deviate more from the calculated values.

Though the CHPP methodology is still a good tool for conservative targets of electrical potential based on plant flow, the analysis on actual data shows that electrical capacities that have been achieved from CHP systems nearly double the calculated values. The deviation seen for higher flows may be due to the fact that the model used to approximate electrical capacity was carried out by CHHP (2011) using a flow of 9.1 MGD and flows in this order result in electrical capacity closer to the calculated estimate more than the higher flows match up. It is therefore recommended that further studies be carried out to establish the relationship between flow and CHP electrical potentials for larger flows. In setting energy targets for new CHP system installations, it is recommended that decision makers use the CHPP methodology for conservative goal setting, but also consider the achievable potentials based on actual systems as presented in this study.

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