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"Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field"

U.S. Environmental Protection Agency Combined Heat and Power Partnership

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Opportunities for Combined Heat and Power at Wastewater Treatment Facilities:

Market Analysis and Lessons from the Field

U.S. Environmental Protection Agency
Combined Heat and Power Partnership

October 2011

The U.S. Environmental Protection Agency (EPA) CHP Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. CHP is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. CHP can increase operational efficiency and decrease energy costs while reducing the emissions of greenhouse gases. The CHP Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new CHP projects and promote their energy, environmental, and economic benefits.

The CHP Partnership provides resources about CHP technologies, incentives, emission profiles, and other information on its website at www.epa.gov/chp. For more information, contact the CHP Partnership Helpline at chp@epa.gov or (703) 373-8108.

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EXECUTIVE SUMMARY

Purpose of Report

This report presents the opportunities for combined heat and power (CHP) applications in the municipal wastewater treatment sector, and it documents the experiences of wastewater treatment facility (WWTF) operators who have employed CHP. It is intended to be used by CHP project developers; WWTF operators; state and local government policymakers; and other parties interested in exploring the opportunities, benefits, and challenges of CHP at WWTFs.

Key Findings

- CHP is a reliable, cost-effective option for WWTFs that have, or are planning to install, anaerobic digesters.

  The biogas flow from the digester can be used as fuel to generate electricity and heat in a CHP system using a variety of prime movers, such as reciprocating engines, microturbines, or fuel cells. The thermal energy produced by the CHP system is then typically used to meet digester heat loads and for space heating. A well-designed CHP system using biogas offers many benefits for WWTFs because it:

  — Produces power at a cost below retail electricity.
  — Displaces purchased fuels for thermal needs.
  — May qualify as a renewable fuel source under state renewable portfolio standards and utility green power programs.
  — Enhances power reliability for the plant.
  — Produces more useful energy than if the WWTF were to use biogas solely to meet digester heat loads.
  — Reduces emissions of greenhouse gases and other air pollutants, primarily by displacing utility grid power.

- While many WWTFs have implemented CHP, the potential still exists to use more CHP based on technical and economic benefits.

  As of June 2011, CHP systems using biogas were in place at 104 WWTFs, representing 190 megawatts (MW) of capacity. CHP is technically feasible at 1,351 additional sites and economically attractive (i.e., payback of seven years or less) at between 257 and 662 of those sites.[1]

- The CHP technical potential is based on the following engineering rules of thumb:

  — A typical WWTF processes 100 gallons per day of wastewater for every person served[2], and approximately 1.0 cubic foot (ft^3) of digester gas can be produced by an anaerobic digester per person per day.[3]

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[1] A range is presented due to uncertainties in the data available for WWTFs, making it difficult to support a single, national economic potential.

[2] Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Managers, "Recommended Standards for Wastewater Facilities (Ten-State Standards)," 2004.

[3] Metcalf & Eddy, "Wastewater Engineering: Treatment and Reuse, 4th Edition," 2003.

— The composition of anaerobic digester gas from WWTFs is usually 60 to 70 percent methane with the remainder primarily carbon dioxide (CO_2). The lower heating value (LHV) of digester gas ranges from 550 to 650 British thermal units (Btu)/ft^3, and the higher heating value (HHV) ranges from 610 to 715 Btu/ft^3, or about 10 percent greater than the LHV.[4]

- Each million gallons per day (MGD) of wastewater flow can produce enough biogas in an anaerobic digester to produce 26 kilowatts (kW) of electric capacity and 2.4 million Btu per day (MMBtu/day) of thermal energy in a CHP system.

- The cost to generate electricity using CHP at WWTFs ranges from 1.1 to 8.3 cents per kilowatt-hour (kWh) depending on the CHP prime mover and other factors.

  Current retail electric rates range from 3.9 to over 21 cents per kWh, so CHP can have clear economic benefits for WWTFs.

- On a national scale, the technical potential for additional CHP at WWTFs is over 400 MW of biogas-based electricity generating capacity and approximately 38,000 MMBtu/day of thermal energy.

  This capacity could prevent approximately 3 million metric tons of carbon dioxide emissions annually, equivalent to the emissions of approximately 596,000 passenger vehicles.

- Also on a national scale, the economic potential ranges from 178 to 260 MW. This represents 43 to 63 percent of the technical potential.[5] The vast majority of economic potential comes from large (>30 MGD) WWTFs that can support larger CHP units.

- Translating CHP potential into actual successes requires an understanding of operational realities. This report includes interviews of 14 owners/operators of CHP systems at WWTFs across the country. Key operational observations from these interviews are included in Section 5.

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[4] Metcalf & Eddy, "Wastewater Engineering: Treatment and Reuse, 4th Edition," 2003. A fuel's LHV does not include the heat of the water of vaporization.

[5] A range is presented due to uncertainties in the data available for WWTFs, making it difficult to support a single, national economic potential. Economic potential is defined as a payback period of seven years or less.

1.0 Introduction

In April 2007, the U.S. Environmental Protection Agency's (EPA's) Combined Heat and Power Partnership (CHPP) released its first report identifying the opportunities for and benefits of combined heat and power (CHP) at wastewater treatment facilities (WWTFs).[6] The primary purpose of the 2007 report was to provide basic information for assessing the potential technical fit for CHP at certain WWTFs—specifically, those with influent flow rates greater than 5 million gallons per day (MGD) that have anaerobic digesters. The 2007 report showed that these larger facilities produce enough biogas from anaerobic digestion, based on typical practices, to fuel a CHP system. The report also provided basic information on the cost to generate power and heat at WWTFs with CHP.

Since the release of the 2007 report, CHPP Partners and other stakeholders have expressed increased interest in CHP at WWTFs and several additional reports on CHP at WWTFs have been released.[7] This updated report has been prepared in response to the increased interest. The primary purposes of this update (which is intended to replace the 2007 report) are to:

- Expand the evaluation of technical and economic potential for CHP to include smaller WWTFs with influent flow rates of 1 to 5 MGD.
- Present operational observations obtained through interviews with WWTF operators who have employed CHP.

The updated report is intended to be used by CHP project developers; WWTF operators; federal, state, and local government policymakers; and other parties who are interested in exploring the opportunities, benefits, and challenges of CHP at WWTFs. The report is organized accordingly:

- ***Section 2*** provides an overview of CHP and its benefits at WWTFs.
- ***Section 3*** describes the existing CHP capacity at WWTFs and the potential market for additional CHP at WWTFs.
- ***Section 4*** analyzes the technical and economic potential for CHP at WWTFs, presenting analyses of electric and thermal energy generation potential at WWTFs, as well as cost-to-generate estimates under three digester gas utilization cases.
- ***Section 5*** presents first-hand observations gathered through interviews of WWTF operators regarding the benefits and challenges of CHP development and operation.
- ***Appendix A*** lists the data sources and types of data used in the analysis.
- ***Appendix B*** provides anaerobic digester design criteria used in the technical potential analysis.
- ***Appendix C*** presents analysis of the space heating capability of CHP at WWTFs.

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[6] The 2007 report was titled, "The Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities."

[7] Recent reports pertaining to CHP at WWTFs include:

- Brown & Caldwell, "Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities," December 2010. Available at: http://water.epa.gov/scitech/wastetech/publications.cfm.
- Association of State Energy Research & Technology Transfer Institutions, "Strategic CHP Deployment Assistance for Wastewater Treatment Facilities," October 2009. Available at: http://www.asertti.org/wastewater/index.html.
- California Energy Commission, "Combined Heat and Power Potential at California's Wastewater Treatment Plants," September 2009. Available at: http://www.energy.ca.gov/2009publications/CEC-200-2009-014/CEC-200-2009-014-SF.PDF.

- ***Appendix D*** presents the cost to generate by state for CHP at WWTFs under the three digester gas utilization cases presented in the economic potential analysis.
- ***Appendix E*** lists additional resources available from the CHPP and other organizations.

2.0 CHP and Its Benefits at Wastewater Treatment Facilities

CHP is the simultaneous production of electricity and heat from a single fuel source, such as natural gas, biomass, biogas, coal, or oil. CHP is not a single technology, but an energy system that can be modified depending on the needs of the energy end user. CHP systems consist of a number of individual components configured into an integrated whole. These components include the prime mover, generator, heat recovery equipment, and electrical interconnection. The prime mover that drives the overall system typically identifies the CHP system. Prime movers for CHP systems include reciprocating engines, combustion turbines, steam turbines, microturbines, and fuel cells.[8]

CHP plays an important role in meeting U.S. energy needs as well as in reducing the environmental impact of power generation. Regardless of sector or application, CHP benefits include:

- **Efficiency benefits**. CHP requires less fuel than separate heat and power generation to produce a given energy output. CHP also avoids transmission and distribution losses that occur when electricity travels over power lines from central generating units.
- **Reliability benefits**. CHP can provide high-quality electricity and thermal energy to a site regardless of what might occur on the power grid, decreasing the impact of outages and improving power quality for sensitive equipment.
- **Environmental benefits**. Because less fuel is burned to produce each unit of energy output, CHP reduces emissions of greenhouse gases and other air pollutants.
- **Economic benefits**. CHP can save facilities considerable money on their energy bills due to its high efficiency, and it can provide a hedge against unstable energy costs.

CHP has been successfully implemented in many different sectors, including WWTFs. CHP at WWTFs can take several forms, including anaerobic digester gas-fueled CHP; non-biogas fueled CHP (e.g., natural gas); heat recovery from a sludge incinerator that can drive an organic rankine cycle system; and a combined heat and mechanical power system (e.g., an engine-driven pump or blower with heat recovery).

The analysis presented in this report is based on CHP fueled by anaerobic digester gas (biogas), and it focuses on WWTFs that already have, or are planning to install, anaerobic digesters. Biogas produced by anaerobic digesters can be used as fuel in various prime movers—typically reciprocating engines, microturbines, and fuel cells—to generate heat and power in a CHP system. The electric power produced can offset all or most of a WWTF's power demand, and the thermal energy produced by the CHP system can be used to meet digester heat loads and, in some cases, for space heating.

It should be noted that CHP is one of several beneficial uses of biogas generated by WWTF anaerobic digesters, and each WWTF must assess its own site-specific technical, economic, and environmental considerations to determine the best use of its biogas. Other, non-CHP uses of biogas include:

- **Digester gas for heat.** WWTFs can use digester gas in a boiler to provide digester heating and/or provide space heating for buildings on site.

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[8] Information about CHP prime movers, including cost and performance characteristics, can be found in the "Catalog of CHP Technologies." Available at: http://www.epa.gov/chp/basic/catalog.html.

- **Digester gas purification to pipeline quality.** WWTFs can market and sell properly treated and pressurized biogas to the local natural gas utility.
- **Direct biogas sale to industrial user or electric power producer.** WWTFs can treat, deliver, and sell biogas to a local industrial user or power producer where it can be converted to heat and/or power.
- **Biogas to vehicle fuel.** WWTFs can treat and compress biogas on site to produce methane of a quality suitable for use as fleet vehicle fuel.

A well-designed CHP system using biogas offers many benefits for WWTFs because it:

- Produces power at a cost below retail electricity.
- Displaces purchased fuels for thermal needs.
- May qualify as a renewable fuel source under state renewable portfolio standards and utility green power programs.
- Enhances power reliability for the plant.
- Produces more useful energy than if the WWTF were to use biogas solely to meet digester heat loads.
- Reduces emissions of greenhouse gases and other air pollutants, primarily by displacing utility grid power.

The benefits of CHP deployment at WWTFs are in addition to those provided by anaerobic digesters. The typical benefits of anaerobic digesters at WWTFs include enhanced biosolids management; reduced odors; lower fugitive methane emissions; and additional revenue sources such as soil fertilizers that can be produced from digester effluent.

3.0 The Market

This section characterizes the market for CHP at WWTFs. It first presents information about WWTFs that currently utilize CHP, and then discusses the CHP market potential at WWTFs, focusing on WWTFs that do not currently utilize CHP but that have anaerobic digesters.

For economic reasons, WWTFs that already operate anaerobic digesters[9], or those planning to implement anaerobic digestion, present the best opportunity for CHP; therefore, the analysis in this report focuses on WWTFs that have anaerobic digesters. The incorporation of anaerobic digesters into the wastewater treatment process is typically driven by factors other than power and heat generation (e.g., enhanced biosolids management or odor control). However, once in place, anaerobic digesters produce digester gas—or biogas— which is key to CHP feasibility at WWTFs. Biogas is approximately 60 to 70 percent methane, and can be used to fuel a CHP system to produce electricity and useful thermal energy. The electricity generated can offset all or most of a WWTF's electric power demand, and the recovered thermal energy can be used to meet digester heating loads and facility space heating requirements. However, at this time most biogas is used to heat digesters or is flared.[10]

3.1 Wastewater Treatment Facilities with CHP

As of June 2011, wastewater treatment CHP systems were in place at 133 sites in 30 states, representing 437 megawatts (MW) of capacity.[11] Although the majority of facilities with CHP use digester gas as the primary fuel source, some employ CHP using fuels other than digester biogas (e.g., natural gas, fuel oil) because they either do not operate anaerobic digesters (so do not generate biogas), or because biogas is not a viable option due to site-specific technical or economic conditions. Of the 133 WWTFs using CHP, 104 facilities (78 percent), representing 190 MW of capacity, utilize digester gas as the primary fuel source.[12] Table 1 shows the number of sites and capacity (MW) by state that use digester gas as the primary fuel source for CHP.

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[9] Anaerobic digestion is a biological process in which biodegradable organic matter is broken down by bacteria in the absence of oxygen into biogas consisting of methane (CH_4), carbon dioxide (CO_2), and trace amounts of other gases.

[10] Brown and Caldwell,"Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities,"December 2010. Available at: http://water.epa.gov/scitech/wastetech/publications.cfm.

[11] CHP Installation Database, maintained by ICF International with support from the U.S. Department of Energy and Oak Ridge National Laboratory. Available at: http://www.eea-inc.com/chpdata/index.html.

[12] Some WWTFs blend biogas with natural gas if the volume of biogas from the digesters is not sufficient to meet a facility's thermal and/or electric requirements (e.g., in the winter when digester heat loads are higher).

Table 1: Number of Digester Gas Wastewater CHP Systems and Total Capacity by State

State	Number of Sites	Capacity (MW)	State	Number of Sites	Capacity (MW)
AR	1	1.73	MT	3	1.09
AZ	1	0.29	NE	3	5.40
CA	33	62.67	NH	1	0.37
CO	2	7.07	NJ	4	8.72
CT	2	0.95	NY	6	3.01
FL	3	13.50	OH	3	16.29
IA	2	3.40	OR	10	6.42
ID	2	0.45	PA	3	1.99
IL	2	4.58	TX	1	4.20
IN	1	0.13	UT	2	2.65
MA	1	18.00	WA	5	14.18
MD	2	3.33	WI	5	2.02
MI	1	0.06	WY	1	0.03
MN	4	7.19	**Total**	**104**	**189.8**

Source: CHP Installation Database, ICF, June 2011

Table 1 shows that the states with the greatest number of CHP systems utilizing biogas are California (33), Oregon (10), New York (6), Washington (5), Wisconsin (5), Minnesota (4), and New Jersey (4). States with the greatest capacity are California (62.67 MW), Ohio (16.29 MW), Washington (14.18 MW), Florida (13.50 MW), and New Jersey (8.72 MW). These states include eight of the top 15 largest U.S. cities and six of the 15 most populous U.S. states, and therefore, tend to support the largest treatment facilities where CHP is most economically beneficial. Several of these states offer CHP incentives as well and tend to have higher retail electric rates, which can make CHP more attractive economically.

Several types of CHP prime movers can be used to generate electricity and heat at WWTFs.[13] Table 2 shows the CHP prime movers currently used at WWTFs that use digester gas as the primary fuel source.

Table 2: Number of Sites and Capacity (MW) by CHP Prime Movers

Prime Mover	Number of Sites	Capacity (MW)
Reciprocating engine	54	85.8
Microturbine	29	5.2
Fuel cell	13	7.9
Combustion turbine	5	39.9
Steam turbine	1	23.0
Combined cycle	1	28.0
Total	**104**	**189.8**

Source: CHP Installation Database, ICF, June 2011

The most commonly used prime movers at WWTFs are reciprocating engines, microturbines, and fuel cells. The power capacities of these prime movers most closely match the energy content of biogas generated by digesters at typically sized WWTFs. Opportunities for using

[13] Information about CHP prime movers, including cost and performance characteristics, can be found in the "Catalog of CHP Technologies." Available at: http://www.epa.gov/chp/basic/catalog.html.

combustion turbines, steam turbines, and combined cycle systems are typically found in the few very large WWTFs (i.e., greater than 100 MGD).

3.2 Potential CHP Market

To estimate the potential market for CHP at WWTFs, the CHPP used the EPA 2008 Clean Watershed Needs Survey (CWNS) database[14] to identify WWTFs that do not already operate CHP. As the database was configured to provide a comprehensive assessment of capital needs to meet water quality goals established under the Clean Water Act, the primary indicators used for the CHPP's analysis were the number of facilities with anaerobic digestion and the total influent flow rate to those facilities. The database collection process is voluntary and the data vary in level of completeness. Since the CHPP 2007 report was released, there have been other state-specific data sets that have become available. However, the uniform data collection method applied to the CWNS database introduces a consistency in the data collection methodology. It is also at this time the primary comprehensive dataset on municipal wastewater treatment activity at a national scale. These two criteria rendered the data more representative for the CHPP's national analysis.[15]

The CHPP's 2007 report about CHP at WWTFs showed that influent flow rates of 5 MGD or greater were typically required to produce biogas in quantities sufficient for economically feasible CHP systems. One of the CHPP's goals for this 2011 study, however, was to be inclusive of all market opportunities for CHP at WWTFs. Recognizing that CHP systems can and do operate at facilities with influent flow rates less than 5 MGD, this 2011 analysis uses a lower limit of 1 MGD. Some smaller WWTFs (i.e., between 1 and 5 MGD) can produce sufficient biogas through conventional means (if biosolid loadings are high enough), or augment their digestion process to boost the biogas generation rate of the anaerobic digesters (e.g., addition of collected fats, oils, and greases to digesters; use of microbial stimulants).

Table 3 presents the total number of WWTFs in the United States and the number with anaerobic digestion, excluding WWTFs that already utilize CHP. Table 4 shows the wastewater flow to WWTFs with anaerobic digestion, also excluding those that utilize CHP. Table 3 shows that 1,351 WWTFs greater than 1 MGD utilize anaerobic digesters but do not operate CHP systems. The data indicate that systems with larger flow rates are more likely to have anaerobic digesters, and therefore have greater potential for CHP. This finding is corroborated by the data in Table 4, which indicate that for WWTFs greater than 1 MGD that do not employ CHP, approximately 60 percent of wastewater flow goes to facilities with anaerobic digestion.

[14] EPA's Office of Wastewater Management, in partnership with states, territories, and the District of Columbia, conducts the CWNS every four years in response to Sections 205(a) and 516 of the Clean Water Act and develops a Report to Congress. The 2008 CWNS is available at: http://water.epa.gov/scitech/datait/databases/cwns/.

[15] Water Environment Foundation's Project on the "Preparation of Baseline of the Current and Potential Use of Biogas from Anaerobic Digestion at Wastewater Plants" was initiated in August 2011 to create a robust consensus dataset regarding the current and potential production of biogas from anaerobic digestion at Publicly Owned Treatment Works (POTW) in the United States. EPA is serving on the Advisory Panel for this project, but is not responsible for its content.

Table 3: Number of U.S. Wastewater Treatment Facilities with Anaerobic Digestion and without CHP

WWTFs Flow Rate Range (MGD)	Total WWTFs	WWTFs with Anaerobic Digestion	Percentage of WWTFs with Anaerobic Digestion
>200	10	7	70%
100–200	18	13	72%
75–100	25	17	68%
50–75	24	17	71%
20–50	137	82	60%
10–20	244	140	57%
5–10	451	230	51%
1–5	2,262	845	37%
Total	**3,171**	**1,351**	**43%**

Source: CWNS, 2008

Table 4: Wastewater Flow to U.S. Wastewater Treatment Facilities with Anaerobic Digestion and without CHP

WWTFs Flow Rate Range (MGD)	Total Wastewater Flow (MGD)	Wastewater Flow to WWTFs with Anaerobic Digestion (MGD)	Percentage of Flow to WWTFs with Anaerobic Digestion
>200	3,950	3,010	76%
100–200	2,705	2,076	77%
75–100	2,172	1,469	68%
50–75	1,471	1,078	73%
20–50	4,133	2,491	60%
10–20	3,407	1,959	57%
5–10	3,188	1,630	51%
1–5	5,124	2,082	41%
Total	**26,150**	**15,795**	**60%**

Source: CWNS, 2008

4.0 Technical and Economic Potential

This section presents the technical and economic potential for CHP at WWTFs. The analyses focus on WWTFs that operate anaerobic digesters. In the technical potential subsection, this report presents an estimate of CHP electric capacity and thermal generation based on WWTF influent flow. Owners and operators of WWTFs can compare their influent flow to this estimate to approximate the CHP system size that may be possible at their facility. The economic potential subsection presents cost-to-generate estimates for various CHP prime movers under several digester gas utilization cases. Owners and operators of WWTFs can compare these cost-to-generate estimates to current electricity rates to determine whether CHP might make sense at their facility. In addition, the report provides national estimates of both technical and economic potential based on 2008 CWNS data, as well as an estimate for potential carbon dioxide (CO_2) emissions reductions associated with meeting the national technical potential. The technical and economic estimates presented in this section serve as indicators of CHP potential at WWTFs, but every WWTF considering CHP will need to complete its own site-specific technical and economic analysis to assess the viability of CHP.

4.1 Technical Potential for CHP at Wastewater Treatment Facilities

Section 4.1.1 discusses the assumptions and methodology used in the technical potential analysis. Section 4.1.2 presents the relationship between influent flow and electric and thermal generation potential with CHP. Section 4.1.3 presents the national technical potential estimate for CHP at WWTFs. Section 4.1.4 presents the potential carbon dioxide emissions benefits associated with meeting the national technical CHP potential.

4.1.1 Methodology

To determine the electric and thermal energy generation technical potential for CHP at WWTFs, the analysis modeled the fuel produced and heating required by a typically sized digester. The following assumptions were used to develop the model:

- *Digester type.* There are two types of conventional anaerobic digestion processes—mesophilic and thermophilic—and they are distinguished by the temperature at which they operate. Most anaerobic digesters operate at mesophilic temperatures between 95 and 100°F. Thermophilic digesters operate at temperatures between 124 and 138°F. The thermophilic process is usually faster due to the higher operating temperature but is usually more expensive because of higher energy demands.[16] Because most digesters in operation today are mesophilic, the analysis presented here assumes the use of a mesophilic digester.

- *Flow rate.* The digester model used in the analysis has an influent flow rate of 9.1 MGD, which is based on the sludge capacity of a typically sized digester. A wastewater flow rate of 9.1 MGD produces roughly 91,000 standard cubic feet (ft^3) of biogas per day, which has an energy content of 58.9 million British thermal units per day (MMBtu/day).[17]

[16] Metcalf & Eddy, “Wastewater Engineering: Treatment and Reuse, 4th Edition,” 2003.
[17] Biogas generation was calculated based on 100 gallons of wastewater flow per day per capita (Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Managers, “Recommended Standards

- *Season of operation.* The analysis models both summer and winter digester operation.

Appendix B contains the digester design criteria used for the analysis.

The analysis estimates the biogas utilization of the model digester under five possible cases:

- The first case assumes no CHP system, where only the amount of biogas needed for the digester heat load is utilized and the rest is flared.

- The other four cases assume that a CHP system utilizes the captured biogas to produce both electricity and thermal energy. The cases differ based on the CHP prime mover utilized.

The CHP prime movers chosen for analysis are consistent with those currently used at WWTFs (see Table 2 in Section 3.1).[18] The four modeled CHP prime movers include two reciprocating engines (one rich-burn and one lean-burn),[19] a microturbine, and a fuel cell. The analysis uses the performance characteristics (i.e., electric efficiency and power-to-heat ratio) of commercially available equipment, as stated by the manufacturers. To develop estimates of electric and thermal output, the analysis applies CHP prime mover performance characteristics to the produced biogas (58.9 MMBtu/day). Table 5 presents the performance specifications of the CHP prime movers used to develop the technical potential estimate.

Table 5: Prime Mover Performance Specifications for Use in Technical Potential Model

Prime Mover	Size (kW)	Thermal Output (Btu/kWh)	Power to Heat Ratio	Electric Efficiency (%) (HHV)	CHP Efficiency (%) (HHV)
Reciprocating Engine (Rich-Burn)	280	5,520	0.62	29.1	76
Reciprocating Engine (Lean-Burn)	335	3,980	0.86	32.6	71
Microturbine	260 (4 x 65)	3,860	0.88	26.0	56
Fuel Cell	300	2,690	1.26	42.3	76

4.1.2 Electric and Thermal Generation Potential from CHP Systems at Wastewater Treatment Facilities

Table 6 presents the results of the modeled CHP systems. The results represent an average of winter and summer digester operation. The fuel cell CHP system has the highest electric capacity

for Wastewater Facilities (Ten-State Standards),” 2004), and approximately 1.0 cubic foot per day of digester gas per capita (Metcalf & Eddy, “Wastewater Engineering: Treatment and Reuse, 4th Edition,” 2003).

[18] Although the prime mover specifications are taken from typical equipment available in the marketplace, manufacturer names have been removed to avoid implicitly endorsing any manufacturers or products.

[19] Rich-burn engines are characterized by higher fuel-to-air-ratios, whereas lean-burn engines have lower fuel-to-air-ratios. Lean-burn engines have lower exhaust emissions and achieve higher fuel efficiency due to more complete fuel combustion. Most of the engines installed at WWTFs today are rich-burn, but these are gradually being phased out in favor of lean-burn engines with higher efficiencies and lower emissions.

of the modeled systems (304 kilowatts [kW]) due to its high electric efficiency. In many cases, however, the use of fuel cells at WWTFs is limited because of their high cost and challenges associated with pre-treating biogas before it can be used in a fuel cell. The two most commonly used CHP prime movers at WWTFs—reciprocating engines and microturbines— have electric capacities of 187 to 234 kW and produce 17 to 28 MMBtu of thermal energy based on a flow rate of 9.1 MGD.

Table 6: Electric and Thermal Energy Potential with CHP for Typically Sized Digester

	No CHP System	Reciprocating Engine CHP/ Rich-Burn	Reciprocating Engine CHP/ Lean-Burn	Microturbine CHP	Fuel Cell CHP
Total WWTF Flow (MGD)	9.1	9.1	9.1	9.1	9.1
Heat Requirement for Sludge (Btu/day)	6,693,375	6,693,375	6,693,375	6,693,375	6,693,375
Wall Heat Transfer (Btu/day)	591,725	591,725	591,725	591,725	591,725
Floor Heat Transfer (Btu/day)	1,109,484	1,109,484	1,109,484	1,109,484	1,109,484
Roof Heat Transfer (Btu/day)	741,013	741,013	741,013	741,013	741,013
Total Digester Heat Load (Btu/day)	9,135,597	9,135,597	9,135,597	9,135,597	9,135,597
Fuel Required for Digester Heat Load* (Btu/day) (HHV)	**11,419,496**				
Energy Potential of Gas (Btu/day) (HHV)	58,901,700	58,901,700	58,901,700	58,901,700	58,901,700
% of Gas Used for Digester Heat Load (Btu/day)	19.4%				
Excess Digester Gas (Btu/day)**	**47,482,204**				
Electric Efficiency (HHV)		29.1%	32.6%	26.0%	42.3%
Power-to-Heat Ratio		0.62	0.86	0.88	1.26
Total CHP Efficiency (HHV)		76%	71%	56%	76%
Electric Production (Btu/day)		**17,140,395**	**19,201,954**	**15,314,442**	**24,915,419**
Electric Production (kW)		**209**	**234**	**187**	**304**
Heat Recovery (Btu/day)		**27,645,798**	**22,327,854**	**17,402,775**	**19,774,142**
Digester Heat Load (Btu/day)		**9,135,597**	**9,135,597**	**9,135,597**	**9,135,597**
Additional Heat Available* (Btu/day)**		**18,510,201**	**13,192,257**	**8,267,178**	**10,638,545**

Note: Analysis assumes 50 percent summer and 50 percent winter digester operation.
*Assumes 80 percent efficient boiler.
**Assumes no other uses except boiler.
***Available for non-digester heating uses at the facility (e.g., space heating, hot water).

Based on the modeled CHP systems and 9.1 MGD, the analysis developed an engineering rule of thumb for assessing CHP potential. The analysis shows that 1 MGD of influent flow equates to 26 kW of electric capacity and 2.4 MMBtu/day of thermal energy potential. To develop a relationship between influent flow rate (i.e., MGD) and CHP capacity, the analysis takes the average outputs of the four prime movers, yielding the result that an influent flow rate of 9.1 MGD produces 234 kW of electric capacity and approximately 22 MMBtu/day of thermal energy output. The analysis scaled this result to a per MGD basis to provide a simple relationship between influent flow and CHP capacity that WWTF operators can use to approximate a CHP system size at their facilities.

4.1.3 National Electric Generation Potential from CHP at Wastewater Treatment Facilities

Table 7 summarizes the CHP technical potential at WWTFs in the United States. As shown in Tables 3 and 4 (see Section 3.2), the 2008 CWNS identified 1,351 WWTFs greater than 1 MGD that have anaerobic digesters but that do not utilize CHP, representing 15,795 MGD of wastewater flow. Using the results developed in the technical potential analysis (i.e., 1 MGD of influent flow can produce 26 kW of electric capacity and 2.4 MMBtu/day of thermal energy), these 1,351 WWTFs could produce approximately 411 MW of electric capacity and 37,908 MMBtu/day of thermal energy if they all installed and operated CHP.

Table 7: CHP Technical Potential at Wastewater Treatment Facilities in the United States

Facility Type	Number of WWTFs	Wastewater Flow (MGD)	Electric Potential (MW)*	Thermal Potential (MMBtu/day)*
WWTFs with anaerobic digestion and no CHP (>1 MGD)	1,351	15,795	411	37,908

*Electric and thermal potential estimates assume that 26 kW of electric capacity and 2.4 MMBtu/day result from a wastewater influent flow rate of 1 MGD.

Note: An additional 269 MW of electric capacity and 24,852 MMBtu/day of thermal energy is possible at WWTFs greater than 1 MGD that do not currently operate anaerobic digesters. However, as stated earlier, power and heat generation is typically not a primary driver for installing and operating anaerobic digesters, and because it is unlikely that all these WWTFs will install anaerobic digesters, this potential is unlikely to be achieved.

4.1.4 Potential Carbon Dioxide Emissions Benefits

As described in Section 4.1.3, 411 MW of CHP technical potential exists at WWTFs that operate anaerobic digesters. This subsection presents an estimate of the CO_2 emissions that would be prevented if this potential were to be achieved.

The following assumptions were used to develop the estimate of CO_2 emissions prevented by CHP at WWTFs with anaerobic digesters:

- Prior to CHP development, WWTFs purchase electricity from the grid and use biogas from the digesters in on-site boilers to meet digester heat loads and space heating needs, and flare any excess biogas. (CO_2 emissions reductions therefore arise from displaced grid electricity only.)
- CO_2 emissions from biogas combustion are emitted regardless of whether or not CHP is employed, and therefore biogas combustion with CHP yields no net positive CO_2 emissions.
- All of the electricity produced is utilized on site and excess power is not exported to the grid.
- The CHP system operates year-round.

Since all of the estimated CO_2 emissions reductions are associated with displaced grid-supplied electricity, the key determinant for estimating total emissions reductions is a grid-based CO_2 emissions factor. The analysis uses the 2010 Emissions & Generation Resource Integrated

Database (eGRID)[20] to obtain this factor. eGRID data include total mass emissions and emissions rates for nitrogen oxides, sulfur dioxide, CO_2, methane, and nitrous oxide; net generation; and resource mix associated with U.S. electricity generation. This analysis uses the national all-fossil average CO_2 emissions factor (1,744.81 lb CO_2/megawatt-hour [MWh] produced), because it most closely approximates the generation mix that is displaced by CHP.[21]

eGRID CO_2 emissions factors relate pollutant emissions to the amount of electricity generated and not the amount of electricity delivered. Based on the assumption that all of the electricity generated by the CHP system is used on site at the WWTF, the eGRID factor is adjusted to account for transmission and distribution (T&D) losses associated with displaced grid electricity, since these losses do not occur with CHP. According to eGRID, the U.S. average T&D line loss percentage is 6.2 percent, meaning that 1 MWh produced results in 0.938 MWh delivered. As a result, the adjusted all-fossil average CO_2 emission factor is 1,860.14 lb CO_2/MWh delivered.

Multiplying the adjusted CO_2 grid emissions factor by the electric potential estimate yields avoided CO_2 emissions of 3,040,726 metric tons per year, which is equivalent to the emissions from 596,052 passenger vehicles.[22] Table 8 presents these results.

Table 8: Potential Carbon Dioxide Emissions Displaced with CHP at Wastewater Treatment Facilities

Input/Output	Value
Electric potential at WWTFs with anaerobic digesters	411 MW
Total annual electric production (assumes year-round operation)	3,602,826 MWh
Adjusted all-fossil average CO_2 emissions factor	1,860.14 lb CO_2/MWh
Total displaced CO_2 emissions	**3,350,880 tons CO_2/year or 3,040,726 metric tons CO_2/year**
Equivalent number of passenger vehicles	**596,052**

4.2 Economic Potential for CHP at Wastewater Treatment Facilities

Section 4.2.1 describes the assumptions and methodology used in the economic potential analysis. Section 4.2.2 presents a discussion of the heating requirements of WWTFs and develops estimates for the thermal energy requirements of anaerobic digesters. Section 4.2.3 presents the cost-to-generate estimates for each of the digester gas utilization cases. Section 4.2.4 presents an estimate of national economic potential based on 2008 CWNS data and the cost-to-generate results.

[20] eGRID is the most comprehensive source of data on the environmental characteristics of electricity generated in the United States. Available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.
[21] For more information on the use and value of eGRID emission data, see http://www.epa.gov/cleanenergy/documents/egridzips/The_Value_of_eGRID_Dec_2009.pdf.
[22] Equivalent passenger vehicles are calculated using the EPA Greenhouse Gas Equivalencies Calculator. Available at: http://www.epa.gov/cleanenergy/energy-resources/calculator.html.

4.2.1 Methodology

To determine the economic potential for CHP at WWTFs, the analysis developed estimates of the cost to generate electricity on site using digester gas for three digester gas utilization cases. The following assumptions were used to develop cost-to-generate estimates:

- *Digester gas utilization cases.* Three cases of different uses of digester gas were considered in order to evaluate the thermal credit associated with CHP.[23] (The thermal credit represents the avoided fuel costs achieved through CHP heat recovery on a per kWh basis.)

    - **Case 1:** Assumes digester gas is used for both digester heating and space heating prior to CHP implementation.
    - **Case 2:** Assumes digester gas is used for digester heating only prior to CHP implementation and natural gas is used for space heating.
    - **Case 3:** Assumes digester gas is not used for heating, and natural gas is used for digester and space heating prior to CHP implementation.

    Research conducted for this analysis indicates that Case 2 is the most frequent practice prior to CHP implementation.[24,25,26] It is much less common to use digester gas to meet both digester and space heating needs, or to not use it at all. The cost-to-generate analysis evaluates all three cases, however, to provide a comprehensive examination of all possible digester gas utilization options and the benefits of using CHP thermal output.

- *Thermal credit.* For all thermal credits, the analysis uses the 2010 national average industrial gas price of $5.40 per thousand cubic feet.[27]

- *WWTF plant size.* The plant sizes selected for the analysis are representative of the range of facility sizes that are applying CHP.

- *CHP prime mover*. The CHP prime movers chosen for analysis are consistent with those currently used at WWTFs (see Table 2, Section 3.1). Systems are assumed to be available 95 percent of the time, with 5 percent downtime for maintenance and repairs. For systems using combustion turbines, however, availability is estimated at 98 percent, based on Solar Turbines data.

- *CHP prime mover size.* CHP prime mover size is based on the relationship between wastewater influent flow and CHP electric capacity as derived in the technical potential analysis (see Section 4.1), which shows that 1 MGD of flow can produce 26 kW of electric capacity in a CHP system.

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[23] The CHPP's 2007 report evaluated these same three cases, with Case 3 providing the highest thermal value because the CHP thermal output displaces natural gas purchases, and Case 1 providing the lowest thermal value because the CHP thermal output does not displace any purchased fuel.
[24] Fishman, Bullard, Vogt and Lundin, "Beneficial Use of Digester Gas – Seasonal and Lifecycle Cost Considerations," 2009.
[25] Brown and Caldwell (prepared for Town of Fairhaven, Massachusetts, Board of Public Works), "Anaerobic Digestion and Combined Heat and Power Feasibility Study," December 19, 2008.
[26] SEA Consultants, "City of Pittsfield Feasibility Study, Wastewater Treatment Plant," April 2008.
[27] Energy Information Administration, Form EIA-857, "Monthly Report of Natural Gas Purchases and Deliveries to Consumers," Washington, D.C.

- *Interest rate and project lifespan*. The analysis assumes a 5 percent interest rate and a 20-year lifespan.

The analysis calculates the cost to generate electricity under each of the three digester gas utilization cases using the thermal energy requirement for anaerobic digesters[28] (Table 9) and CHP prime mover price and performance specifications (Table 11).

4.2.2 Heating Requirements of Wastewater Treatment Facilities

A critical characteristic of any economic CHP application is to use as much CHP thermal output as possible. For WWTFs, recovered thermal energy from CHP can be used for digester heating and space heating. This subsection presents a discussion of the heating requirements of WWTFs and develops estimates of the thermal energy requirements for anaerobic digesters used in the CHP cost-to-generate estimates. It also presents the results of an analysis of how much CHP thermal output can be utilized to meet space heating requirements at WWTFs.

Thermal Energy Requirements for Anaerobic Digesters

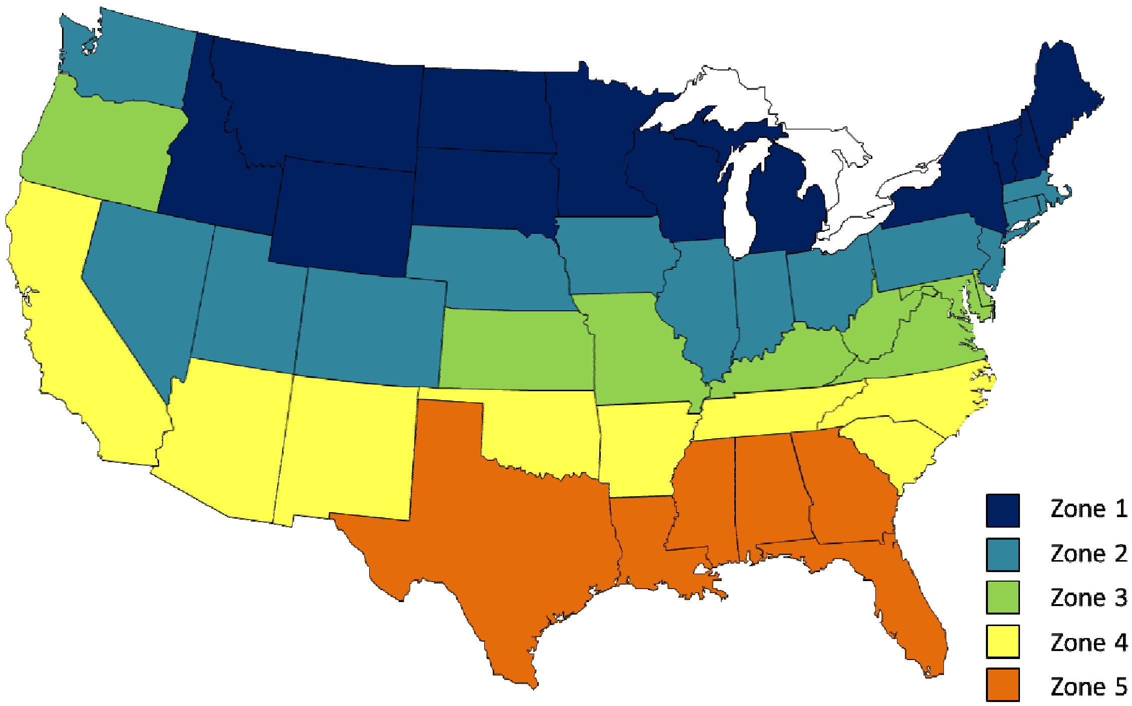
Climate is the most important factor determining digester heating requirements. When ambient air and sludge temperatures are low, it takes more energy to heat the digesters. The United States can be divided into five different climate zones[29] based on cooling and heating degree days:

Zone 1 – Cold climate with more than 7,000 heating degree days
Zone 2 – Cold/moderate climate with 5,500 to 7,000 heating degree days
Zone 3 – Moderate/mixed climate with 4,000 to 5,500 heating degree days
Zone 4 – Warm/hot climate with fewer than 4,000 heating degree days and fewer than 2,000 cooling degree days
Zone 5 – Hot climate with fewer than 4,000 heating degree days and more than 2,000 cooling degree days

Figure 1 shows the five U.S. climate zones by state. (States that span more than one zone are assigned to the zone that covers most of the state.)

[28] Greater thermal energy requirements for anaerobic digesters means that there is less CHP recovered heat available to displace purchased natural gas for space heating loads, resulting in a smaller thermal credit.
[29] U.S. Energy Information Administration, Commercial Buildings Energy Consumption Survey, Washington, DC, 2003.

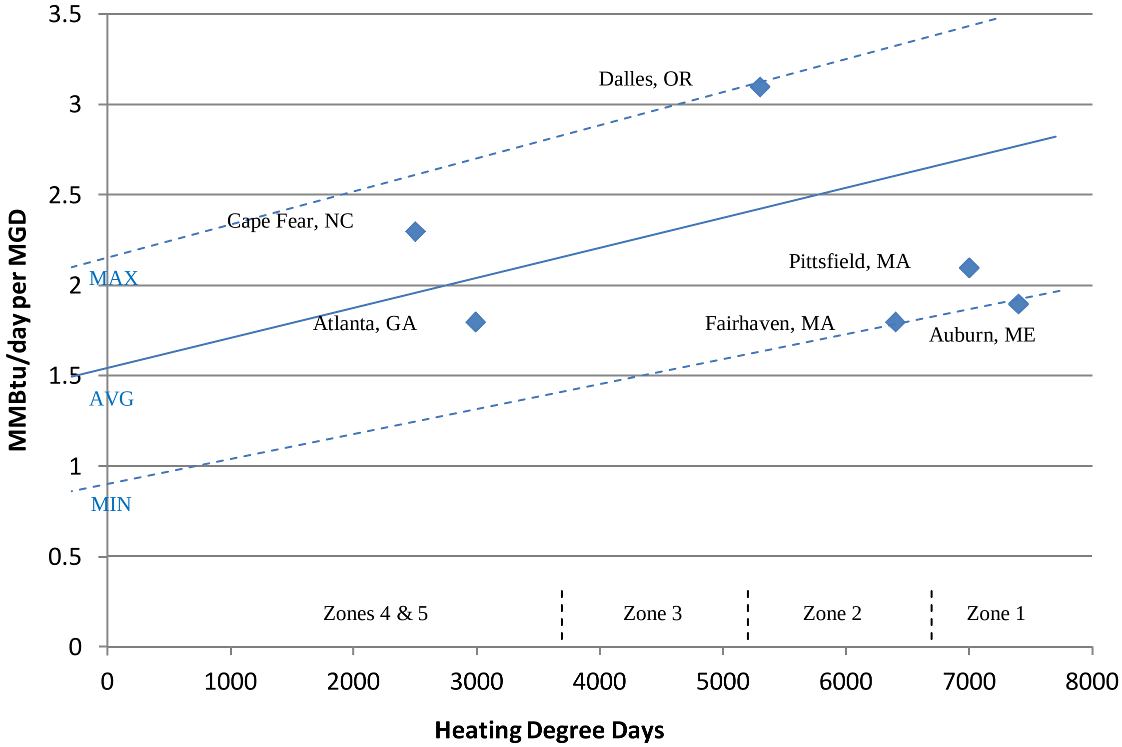
Figure 1: Map of Five U.S. Climate Zones by State



Recent feasibility studies and technical papers for various anaerobic digester gas projects were examined to determine how digester heating requirements correlate to climate (see Figure 2). These feasibility analyses and technical papers assessed digester gas projects in the following locations: Georgia (Zone 5), North Carolina (Zone 4), Oregon (Zone 3), Massachusetts (Zone 2), and Maine (Zone 1). Using these locations, the analysis determined the minimum and maximum energy requirements in terms of heating degree days. In each case, the average energy required each day (MMBtu/day) was divided by the size of the WWTF, as measured in MGD.

With minimum and maximum bounds for the energy requirements, the average value for MMBtu/day/MGD was determined. This was accomplished by first plotting the data points and constructing parallel lines that roughly intersect the two highest and the two lowest data points. These two lines represent the maximum and minimum heating requirements. The average heating requirement line was developed by adding a line that divides equally the area between these two lines. Figure 2 shows the data points used, along with the minimum, maximum, and average values, according to heating degree days. Table 9 presents the minimum, maximum, and average values in tabular form. In each case, the average energy required each day (MMBtu/day) was divided by the size of the WWTF, as measured in MGD. The average values for each zone were used in the cost-to-generate analysis.

Figure 2: Thermal Energy Requirements for Anaerobic Digesters by Heating Degree Days



Sources:

Atlanta, GA: Hardy, Scott A., AWEA Annual Conference 2011, "Achieving Economic and Environmental Sustainability Objectives through On-Site Energy Production from Digester Gas," April 11, 2011.
Auburn, ME: CDM, Lewiston Auburn Water Pollution Control Authority, "Maine: Anaerobic Digestion and Energy Recovery Project, Conceptual Design Report," October 2009.
Cape Fear, NC: Fishman, Bullard, Vogt and Lundin, "Beneficial Use of Digester Gas – Seasonal and Lifecycle Cost Considerations," 2009.
Dalles, OR: Carollo, "The Dalles Wastewater Treatment Plant Cogeneration Feasibility Study," September 2009.
Fairhaven, MA: Brown and Caldwell (prepared for Town of Fairhaven, Massachusetts, Board of Public Works), "Anaerobic Digestion and Combined Heat and Power Feasibility Study," December 19, 2008.
Pittsfield, MA: SEA Consultants, "Feasibility Study – Wastewater Treatment Plant: City of Pittsfield," April 2008.

Table 9: Thermal Energy Requirements for Anaerobic Digesters by Climate Zone

	Average MMBtu/day/MGD		
Climate Zone	**Minimum**	**Maximum**	**Average**
Zone 1 (Cold)	1.8	3.7	2.8
Zone 2 (Moderate/Cold)	1.6	3.4	2.5
Zone 3 (Moderate/Mixed)	1.4	3.0	2.3
Zone 4 (Warm/Hot)	1.2	2.8	2.0
Zone 5 (Hot)	1.0	2.6	1.8

Space Heating Capability of CHP at Wastewater Treatment Facilities

In addition to estimating the thermal energy requirements for anaerobic digesters, the analysis also developed estimates of how much CHP thermal output is available for space heating after digester heating requirements are met. The estimates of surplus thermal output for space heating were taken into consideration when developing the value of the thermal credit used in the cost-to-generate analysis.

The analysis revealed that a substantial amount of surplus heat for space heating is available only in warm and hot climates, where demand for space heating is minimal, except in cold winter months. In these warm and hot climates, up to 25 percent of the CHP thermal output is available for space heating. In cold climates, where more energy is required to heat the digester, surplus thermal energy for space heating is generally not available. In these cooler climates, the analysis estimated that less than 10 percent of the CHP thermal output is available, and in many cases there is none left for space heating.

While the data suggest that surplus heat may not be available in colder climates after the digester heating needs have been met, some facilities in these climates do in fact have surplus heating. For example, one of the WWTFs interviewed by the CHPP, the town of Lewiston, NY (see Section 5), has enough thermal output to heat one building in the summer and to meet 95 percent of that building's winter heating requirement. This discrepancy between estimated and realized thermal surplus can be attributed to a number of factors:

- Digester heating requirements depend on many different factors, and design and construction of the digester can influence the heat loss due to factors such as insulation.
- Certain methods for increasing digester gas production can allow for a larger CHP system and more surplus thermal output for space heating. These methods include mixing of the contents of the digester tank, or incorporating fats, oils, and greases (FOG) into the digester.
- WWTFs can also increase the size of the CHP system and incorporate natural gas in their fuel usage to increase the amount of CHP thermal output available for space heating.

Further details about the analysis of space heating capability of CHP can be found in Appendix C.

4.2.3 Estimated Cost to Generate Electricity

This subsection presents estimates of the cost to generate electricity with CHP using digester gas for each of the three digester gas utilization cases. The cost-to-generate calculation involves calculating the investment cost (CHP system and gas pretreatment equipment) on a per-kWh generated basis; adding in maintenance costs; and applying a thermal credit, as appropriate, to derive the full cost per kWh to own and operate a CHP system. WWTF operators can compare the cost-to-generate estimates to the current retail electric rate that they pay to help them evaluate if a more detailed analysis of CHP makes sense for their facility.

Based on the results of the analysis, the following observations can be made:

- The cost to generate electricity using CHP at WWTFs ranges from 1.1 to 8.3 cents per kWh depending on the CHP prime mover and other factors. Current retail electric rates range from 3.9 to more than 21 cents per kWh, so CHP can have clear economic benefits for WWTFs.
- Cost to generate tends to decrease as the prime mover increases in size.

- The more thermal energy a WWTF can use throughout the year, the lower the cost to generate.

Table 10 presents installed cost data for digester gas-fueled CHP systems. Gas pretreatment equipment is typically required for digester gas generators, so these costs are included. Data were obtained from case studies and feasibility studies for digester gas reciprocating engines, microturbines, fuel cells, and combustion turbines.

Table 10: Installed Cost Data Points for Anaerobic Digester Gas CHP Systems

Facility Name	State	Prime Mover	Size (kW)	Total Installed Cost	Cost per kW
Essex Junction Wastewater Treatment Facility[1]	VT	Microturbine	60	$303,000	$5,000
Lewiston Wastewater Treatment Facility[2]	NY	Microturbine	60	$300,000	$5,000
Chiquita Water Reclamation Plant[1]	CA	Microturbine	60	$275,000	$4,600
Albert Lea Wastewater Treatment Facility[1]	MN	Microturbine	120	$500,000	$4,200
Columbia Blvd. Wastewater Treatment Plant[3]	OR	Microturbine	120	$346,000	$2,900
Fairfield Wastewater Treatment Facility[4]	CT	Fuel Cell	200	$1,200,000	$6,000
Wildcat Hill[2]	AZ	Reciprocating Engine	292	$1,750,000	$6,000
Vander Haak Dairy Farm[3]	WA	Reciprocating Engine	300	$1,200,000	$4,000
Gresham Wastewater Treatment Plant[5]	OR	Reciprocating Engine	395	$1,352,000	$3,400
Janesville Wastewater Treatment Facility[1]	WI	Reciprocating Engine	400	$910,000	$2,300
King County South Treatment Plant[6]	WA	Fuel Cell	1,000	$5,000,000	$5,000
Salt Lake City Water Reclamation Plant[7]	UT	Reciprocating Engine	1,400	$3,500,000	$2,500
Rochester Wastewater Reclamation Plant[1]	NY	Reciprocating Engine	2,000	$4,000,000	$2,000
Southside Wastewater Treatment Plant[8]	TX	Combustion Turbine	4,200	$10,500,000	$2,500
Del Rio Wastewater Treatment Plant[8]	TX	Combustion Turbine	4,200	$9,400,000	$2,200
Generic Site[9]	USA	Combustion Turbine	4,910	$8,758,000	$1,800

[1] Midwest CHP Application Center: RAC Project Profiles, http://www.chpcentermw.org/15-00_profiles.html
[2] Project Interview, 9/14/2010
[3] Northwest CHP Application Center: Case Studies, http://chpcenternw.org/ProjectProfilesCaseStudies.aspx
[4] Project Interview, 9/22/2010, installation uses natural gas and not digester gas
[5] http://files.harc.edu/Sites/GulfCoastCHP/CaseStudies/GreshamORWastewaterServices.pdf
[6] Estimate from Greg Bush, King County Project Manager on new MCFC Installation
[7] http://www.slcgov.com/utilities/NewsEvents/news2003/news552003.htm
[8] Estimate by CDM (2005)
[9] Estimate by Solar Turbines (2010) for landfill site

Based on data from Table 10:

- Microturbine CHP systems range from $3,000/kW to $5,000/kW.[30]

[30] Microturbine CHP systems can be the most versatile option for smaller (i.e., <10 MGD) WWTFs.

- Reciprocating engine CHP systems in the 300 kW to 1 MW size range typically cost between $2,500/kW and $4,000/kW. Larger engine systems over 1 MW in size tend to range from $2,000/kW to $3,000/kW.[31]
- Combustion turbine CHP systems are generally the least expensive option on a per-kW basis, ranging between $1,800/kW and $2,800/kW.[32]
- In general, fuel cell systems are the highest cost option, at $5,000/kW to $6,000/kW, even for large gensets greater than 1 MW.[33]

Using the cost data points shown in Table 10, the analysis developed size ranges and costs for the different prime movers for use in the cost-to-generate estimates. Specifications for the prime movers, such as maintenance costs, efficiencies, and system availability (used to estimate down time), were also estimated based on manufacturer data. The results are presented in Table 11.

Table 11: Prime Mover Price and Performance Specifications for Use in Economic Potential Model

Prime Mover	Min Size (kW)	Max Size (kW)	Modeled Installed Cost ($/kW)	Maintenance ($/kWh)*	Thermal Output (Btu/kWh)	Electric Efficiency (%)	CHP Efficiency (%)
Small Rich-Burn Engine	30	100	4,500	0.03	5,800	28	76
Microturbine	30	250	4,000	0.025	3,900	26	55
Rich-Burn Engine	100	300	3,600	0.025	5,500	29	76
Fuel Cell	200	2,000	5,500	0.03	2,700	42	76
Small Lean-Burn Engine	300	900	3,200	0.02	4,000	32	71
Lean-Burn Engine	1,000	4,800	2,500	0.016	3,400	38	75
Combustion Turbine	4,000	16,000	2,100	0.012	3,900	35	75

Note: All equipment and maintenance costs include gas pretreatment. Electric and CHP efficiencies are based on HHV of the digester gas supplied.
* Maintenance costs for WWTFs using CHP can vary considerably. During the interviews of WWTF operators with CHP installations (see Section 5), it was found that some facilities have maintenance costs as high as 7 cents per kWh, primarily due to excessive contaminants in the digester gas leading to very high fuel treatment costs. Other sites were able to keep maintenance costs down due to cleaner digester gas and ideal maintenance strategies. As a result, the maintenance costs in Table 11 should be seen as estimates and are not intended to indicate what any individual site will experience.

The analysis used the CHP prime mover price and performance specification data in Table 11 and the thermal energy requirement for anaerobic digesters data in Table 9 to develop cost-to-generate estimates for CHP at WWTFs. Tables 12 through 14 present the cost-to-generate estimates for the three digester gas utilization cases:

- Table 12 presents the cost-to-generate results for Case 1. This case assumes the site uses digester gas in its boiler to provide digester and space heating prior to CHP; therefore, no

[31] Some smaller rich-burn engine systems have been employed at smaller WWTFs, but they tend to be costly and do not offer the benefits of lean-burn technology in this smaller (under 300 kW) size. Rich-burn engines tend to produce more emissions and have lower electric efficiencies than their lean-burn counterparts, so deployment of rich-burn engines has declined in recent years as lean-burn engines have been produced at increasingly smaller sizes.
[32] Combustion turbines are mostly limited to WWTF applications 4 MW or larger in size.
[33] Some states (e.g., Connecticut) offer incentives for fuel cell installations, which can help lower costs.

value is given to the thermal output of the CHP because it does not displace any natural gas purchases. As a result, there is no variation in the value of thermal output by climate zone, and the cost to generate is estimated to be constant for each climate zone. Of the three cases modeled, Case 1 results in the highest cost to generate, although in areas with high retail electric rates, CHP projects can have an acceptable payback period.

- Table 13 presents the cost-to-generate results for Case 2. This case assumes the site uses digester gas in its boiler to provide digester heating and purchases natural gas for space heating (when needed) prior to CHP, resulting in a thermal credit for reductions in natural gas purchases used for space heating. To account for the fact that space heating requirements are highest during cold winter periods when digester heating loads are also at their peak, the analysis employed a seasonal digester load factor to adjust for peak loads.[34] For most climate zones and WWTF capacities, the thermal credit was very small and had minimal impact on the cost to generate. The thermal credit for space heating results in a lower cost to generate only in warmer climates, where less energy is required to heat the digester.

- Table 14 presents the cost-to-generate results for Case 3. This case assumes the site uses natural gas to provide all digester and space heating, resulting in a full thermal credit. In this case, the thermal credit is much more substantial and reduces the cost to generate by several cents in all climates for all WWTF sizes as compared to Case 2. The research conducted for this analysis indicates, however, that Case 3 is atypical and that Case 2 represents the most frequently observed practice.

Appendix D provides state-by-state cost-to-generate estimates for Case 1, Case 2, and Case 3 for each type of CHP system.

Table 12: Estimated Cost to Generate Anaerobic Digester Gas Electricity (Case 1 – No Natural Gas Purchases Displaced)

			Estimated Cost to Generate ($/kWh)				
Climate Zone	**WWTF Plant Size (MGD)**	**Corresponding CHP System Size (kW)**	**Micro-turbine**	**Rich-Burn Engine**	**Fuel Cell**	**Lean-Burn Engine**	**Turbine**
1–5 (All Zones)	1–5	30–130	0.064	0.073	---	---	---
	5–10	130–260	0.064	0.060	0.083	---	---
	10–20	260–520	0.064	0.060	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.032

[34] Average digester loads are lower than winter digester loads, and subtracting average digester loads from CHP thermal output leaves more thermal output for space heating than actually is available during winter period. Using seasonal loads is necessary to avoid overstating the amount of surplus heat available for space heating, and the size of the thermal credit. The seasonal digester load factor is the ratio of the winter digester heat load to the average monthly digester heat load. The seasonal digester load factor chosen for the analysis was 1.36 which is based on data from the Cape Fear, NC, and Pittsfield, MA, feasibility analyses (these two analyses provided seasonal data whereas the other analyses cited in Figure 2 did not).

Table 13: Estimated Cost to Generate Anaerobic Digester Gas Electricity (Case 2 – CHP Heat Displaces Natural Gas Space Heating)

			Estimated Net Cost to Generate ($/kWh)				
Climate Zone	**WWTF Plant Size (MGD)**	**Corresponding CHP System Size (kW)**	**Micro-turbine**	**Rich-Burn Engine**	**Fuel Cell**	**Lean-Burn Engine**	**Turbine**
1 – Cold	–	30–130	0.064	0.073	---	---	---
	5–10	130–260	0.064	0.060	0.083	---	---
	10–20	260–520	0.064	0.060	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.032
2 – Cold/ Moderate	1–5	30–130	0.064	0.073	---	---	---
	5–10	130–260	0.064	0.060	0.083	---	---
	10–20	260–520	0.064	0.060	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.032
3 – Moderate/ Mixed	1–5	30–130	0.064	0.073	---	---	---
	5–10	130–260	0.064	0.059	0.083	---	---
	10–20	260–520	0.064	0.059	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.032
4 – Warm/ Hot	1–5	30–130	0.064	0.073	---	---	---
	5–10	130–260	0.064	0.058	0.083	---	---
	10–20	260–520	0.064	0.058	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.032
5 – Hot	1–5	30–130	0.064	0.072	---	---	---
	5–10	130–260	0.064	0.058	0.083	---	---
	10–20	260 - 520	0.064	0.058	0.083	0.051	---
	20–40	520–1,040	---	---	0.083	0.051	---
	40–150	1,040–3,900	---	---	0.083	0.040	---
	>150	>3,900	---	---	---	0.040	0.031

Table 14: Estimated Cost to Generate Anaerobic Digester Gas Electricity (Case 3 – CHP Heat Displaces Natural Gas for Both Digester and Space Heating)

			Estimated Net Cost to Generate ($/kWh)				
Climate Zone	**WWTF Plant Size (MGD)**	**Corresponding CHP System Size (kW)**	**Micro-turbine**	**Rich-Burn Engine**	**Fuel Cell**	**Lean-Burn Engine**	**Turbine**
1 – Cold	1–5	30–130	0.043	0.044	---	---	---
	5–10	130–260	0.043	0.035	0.068	---	---
	10–20	260–520	0.043	0.035	0.068	0.029	---
	20–40	520–1,040	---	---	0.068	0.029	---
	40–150	1,040–3,900	---	---	0.068	0.022	---
	>150	>3,900	---	---	---	0.022	0.011
2 – Cold/ Moderate	1–5	30–130	0.043	0.047	---	---	---
	5–10	130–260	0.043	0.037	0.068	---	---
	10–20	260–520	0.043	0.037	0.068	0.029	---
	20–40	520 - 1,040	---	---	0.068	0.029	---
	40–150	1,040–3,900	---	---	0.068	0.022	---
	>150	>3,900	---	---	---	0.022	0.011
3 – Moderate/ Mixed	1–5	30–130	0.043	0.050	---	---	---
	5–10	130 - 260	0.043	0.039	0.068	---	---
	10–20	260–520	0.043	0.039	0.068	0.030	---
	20–40	520–1,040	---	---	0.068	0.030	---
	40–150	1,040–3,900	---	---	0.068	0.022	---
	>150	>3,900	---	---	---	0.022	0.012
4 – Warm/Hot	1–5	30–130	0.043	0.052	---	---	---
	5–10	130–260	0.043	0.040	0.068	---	---
	10–20	260–520	0.043	0.040	0.068	0.033	---
	20–40	520–1,040	---	---	0.068	0.033	---
	40–150	1,040–3,900	---	---	0.068	0.022	---
	>150	>3,900	---	---	---	0.022	0.014
5 – Hot	1–5	30–130	0.045	0.053	---	---	---
	5-10	130–260	0.045	0.042	0.068	---	---
	10–20	260–520	0.045	0.042	0.068	0.034	---
	20–40	520–1,040	---	---	0.068	0.034	---
	40–150	1,040–3,900	---	---	0.068	0.024	---
	>150	>3,900	---	---	---	0.024	0.016

4.2.4 National Economic Potential Scenarios

Using the cost-to-generate results presented in the previous subsection and the 2008 CWNS data, national economic potential estimates were developed. Two scenarios were evaluated due to uncertainties in 2008 CWNS data:

- **Scenario 1: Most Facilities Do Not Use Digester Gas Prior to CHP**. This scenario assumes that the 2008 CWNS data on how WWTFs use their digester gas are completely accurate, meaning that most WWTFs with anaerobic digesters do not use their biogas in any way. As mentioned in Section 3.2, however, there are limitations to using CWNS data, and the CWNS finding that biogas is used minimally is inconsistent with research and interviews conducted as part of this report.

- **Scenario 2: All Facilities Use Digester Gas to Heat Digester Prior to CHP**. This scenario assumes that the research conducted in preparing this report is correct, and that most WWTFs use their digester gas to heat the digester. For the purposes of the analysis, Scenario 2 assumes that ***all*** WWTFs use their digester gas to heat the digester only and use natural gas for any additional space heating needs prior to CHP implementation.

For both scenarios, the analysis estimates the national economic potential by estimating the simple payback period for each WWTF and summing all CHP system sizes (MW) that have a payback period of seven years or less. The analysis was done for each WWTF in the United States greater than 1 MGD that has an anaerobic digester but does not have CHP installed. Payback period was determined by dividing the total capital investment for CHP by the total annual savings achieved through CHP use.[35]

The results show an economic potential range for CHP of 178 to 260 MW at WWTFs greater than 1 MGD with anaerobic digesters, with Scenario 1 providing an upper bound and Scenario 2 the lower bound.

Details concerning each of the scenario analyses are discussed below.

Scenario 1: Most Facilities Do Not Use Digester Gas Prior to CHP

Scenario 1 assumes that the 2008 CWNS data are completely accurate, indicating that most WWTFs with anaerobic digesters do not use their biogas in any way. Based on research and through the facility interviews conducted as part of this report, however, the authors believe that most WWTFs use at least some of their digester gas. The CWNS data suggest otherwise—that 1,148 of the 1,351 facilities evaluated do not use their digester gas. As a result of this discrepancy, the analysis of the CWNS is presented here as a scenario of what the economic potential could be <u>if</u> the CWNS data were fully accurate, and the scenario is meant to serve as an upper bound of CHP economic potential.

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[35] Total annual cost savings were calculated by adding the annual electric and natural gas bill savings and subtracting the annual maintenance costs. Annual electric bill savings were derived from annual CHP electrical output multiplied by state average industrial electricity prices from 2010 (EIA). Annual natural gas bill savings were estimated using the thermal credit calculation described in Section 4.2.3 on cost to generate that were based on annual avoided gas purchases for each potential project, using 2010 state industrial natural gas prices (EIA). Annual maintenance costs were derived from the maintenance costs as shown in Table 12, multiplied by the CHP annual electric output.

Table 15 presents the number of WWTFs and the total capacity for each digester gas utilization case, with an estimated payback period of less than seven years (see Section 4.2.1 for an explanation of the three digester gas utilization cases).

Table 15: Economic Potential of U. S. Wastewater Treatment Facilities (Scenario 1 – Most Facilities Do Not Utilize Digester Gas Prior to CHP)

Digester Gas Utilization Case Prior to CHP	WWTFs Analyzed	Number of Facilities Evaluated	Facilities with Economic Potential	Potential Capacity (MW)
Case 1: Digester Gas Used for both Digester Heating and Space Heating	Those Utilizing Digester Gas (not for CHP)	203	88	74
Case 2: Digester Gas Used for Digester Heating Only	Those Utilizing Digester Gas (not for CHP)	203	88	74
Case 3: Digester Gas Not Used	Those Not Utilizing Digester Gas	1,148	574	186
	Total	**1,351**	**662**	**260**

The analysis revealed no difference in economic potential between Case 1 (i.e., no natural gas purchases displaced) and Case 2 (i.e., CHP heat displaces natural gas space heating). This is because most of the heat recovered from CHP units is required for digester heating, leaving little (if any) thermal output for space heating, For Case 3 (i.e., CHP heat displaces natural gas for both digester and space heating), full thermal credit is given for recovered CHP heat, assuming that natural gas is used to heat the digester and provide space heating prior to CHP.

Scenario 1 shows economically feasible CHP potential at 662 WWTFs across the country, with a national potential capacity of 260 MW. Since Case 1 and Case 2 draw from the same pool of WWTFs (i.e., those that are currently using their digester gas), their potentials are not additive. The estimated economic potential of 260 MW represents approximately 63 percent of the 411 MW of national technical potential presented in Section 4.1.3.

Scenario 2: All Facilities Use Digester Gas to Heat Digester

Scenario 2 assumes that all of the WWTFs larger than 1 MGD that do not already employ CHP use their digester gas for heating the digester and use natural gas for any additional space heating needs prior to CHP implementation; therefore, all facilities evaluated under this scenario fall under Case 2 (i.e., using digester gas to heat only the digester prior to CHP implementation). As mentioned previously, Case 2 is the most common situation for a WWTF that has not already implemented CHP.

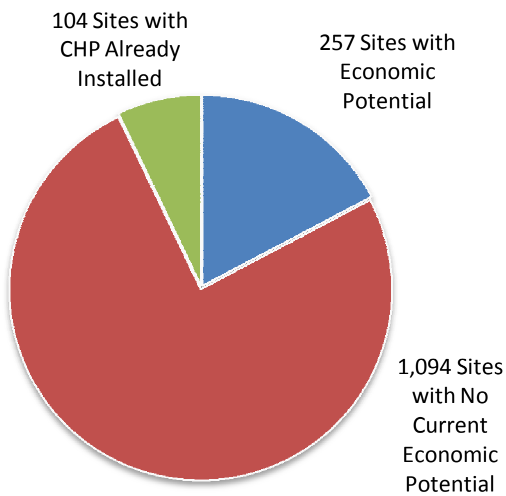
Table 16 presents the number of WWTFs with economic potential and the total capacity under Scenario 2.

Table 16: Economic Potential of U.S. Wastewater Treatment Facilities (Scenario 2 – All Facilities Use Digester Gas to Heat Digester Prior to CHP)

Digester Gas Utilization Case Prior to CHP	WWTFs Analyzed	Number of Facilities in Data Pool	Facilities with Economic Potential	Potential Capacity (MW)
Case 2: Digester Gas Heats Digester	Those with Digesters >1 MW not using CHP	1,351	257	178
	Total	**1,351**	**257**	**178**

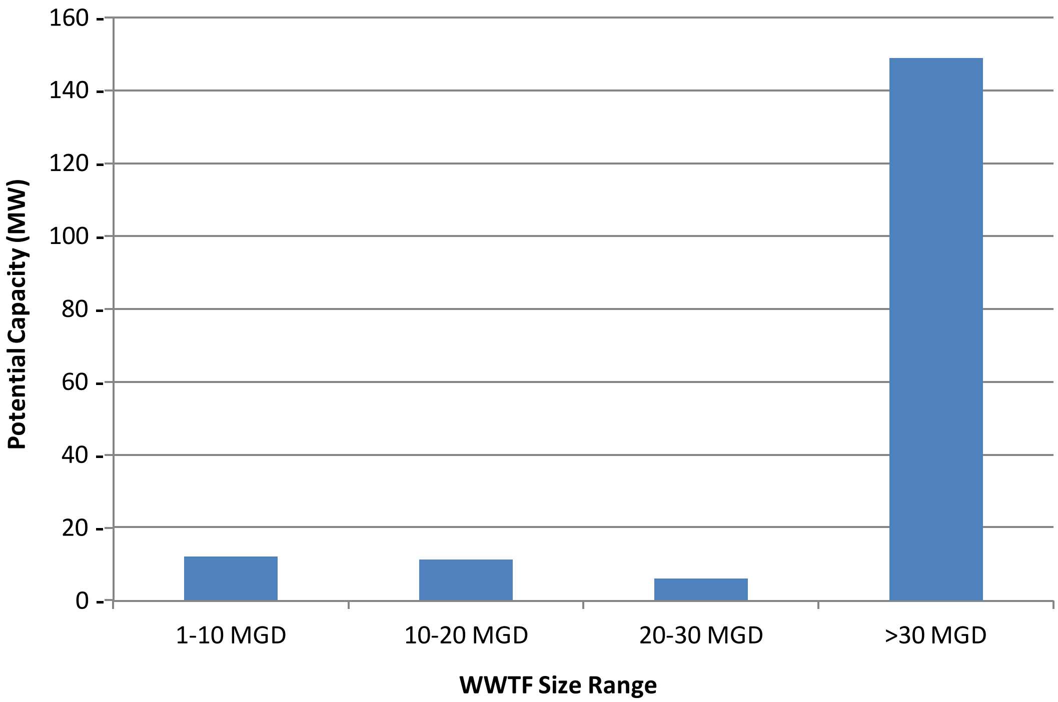
Scenario 2 shows economic CHP potential at 257 sites across the country, with a national potential capacity of 178 MW. The estimated economic potential of 178 MW represents approximately 43 percent of the 411 MW of national technical potential presented in Section 4.1.3. These data are graphically presented in Figure 3 below.

Figure 3: Wastewater Treatment Facilities with Anaerobic Digesters – Number of Sites with Economic Potential (Scenario 2)



Under Scenario 2, the vast majority of potential comes from large WWTFs (i.e., >30 MGD) that can support larger CHP units. At smaller facilities using digester gas for digester heating prior to CHP implementation, it is difficult to support CHP unless the facility is located in an area with extremely high electricity prices, or the facility is willing to accept a longer payback period. Figure 4 shows economic potential broken down by WWTF size.

Figure 4: Economic Potential by Wastewater Treatment Facility Size (Scenario 2)



5.0 Wastewater Treatment Facility Interviews: CHP Benefits, Challenges, and Operational Insights

The previous sections of this report demonstrate that there is both technical and economic potential for increased CHP use at WWTFs in the United States. Translating potential into actual successes, however, requires an understanding of operational realities. This section builds on the previous sections by presenting operational experiences from WWTFs that have already implemented CHP. To assess operational experiences with CHP at WWTFs, interviews of a number of WWTFs that utilize CHP were conducted. The focus of these conversations was to gain a better understanding of their decision to utilize CHP, the benefits they have realized from CHP to date, and the challenges/barriers of operating and maintaining CHP systems. Much of the information obtained through the interviews affirms common elements reported in other recent studies on CHP at WWTFs,[36] but new operational insights were also discovered.

This section first provides an overview of the WWTFs interviewed by the CHPP and explains how they were chosen. It also provides descriptions of the interview format used and the questions asked. Subsequent subsections summarize the information obtained through the interviews and are organized by:

- Drivers for installing CHP and operational benefits
- Challenges to CHP project development and operation/maintenance (O&M)
- Operational insights and observations

5.1 Wastewater Treatment Facilities Interviewed and Interview Format

When selecting WWTFs to interview, the objective was to build a representative pool of WWTFs so that the results were indicative of the sector. WWTFs selected to be interviewed, therefore, represent operational, geographical, and technological diversity. Thirty WWTFs were initially identified, and 14 were ultimately interviewed. Table 17 provides a summary of the 14 WWTFs interviewed.

Of the 14 CHP systems represented, the prime mover breakdown matches closely with what is seen in the marketplace (see Table 2, Section 3.1), with nine operating reciprocating engines, four operating microturbines, and one operating a fuel cell system. CHP system sizes range from 60 kW to 3.075 MW, and WWTF flow capacities range from 2 MGD to 75 MGD. The earliest CHP system was installed in 1987 and the most recent in 2009. The 14 WWTFs are also located across the country, with four operating in the East, one operating in the Southeast, five operating in the Midwest, and four operating in the West.

[36] Association of State Energy Research & Technology Transfer Institutions, "Strategic CHP Deployment Assistance for Wastewater Treatment Facilities," October 2009. Available at: http://www.asertti.org/wastewater/index.html; Brown & Caldwell, "Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities," December 2010. Available at: http://water.epa.gov/scitech/wastetech/publications.cfm.

Table 17: Wastewater Treatment Facilities Interviewed

Wastewater Treatment Facility Name	Location	Average Flow Rate (MGD)	CHP Prime Mover	CHP Capacity (MW)	CHP Installation Date
Albert Lea Wastewater Treatment Plant	Albert Lea, MN	5.0	Microturbine	0.120	2004
Allentown Wastewater Treatment Plant	Allentown, PA	31.0	Microturbine	0.360	2001
Bergen County Utilities Authority	Little Ferry, NJ	75.0	Reciprocating Engine	2.812	2008
Chippewa Falls Wastewater Treatment Plant	Chippewa Falls, WI	2.0	Microturbine	0.060	2003
City of Great Falls Wastewater Treatment Plant	Great Falls, MT	21.0	Reciprocating Engine	0.540	2008
City of Santa Maria Wastewater Treatment Plant	Santa Maria, CA	7.8	Reciprocating Engine	0.300	2009
Columbia Boulevard Wastewater Treatment Plant	Portland, OR	60.0	Reciprocating Engine	1.700	2008
Des Moines Metro Wastewater Reclamation Facility	Des Moines, IA	70.0	Reciprocating Engine	1.800	1987
Fairfield Water Pollution Control Authority	Fairfield, CT	9.0	Fuel Cell (Natural Gas)	0.200	2005
Fourche Creek Treatment Plant	Little Rock, AR	15.0	Reciprocating Engine	1.100	2009
Rock River Water Reclamation Plant	Rockford, IL	31.0	Reciprocating Engine	3.075	2004
Theresa Street Wastewater Treatment Facility	Lincoln, NE	19.5	Reciprocating Engine	0.900	1992
Town of Lewiston Water Pollution Control Center	Lewiston, NY	2.0	Microturbine	0.060	2001
Wildcat Hill Wastewater Treatment Plant	Flagstaff, AZ	3.5	Reciprocating Engine	0.292	2008

Phone interviews were conducted with the facility operators over a two-month period in August and September 2010. The interviews were conducted in an unstructured format and sought to gain information on specific CHP drivers, benefits, and challenges/barriers. The interviews covered the following operational areas:

- The key operational characteristics of the CHP system (e.g., prime mover type and heat recovery equipment; heat recovery use; CHP sizing relative to facility demand; biogas treatment method; system start-up date).
- The key drivers for installing CHP.
- Degree of local support the WWTF received in installing the CHP system.
- Whether the WWTF received financial incentives for the CHP system, and if incentives were critical to project viability.
- The primary challenges and barriers encountered with CHP development and operation, and how they were overcome.
- The WWTF's experience working with the local utility.
- The benefits achieved to date, and the benefits the WWTF expects to achieve in the future.
- Going forward, whether the WWTF would consider CHP as part of any anticipated facility expansions; if not, what would make a difference in considering CHP.
- Lessons the WWTF can impart to other facilities considering CHP.

5.2 Drivers and Benefits

WWTFs can experience efficiency, reliability, environmental, and economic benefits with CHP. Table 18 presents the primary drivers and benefits reported by the WWTFs, which specifically include the following:

- Energy cost savings
- Federal, state, local, and utility incentives
- Energy/sustainability plans and emissions reductions
- Enhanced reliability
- Facility upgrades
- Increased biogas production
- Enhanced biosolid management
- "Green" publicity/positive public relations
- Utility load shedding

The interview results clearly show strong benefits from operating CHP at WWTFs and suggest that CHP is a proven method of utilizing digester gas to both produce and conserve energy.

Table 18: Interview Results – Drivers and Benefits

Driver/Benefit	Summary	Examples
Energy Cost Savings	Each WWTF interviewed utilizes their biogas in a CHP system to displace electricity and/or fuel for digester heat loads that they would otherwise have to purchase, leading to significant energy cost savings for the facility. Some facilities said they use the savings generated from CHP to invest in other infrastructure upgrades needed at the facility, and some of the facilities mentioned that the use of CHP makes them more conscious of the energy they use, resulting in additional projects that improve energy efficiency and reduce costs. Several facilities also noted the desire to hedge against possible energy price increases as a driver for CHP.	• The 120 kW microturbine CHP system at Albert Lea Wastewater Treatment Plant generates approximately $100,000 in annual energy savings. Approximately 70 percent of the savings derives from reduced electricity and fuel purchases and 30 percent from reduced maintenance costs. The facility noted that CHP made the facility more conscious of its energy use, leading to a number of other energy-efficiency improvements, which resulted in further cost savings. • The 1.7 MW reciprocating engine CHP system at the Columbia Boulevard Wastewater Treatment Plant operates at an overall efficiency of 82 percent and generates approximately $700,000 in annual energy savings. The system offsets approximately 40 percent of the facility's electric power demand. • The 900 kW reciprocating engine CHP system at Theresa Street Wastewater Treatment Facility generates $50,000 to $100,000 in annual energy savings out of an operational budget of $4.5 million. • The 3.075 MW reciprocating engine CHP system at the Rock River Water Reclamation Plant saves the facility approximately 50 percent on its energy bill, an annual savings of approximately $250,000. • The business case for CHP clearly drove CHP installation for the Santa Maria Wastewater Treatment Plant. Prior to installing its 300 kW reciprocating engine CHP system, the facility was paying 13 to 15 cents per kWh, but with CHP, the facility is now only paying the equivalent of 8 cents per kWh.[37] • The 1.8 MW reciprocating engine CHP system at the Des Moines Metro Wastewater Reclamation Facility has reduced the electrical bill by $500,000/year since 2002.
Federal, State, Local, and Utility Incentives[38]	A number of the facilities interviewed received financial incentives that helped pay for the cost of installing CHP, with some describing the incentives as a key component to project viability. Incentive examples include government grants or payments for the "green" attributes of power generated at WWTFs using biogas, and utility programs targeted at expanding clean energy or energy efficiency. In addition, some facilities can sell excess power to the grid through power purchase agreements, which has enhanced CHP project economics at those sites.	• Fairfield Water Pollution Control Authority cited availability of public funding as a key driver for installing their 200 kW fuel cell CHP system. Their system is fueled with natural gas; the site previously had biogas-fueled microturbines but had challenges with gas treatment. The facility received $880,000 in funding from the Connecticut Clean Energy Fund, approximately two-thirds of the total $1.2 million CHP system cost. • For the Town of Lewiston Water Pollution Control Center, state and utility funding provided 100 percent of the $300,000 project cost of the 60 kW microturbine CHP system. • Allentown Wastewater Treatment Plant developed its 360 kW microturbine CHP system under a Master Energy Savings agreement with its local utility. Under the arrangement, installation of the system was funded through a 10-year lease/purchase agreement, and an O&M agreement with the utility provides for fixed O&M costs (with an escalator) through 2014. In exchange, the facility receives guaranteed energy savings achieved

[37] The costs of purchasing backup power when the CHP system is down have made the total costs about the same as prior to CHP, but this has been attributed to the contract with the third party not covering expected hours of operation or backup charges.

[38] National and state level incentives applicable to CHP and biogas can be found in the CHPP Funding Database (http://www.epa.gov/chp/funding/funding.html) and the Database of State Incentives for Renewable Energy (DSIRE) (http://www.dsireusa.org/).

Driver/Benefit	Summary	Examples
		through the operation of the CHP system and other Energy Conservation Measures constructed throughout the plant. The arrangement was a direct result of the Guaranteed Energy Savings Act passed by the Pennsylvania legislature. • Albert Lea Wastewater Treatment Plant developed its CHP system through an innovative relationship with its local utility. Under the agreement, the utility helped pay for the CHP system and agreed to maintain it for the first five years of operation. In exchange, the utility received clean energy credits for use under Minnesota's Conservation Improvement Program. • The Columbia Boulevard Wastewater Treatment Plant took advantage of the Oregon Business Energy Tax Credit and received money from the Oregon Energy Trust in exchange for the clean energy credits generated from the CHP system. The Business Energy Tax Credit provided 33.5 percent of the total CHP system cost. Although the WWTF is not a tax-paying entity, the tax credit rules allow public entities to sell the credit to entities that are subject to state tax.
Energy/Sustainability Plans and Emissions Reductions	Many states, localities, and facilities have implemented energy and sustainability plans aimed at increasing energy efficiency and clean sources of energy. Several facilities noted that CHP at their WWTF was a driver for helping to meet a state/local/facility sustainability plan. In addition, some of the facilities noted that, as environmental organizations, their goal is to enhance the health and welfare of their communities. These facilities see CHP as a means to help further fulfill this goal because of CHP's ability to displace grid-based electricity with clean, renewably fueled electricity—decreasing emissions of pollutants such as nitrogen oxide, sulfur dioxide, and CO_2.	• The Wildcat Hill Wastewater Treatment Plant, the Great Falls Wastewater Treatment Plant, the Des Moines Metro Wastewater Reclamation Facility, and the Bergen County Utilities Authority cited sustainability plans as a driver/benefit of CHP installation. Both the Wildcat Hill and Great Falls facilities cited sustainability plans as the primary driver for CHP installation. • The Columbia Boulevard Wastewater Treatment Plant's CHP system helps the city of Portland meet its sustainability plan, but the plan was not a driver for the CHP installation. The facility is considering expanding the CHP system, however, and sees the city's sustainability plan as a driver for the expansion. • Prior to CHP installation, the Allentown Wastewater Treatment Plant fired a small portion of its biogas in boilers for heat, flared the remaining biogas, and purchased all of its electricity. The facility cited the desire to reduce CO_2 emissions associated with purchased electricity to be more in line with its environmental mission as a driver for CHP installation.
Enhanced Reliability	If interconnected in a way that also allows grid-independent operation, CHP systems can enable WWTFs to sustain operations in case of a grid outage. Some facilities stated that the ability to operate independently from the grid was a key driver for CHP. Most of the facilities, however, said they are designed to shut down when the grid goes down, to satisfy local utility requirements.	• The Rock River Reclamation Plant first installed a 2 MW reciprocating engine CHP system in mid-2004. In the spring of 2010, the facility expanded the CHP system to include three reciprocating engines with a total capacity of 3.075 MW. The main driver cited for the CHP system upgrade was the desire to fully meet the facility's electric demand on site, allowing the facility to operate independently from the grid if needed. The facility has a total electric demand of 2.2 MW, and with the new CHP system, the facility has plenty of excess capacity. In addition to having the ability to operate independently from the grid, the facility's excess capacity also enables it to take one engine off line at a time for maintenance while still maintaining the ability to fully meet the facility's electric demand.
Facility Upgrades	A portion of the facilities incorporated CHP as part of a scheduled facility equipment and process upgrade. Some of these facilities operated CHP for a number of years and noted	• In 1988, the Des Moines Metro Wastewater Reclamation Facility underwent a complete facility redesign, which included installing anaerobic digesters and a 1.8 MW reciprocating engine CHP system. In 1997, the facility started to experiment with taking industrial waste and fats, oils, and greases (FOG) to boost biogas production, and

Driver/Benefit	Summary	Examples
	that the scheduled facility upgrade allowed them to install a newer CHP system that would help simplify O&M, increase system reliability, and offer increased efficiencies.	today, approximately 70 percent of the biogas produced at the facility is derived from hauled waste. The facility plans to take in additional hauled waste and is upgrading its anaerobic digesters to accommodate the increased load. To take advantage of the resulting increased biogas production, the facility plans to install four additional reciprocating engines, two of which will be incorporated with the CHP system. The other two will be used as standby power.
Increased Biogas Production	Some facilities noted that they are taking on additional waste streams that will boost their biogas production, and CHP was a natural fit to capitalize on the increased fuel availability. Additional waste streams include wastes from other nearby treatment facilities, additional industrial wastes, or FOG.	• The Des Moines Metro Wastewater Reclamation Facility noted that it is upgrading its anaerobic digesters to handle additional hauled wastes, and that expanding its existing CHP system will give the facility the ability to make efficient use of the increased biogas generation. • Little Rock, Arkansas, currently has a program in place for pretreatment of FOG to which participants must adhere. The Fourche Creek Treatment Plant is interested in how it might adapt one of its existing digesters to handle FOG, which is a possibility for future expansion. The facility would consider CHP expansion to handle any increases in biogas generation.
Enhanced Biosolid Management	Once the decision was made to incorporate anaerobic digesters into the treatment process, all facilities recognized that utilizing the resulting biogas in a CHP system made sense. Treating biosolids in anaerobic digesters reduces biosolid mass, decreasing the burdens associated with drying biosolids on site and/or shipping them to landfills, while also producing biogas that can be used to generate power and heat on site.	• The Theresa Street Wastewater Treatment Facility described keeping raw sludge out of landfills through better biosolids management as a key driver for installing anaerobic digesters on site. With the digesters in place, CHP allowed the facility to generate clean power and heat with the resulting biogas.
"Green" Publicity/Positive Public Relations	A couple of facilities noted that the "green" attributes of CHP at WWTFs (i.e., increased efficiency and reduced emissions through the use of renewable biogas), and the myriad other benefits offered by CHP, generated public interest and positive awareness for the facility. Although not a driver for initial installation, WWTFs see the positive response from the public as a benefit and a driver for continued operation.	• Both the Allentown Wastewater Treatment Plant and the Columbia Boulevard Wastewater Treatment Plant reported that their CHP systems were very well received by their communities and generated a lot of positive buzz.
Utility Load Shedding	On-site generation of power at WWTFs can help utilities that operate in constrained areas shed load rather than invest in new generation infrastructure or add additional burden to existing transmission and distribution systems.	• The Fairfield Water Pollution Control Authority noted that its CHP system not only helps the local utility avoid installing new capacity, but also enables the facility to avoid the premium price paid for electricity during high demand periods. The Fairfield facility is located in Southwestern Connecticut, a highly constrained electric area.

5.3 Challenges

Despite the benefits associated with CHP, there are several key challenges to CHP development and operation, regardless of sector or application. These include regulated fees and tariffs, interconnection issues, environmental permitting, and technical barriers. All of the WWTFs interviewed noted these as challenges to CHP development and operation to some degree, but also reported others specific to CHP operation at WWTFs, including:

- Staff education/training with CHP
- Gas pretreatment
- Utility issues
- Lack of adequate biosolid supply
- Permitting issues

Although not discussed in detail by the interviewed WWTFs, it should also be noted that obtaining the capital needed for a CHP system at a WWTF can pose a significant challenge for a WWTF and should not be overlooked. There are also specific challenges associated with utilizing biogas beyond gas pretreatment. A more detailed investigation of biogas utilization challenges is currently being undertaken by the Water Environment Research Foundation (WERF) in a report titled, "Barrier to Biogas Utilization Survey" (WERF Project Number OWSO11C10).

The interviewed WWTFs all successfully implemented CHP, so all challenges encountered were overcome in various ways, though they were not insignificant. Table 19 presents the key challenges reported by the interviewed WWTFs along with relevant examples. A key finding is that WWTFs need to recognize that CHP is a separate function beyond traditional wastewater treatment, and therefore, it is important to dedicate O&M staff time or contract with a third party to operate and maintain the CHP system.

Table 19: Interview Results – Challenges

Challenge	Summary	Examples
Staff Education/Training with CHP	Most facilities interviewed identified the training of staff in O&M of CHP and its components (e.g., gensets, heat recovery, gas pretreatment, anaerobic digesters) as a key challenge to CHP implementation. These facilities noted that on-site energy production was a new experience for them, and the process of transitioning from a wastewater treatment-only facility to one that also produces on-site power and heat was a hurdle for staff to overcome. Some facilities, however, entered into O&M contracts with service providers, so they did not have to take on the responsibility of training/hiring staff. Some also required CHP equipment manufacturers to provide the requisite training.	• The Rock River Water Reclamation Plant stated that it had to overcome the process of transitioning from a wastewater treatment-only utility to one that also generated power and heat. This process required the training of its staff, which it did by hiring an engineering firm. The CHP system requires at least a half-time employee equivalent, which the facility absorbed into its existing staff. • Under the arrangement between Albert Lea Wastewater Treatment Plant and its local utility, the local utility installed, maintained, and operated the CHP system for five years; 2010 was the first year in which the facility operated and maintained the CHP system itself. The facility noted that the five years of O&M provided by the local utility essentially constituted an extended training period for the facility's staff. • Under the Master Energy Savings agreement between the Allentown Wastewater Treatment Plant and its local utility, the facility is paying the local utility a fee to maintain and operate the CHP system until 2014. • The Des Moines Metro Wastewater Reclamation Facility noted that operating and maintaining its reciprocating engines has been a challenge. The environment is noisy, oily, and physically demanding. The facility described the importance of not only training its staff to maintain and operate the CHP system, but also getting them to take ownership of the equipment. The facility plans to expand its CHP system in the coming years and said that it plans to require the engine manufacturer to provide training. • The Columbia Boulevard Wastewater Treatment Plant purchased a maintenance contract from its engine manufacturer. The bulk of the maintenance for the CHP system is supplied through this contract, but the facility still relies on staff to help maintain the system. The biggest challenge reported by the facility is sometimes inadequate response time under the maintenance contract.
Gas Pretreatment	Many facilities noted that understanding the importance of gas pretreatment and developing a gas pretreatment strategy was a key challenge. Digester gas at WWTFs contains contaminants such as hydrogen sulfide, siloxanes, and excess moisture that can impair CHP equipment if not properly pretreated. Gas pretreatment is more of a concern for some CHP prime movers than others (e.g., microturbines are more sensitive to contaminants than some reciprocating engines).	• The Chippewa Falls Wastewater Treatment Plant reported biogas conditioning as the number one challenge to developing its microturbine CHP system. Despite some early struggles and setbacks getting the conditioning system to work properly, with the help of an experienced engineering consultant, the facility no longer experiences any significant gas cleanup issues. • The Great Falls Wastewater Treatment Plant reported dealing with high hydrogen sulfide levels, which leads to frequent replacement of its iron sponge and considerable maintenance costs. • The Town of Lewiston Water Pollution Control Center initially had much higher moisture levels than planned and had to incorporate better moisture removal equipment. • Allentown Wastewater Treatment Plant's CHP system did not initially include a gas conditioning system, which led to significant downtime. Hydrogen sulfide and siloxanes in the digester gas damaged the compressors and microturbines. The utility subsequently installed a gas conditioning system but noted that the facility still experiences a significant amount of downtime as a result of the lack of redundancy in

Challenge	Summary	Examples
		the glycol chiller and digester gas compressor.
Utility Issues	A number of facilities indicated that burdensome interconnection requirements or high tariff and standby rates were significant challenges to developing CHP. Some mentioned that their utility restricts sales of excess power to the grid, impairing project economics. However, opportunities may exist for WWTFs to partner with their local utility to help move a CHP project forward.	• The Des Moines Metro Wastewater Reclamation Facility stated that working with the local utility on interconnection was a challenge. It took the facility one to two years to negotiate an interconnection agreement, creating great expense in terms of both money and staff time. • The Rock River Water Reclamation Plant reported that working with the local utility on interconnection was very difficult, time consuming, and expensive. Of note, the facility stated that the cost of interconnection represented 10 percent of the total cost associated with CHP implementation. • Fourche Creek Treatment Plant initially experienced problems with grid interruptions. To remedy this, the facility installed a fiber interlock between the plant and the electric substation that allows the facility to completely disconnect from the grid when there are interruptions. This is mainly a safety feature that helps protect the CHP system equipment and helps to ensure smooth operation of the system. • The Columbia Boulevard Wastewater Treatment Plant experienced resistance from the local utility concerning selling power back to the utility under a contract. The utility was not opposed to the facility operating CHP, but it forced the facility to install reverse power relays to prevent any power export back to the grid. The facility would have preferred the option of selling excess power. • The Theresa Street Wastewater Treatment Facility did not experience any problems working with the local utility on interconnection. However, although the facility is able to sell excess power, it feels it does not receive enough credit for the power it supplies. The facility buys power at 5.5 cents per kWh but receives only 2.5 cents per kWh for power sold back to the grid. • The Wildcat Hill Wastewater Treatment Plant ultimately partnered with the local utility to provide renewable energy credits (RECs) and motivate the utility to help move the project forward.
Lack of Adequate Biosolid Supply	Some WWTFs do not treat enough wastewater to generate sufficient biogas to make CHP economically feasible. In many cases, this holds true for facilities with flow rates less than 5 MGD. However, smaller facilities can make CHP viable by hauling additional waste such as FOG or taking on industrial waste streams that are high in biological oxygen demand (BOD)[39]. Larger facilities can also expand their opportunities for CHP by increasing their biogas generation potential through processing of FOG or other industrial waste streams.	• The Chippewa Falls Wastewater Treatment Plant was one of three facilities interviewed with an influent flow rate less than 5 MGD. Prior to installing a 60 kW microturbine CHP system, the facility operated gas-powered blowers with the biogas they produced and captured the waste heat off the blowers to help meet digester heat loads. Although the facility only treats an average of 2 MGD, approximately 50 percent of the BOD treated by the facility comes from a local brewer. This enhanced BOD content allows the facility to generate enough biogas to power its CHP system.

[39] BOD is the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water. It is a common measure of the biosolid loading in wastewater treatment streams and an indicator of biogas generation potential.

Challenge	Summary	Examples
Permitting Issues	A couple of facilities noted that obtaining the correct permits for their CHP system was burdensome and time-consuming. Installing on-site energy production requires facilities to obtain the necessary permits, which can be a new challenge for WWTFs, especially if a Title V Clean Air Act (CAA) permit is needed.	• The Bergen County Utilities Authority reported that its CHP system required careful negotiation of changes to their existing Title V CAA permit. • The Des Moines Metro Wastewater Reclamation Facility reported that the installation of its reciprocating engine CHP system required the facility to obtain a Title V CAA permit. The process of obtaining a Title V permit was somewhat unfamiliar to the facility, and it is still learning about all of the issues involved.

5.4 Operational Insights and Observations

Based on the benefits achieved and challenges encountered, several common operational insights became apparent at the conclusion of the interviews. These insights were considered by all WWTFs as important to any facility considering CHP. Table 20 presents the key CHP operational insights gathered from WWTFs across the following topic areas: organizational acceptance, utility relationship, system design, and O&M.

In general, the insights show that CHP is an added element to a WWTF, beyond traditional treatment of wastewater, and that it requires appropriate planning and attention. To this end, high-level buy-in from facility management is very important to project success. In addition, WWTFs need to be closely involved with the design of the CHP system, including all of its components (e.g., fuel pretreatment), and understand how the system operates and its maintenance requirements.

Coordination with the local utility was also seen as extremely important for developing and operating a successful CHP system. From the beginning, immediate and continuing coordination with the utility is needed to ensure that all components of the CHP system are in line with utility requirements. This process often requires close negotiations over topics such as interconnection, sale of excess power, and potential changes in utility rates. Several of the WWTFs encountered utilities unwilling to buy excess power or allow operation independent of the grid. These restrictions eliminated a potential source of revenue and also one of the primary benefits of CHP, enhanced reliability of the WWTF's power supply.

Table 20: Interview Results – Operational Insights

Topic	Key Insights
Organizational Acceptance	High-level buy-in for CHP can greatly facilitate project approval. A CHP champion is needed to get the project off the ground and for continual successful operation.
	Aligning the project with community goals for renewable energy/energy efficiency can serve as a great justification for the project.
Utility Relationship	Immediate and continuing coordination with the local utility is highly recommended. Issues such as interconnection, sales of excess power, and potential changes in utility rates all require close communication with the local utility and can require significant time to resolve.
	Identifying opportunities for collaboration or partnership with the local utility can be highly beneficial (e.g., master energy savings agreement, sale of RECs, other ownership/O&M agreements).
System Design	CHP projects require due diligence from design through O&M. It is important for facilities to ensure that any consultants or project developers hired are fully versed in all aspects of design, installation, and O&M of CHP systems at WWTFs. WWTFs want to avoid "problem fatigue" that can arise from a poorly designed system and can lead to system shutdown.
	WWTFs should ensure that the fuel treatment and compression systems have been designed to satisfy the CHP manufacturer specifications. A rigorous gas pretreatment approach is needed for certain applications—thorough gas analysis and possible gas treatment may be required.
	In some cases, blending digester gas with natural gas may help maintain desired heat content and composition.
	WWTFs should familiarize themselves with CHP equipment and processes and see what fits best with their plant and staff experience. A comprehensive review of leading facilities that operate CHP is a good idea.
	WWTFs should consider outside waste streams and sludge pre-treatment to improve quantity and quality of digester biogas, but also consider the facility requirements to receive and process these wastes during the design process.
Operations and Maintenance	Specific training for O&M personnel is important for successful operation of a CHP system. Having staff that is well trained regarding mechanical and electrical equipment is extremely beneficial. WWTFs should ensure that agreements with CHP developers or suppliers include proper O&M training.
	WWTFs need to recognize that CHP is a separate function beyond traditional wastewater treatment and should dedicate O&M staff time or contract with a third party to operate and maintain the CHP system. It takes more effort for a WWTF to operate CHP in addition to typical wastewater treatment operations.
	WWTFs should institute a preventive maintenance schedule instead of reactive maintenance.
	WWTFs need to be aware of the maintenance issues related to fuel treatment, including siloxane deposits on CHP equipment. Improper maintenance will lead to more frequent maintenance intervals.
	A comprehensive design/build/operation/maintenance agreement can greatly simplify the process of installing and operating CHP for WWTFs. Even if the maintenance agreement expires after a certain number of years, a facility can gain valuable training experience over that time.

Appendix A: Data Sources Used in the Analysis

To develop an overview of the wastewater treatment sector and the potential for CHP, the CHPP used publicly available information contained in the 2008 CWNS Databases,[40] the Combined Heat and Power Installation Database,[41] EPA's 2010 eGRID,[42] and U.S. Energy Information Administration (EIA) electricity and natural gas prices.[43] The CHPP also conducted WWTF interviews and performed independent research. The following describes each type of data used in the CHPP's analysis.

2008 Clean Watersheds Needs Survey

EPA's Office of Wastewater Management, in partnership with states, territories, and the District of Columbia, conducts the CWNS every four years in response to Sections 205(a) and 516 of the Clean Water Act and develops a Report to Congress. The CWNS is a comprehensive assessment of the capital needs to meet the water quality goals set in the Clean Water Act. Every four years, the states and EPA collect information about:

- Publicly owned wastewater collection and treatment facilities.
- Stormwater and combined sewer overflow (CSO) control facilities.
- Nonpoint source (NPS) pollution control projects.
- Decentralized wastewater management.

Information collected about these facilities and projects includes:

- Estimated needs to address water quality or water quality-related public health problems.
- Location and contact information for facilities and projects.
- Facility populations served and flow, effluent, and unit process information.
- NPS best management practices.

CHP Installation Database

The CHP Installation Database is maintained by ICF with support from the U.S. Department of Energy and Oak Ridge National Laboratory. The database lists all CHP systems in operation in the United States. Information is gathered in real time and originates from industry literature, manufacturer contacts, and regional CHP centers. The database is continually updated.

2010 eGRID

eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include air emissions for nitrogen oxides, sulfur dioxide, carbon dioxide, methane, and nitrous oxide; emission rates; net generation; resource mix; and many other attributes.

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[40] The 2008 CWNS is available through EPA's Office of Wastewater Management and can be accessed at: http://water.epa.gov/scitech/datait/databases/cwns/index.cfm.

[41] The CHP Installation Database is available at: http://www.eea-inc.com/chpdata/index.html.

[42] eGRID is available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

[43] Average industrial electricity prices taken from Energy Information Administration (EIA), "Monthly Electric Sales and Revenue Report with State Distributions Report," year to date through December 2010. Natural gas price data can be found at: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

U.S. EIA Electricity and Natural Gas Prices

Electric Power Monthly is a report prepared by the EIA that summarizes the average price paid by industrial customers purchasing electricity on a state-by-state basis. WWTFs are treated as industrial customers because they are fairly large electricity consumers and they consume power throughout the day and night, as do other industrial facilities. Data are collected from a multitude of EIA forms, as well as from other federal sources.

Wastewater Treatment Facility Interviews

The CHPP attempted to contact 30 WWTFs that have operational CHP systems and ultimately spoke with 14 facilities. The WWTFs chosen for contact and those ultimately interviewed represent operational, geographical, and technological diversity. Information obtained from interviews included operational insights and addressed drivers and benefits of CHP; barriers and challenges encountered; and lessons learned.

Independent Research

The CHPP also conducted independent research, which included reviewing reports, studies, and case studies of WWTFs that employ CHP, and utilizing the extensive CHP resources and contacts available to the CHPP.

Appendix B: Anaerobic Digester Design Criteria Used for Technical Potential Analysis

The following anaerobic digester design criteria were used to estimate the total wastewater influent flow rate that a typically sized digester can treat, as well as the biogas generation rate and the heat load of a typically sized digester. All criteria are based on a typically sized mesophilic digester.

System Design Parameter	Value
Reactor Type[1]	Complete Mix
Reactor Shape[1]	Circular
Organic Load[2] (lbs/day VS)	13,730
Percent Solids in Flow[2] (% w/w)	8
Sludge Density[2] (lbs/gal)	8.5
Flow to Reactor (lbs/day)	171,625
Flow to Reactor (gal/day)	20,191
Flow to Reactor (ft^3/day)	2,699
Reactor Depth[3] (ft)	20
Design Load[1] (lbs VS/ft^3/day)	0.25
Total Reactor Volume (ft^3)	54,920
Reactor Area (ft)	2,746
Reactor Diameter[1] (ft)	60
Retention Time (days)	20
Influent Temp – Winter (°F)	40
Air Temp – Winter (°F)	40
Earth Around Wall Temp – Winter (°F)	40
Earth Below Floor Temp – Winter (°F)	40
Reactor Temp (°F)	98
Influent Temp – Summer (°F)	78
Air Temp - Summer (°F)	78
Earth Around Wall Temp – Summer (°F)	47
Earth Below Floor Temp – Summer (°F)	47
Sp. Heat Sludge[1] (Btu/lb*°F)	1.0
Area Walls (ft^2)	3,769.9
Area Roof (ft^2)	2,827.4
Area Floor (ft^2)	2,827.4
U Walls – Concrete[1] (Btu/hr*ft^2*°F)	0.12
U Roof – Concrete[1] (Btu/hr*ft^2*°F)	0.28
U Floor – Concrete[1] (Btu/hr*ft^2*°F)	0.30
Gas Generation[1] (ft^3/lb VS)	12
Gas Heat Content[1] (Btu/ft^3) (HHV)	650
VS Removal Percent at 20 days[2] (%)	55
VS Removed (lbs/day)	7,552
Gas Generation (ft^3/day)	90,618
Heat Potential of Gas (Btu/day)	58,901,700
Gas Generation per Capita[1] (ft^3/day/person)	1
Population Served by POTW (persons)	90,618
Flow per Capita[3] (gal/day/person)	100
Total POTW Flow (MGD)	9.1

Sources:

1. Metcalf and Eddy, "Wastewater Engineering and Design, 4th Edition", 2003.
2. Eckenfelder, "Principals of Water Quality Management," 1980.
3. Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Managers, "Recommended Standards for Wastewater Facilities (Ten-State Standards)," 2004.

Appendix C: Space Heating Capability of CHP at Wastewater Treatment Facilities

As discussed in Section 4.2.2, the analysis estimated the space heating capability of CHP at WWTFs, demonstrating that after digester loads are met, there is little CHP recovered heat available for space heating in most climates. Based on the results shown in Figure 2 and Table 9 (both in Section 4.2.2), the analysis estimated the amount of heat available for space heating after digester heating is met. By subtracting the average values for digester heating requirements (see Table 9) from the thermal output of representative CHP systems, the amount of heat available for space heating was estimated for three different sizes of WWTFs (i.e., 3, 16, and 40 MGD) for each of the five climate zones. The CHP systems chosen represent typical prime mover types and sizes used at WWTFs, and the WWTF sizes are representative of the range of facility sizes that are applying CHP. The following table presents the results.

Estimated Space Heating Capability for CHP Units in Different Climate Zones

			Thermal Output/Load (MMBtu/day)		
Climate Zone	WWTF Plant Size (MGD)	Representative CHP System	Estimated CHP Thermal Output	Average Digester Load	Surplus Thermal Output for Space Heating
1 – Cold	3	65 kW Microturbine	5.9	8.4	0.0
	16	400 kW Engine	38.4	44.8	0.0
	40	1 MW Engine	81.6	112.0	0.0
2 – Cold/ Moderate	3	65 kW Microturbine	5.9	7.5	0.0
	16	400 kW Engine	38.4	40.0	4.0
	40	1 MW Engine	81.6	100.0	0.0
3 – Moderate/ Mixed	3	65 kW Microturbine	5.9	6.9	0.0
	16	400 kW Engine	38.4	36.8	1.6
	40	1 MW Engine	81.6	92.0	0.0
4 – Warm/Hot	3	65 kW Microturbine	5.9	6.0	0.0
	16	400 kW Engine	38.4	32.0	6.4
	40	1 MW Engine	81.6	80.0	1.6
5 – Hot	3	65 kW Microturbine	5.9	5.4	0.5
	16	400 kW Engine	38.4	28.8	9.6
	40	1 MW Engine	81.6	72.0	9.6

The data in the table above reveal that a substantial amount of surplus heat for space heating is available only in warm and hot climates, where demand for space heating is minimal (except in cold winter months). In cold climates, where more energy is required to heat the digester, surplus thermal energy for space heating is generally not available.

CHP provides for much higher gas utilization than if the digester were heated directly with boilers, since the use of digester gas is much higher in the summer months when heating loads are minimal. Gas utilization by baseloaded CHP systems is fairly constant throughout the year, other than during periods of maintenance, whereas gas utilization for boilers drops significantly during summer periods when some digester heating may be needed but little or no space heating is needed. A WWTF in North Carolina[44] indicated that 63 to 66 percent of available digester gas can be beneficially used with CHP, whereas use of digester gas-fueled boilers would consume only 33 to 38 percent of the gas, with the balance either stack losses or flared gas. This experience is consistent with the interviews of WWTFs conducted for this report, in which a number of facilities indicated that using CHP results in more beneficial use of the digester gas. For example, the Town of Lewiston, NY, indicated that prior to implementing CHP, its boiler used only 40 to 50 percent of the gas, whereas with the CHP system, gas utilization reached 98 percent. Future trends[45] also indicate that more facilities are likely to build gas storage into their digester system, which should result in improved gas utilization. Storing digester gas during periods of low demand and drawing from storage when demand for heat is high minimizes the need for gas flaring. For many WWTFs, improving gas utilization while at the same time eliminating or minimizing flaring is a key driver for implementing CHP.

[44] Fishman, Bullard, Vogt and Lundin, "Beneficial Use of Digester Gas – Seasonal and Lifecycle Cost Considerations," 2009.

[45] Based on a number of recent installations and feasibility studies that included gas storage (City of Riverside, CA; Cape Fear, NC; Ithaca, NY; Rochester NY; and Gloversville-Johnstown, NY).

Appendix D: Cost-to-Generate Estimates by State

To estimate the cost to generate for CHP at WWTFs, the analysis considered three digester gas utilization cases for each WWTF greater than 1 MGD that operates anaerobic digesters.

- **Case 1:** Assumes digester gas is used for both digester heating and space heating prior to CHP implementation.
- **Case 2:** Assumes digester gas is used for digester heating only prior to CHP implementation and natural gas is used for space heating.
- **Case 3:** Assumes digester gas is not used for heating, and natural gas is used for digester and space heating prior to CHP implementation.

Cost to Generate Electricity with Digester Gas (Case 1 – No Thermal Credit)

State	Average Industrial Electricity Price[1] (cents/kWh)	Average Industrial Natural Gas Price[2] ($/1000 scf)	Cost to Generate (cents/kWh)						
			Small Rich-Burn Engine (1-5 MGD)	Microturbine (1-10 MGD)	Rich-Burn Engine (5-15 MGD)	Fuel Cell (10-80 MGD)	Small Lean-Burn Engine (12-40 MGD)	Lean-Burn Engine (40-160 MGD)	Combustion Turbine (>160 MGD)
Alaska	14.1	4.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Alabama	6.1	6.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Arkansas	5.4	7.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Arizona	6.7	8.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
California	10.9	7.0	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Colorado	6.9	5.8	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Connecticut	14.4	9.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Delaware	9.6	14.0	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Florida	8.9	9.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Georgia	6.2	6.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Hawaii	21.9	24.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Iowa	5.4	6.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Idaho	5.1	6.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Illinois	6.7	7.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Indiana	6.0	5.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Kansas	6.2	5.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Kentucky	5.1	5.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Louisiana	5.8	4.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Massachusetts	13.2	12.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Maryland	9.5	8.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Maine	8.8	9.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Michigan	7.2	9.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Minnesota	6.3	5.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Missouri	5.5	9.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Mississippi	6.4	5.9	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Montana	5.6	9.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
North Carolina	6.1	8.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
North Dakota	5.7	5.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Nebraska	5.9	5.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Hampshire	12.8	12.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Jersey	11.6	9.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Mexico	6.0	6.0	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Nevada	7.4	10.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New York	9.7	9.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Ohio	6.3	8.9	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Oklahoma	5.2	12.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Oregon	5.5	7.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Pennsylvania	7.6	10.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Rhode Island	12.8	12.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
South Carolina	5.7	6.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
South Dakota	5.9	5.9	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Tennessee	6.7	6.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Texas	6.3	4.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Utah	4.9	5.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Virginia	6.7	7.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Vermont	9.5	6.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Washington	4.0	9.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Wisconsin	6.8	7.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
West Virginia	5.9	5.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Wyoming	5.0	5.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2

Average industrial electricity prices taken from Energy Information Administration (EIA), "Monthly Electric Sales and Revenue Report with State Distributions Report," year to date through December 2010.

Average industrial natural gas prices taken from EIA, available at: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

Net Cost to Generate Electricity with Digester Gas (Case 2 – Thermal Credit for Space Heating)

State	Average Industrial Electricity Price[1] (cents/kWh)	Average Industrial Natural Gas Price[2] ($/1000 scf)	Cost to Generate (cents/kWh)						
			Small Rich-Burn Engine (1-5 MGD)	Microturbine (1-10 MGD)	Rich-Burn Engine (5-15 MGD)	Fuel Cell (10-80 MGD)	Small Lean-Burn Engine (12-40 MGD)	Lean-Burn Engine (40-160 MGD)	Combustion Turbine (>160 MGD)
Alaska	14.1	4.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Alabama	6.1	6.4	7.1	6.4	5.8	8.3	5.1	4.0	3.2
Arkansas	5.4	7.6	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Arizona	6.7	8.2	7.2	6.4	5.8	8.3	5.1	4.0	3.2
California	10.9	7.0	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Colorado	6.9	5.8	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Connecticut	14.4	9.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Delaware	9.6	14.0	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Florida	8.9	9.4	7.0	6.4	5.7	8.3	5.1	4.0	3.2
Georgia	6.2	6.7	7.0	6.4	5.6	8.3	5.0	4.0	3.2
Hawaii	21.9	24.2	6.8	6.4	5.3	8.3	5.1	4.0	3.2
Iowa	5.4	6.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Idaho	5.1	6.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Illinois	6.7	7.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Indiana	6.0	5.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Kansas	6.2	5.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Kentucky	5.1	5.3	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Louisiana	5.8	4.6	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Massachusetts	13.2	12.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Maryland	9.5	8.6	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Maine	8.8	9.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Michigan	7.2	9.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Minnesota	6.3	5.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Missouri	5.5	9.6	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Mississippi	6.4	5.9	7.1	6.4	5.8	8.3	5.1	4.0	3.2
Montana	5.6	9.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
North Carolina	6.1	8.1	7.2	6.4	5.8	8.3	5.1	4.0	3.2
North Dakota	5.7	5.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Nebraska	5.9	5.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Hampshire	12.8	12.1	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Jersey	11.6	9.7	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New Mexico	6.0	6.0	7.2	6.4	5.9	8.3	5.1	4.0	3.2
Nevada	7.4	10.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
New York	9.7	9.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Ohio	6.3	8.9	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Oklahoma	5.2	12.6	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Oregon	5.5	7.3	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Pennsylvania	7.6	10.2	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Rhode Island	12.8	12.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
South Carolina	5.7	6.1	7.2	6.4	5.8	8.3	5.1	4.0	3.2
South Dakota	5.9	5.9	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Tennessee	6.7	6.2	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Texas	6.3	4.6	7.2	6.4	5.8	8.3	5.1	4.0	3.2
Utah	4.9	5.5	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Virginia	6.7	7.1	7.3	6.4	5.9	8.3	5.1	4.0	3.2
Vermont	9.5	6.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Washington	4.0	9.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Wisconsin	6.8	7.6	7.3	6.4	6.0	8.3	5.1	4.0	3.2
West Virginia	5.9	5.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2
Wyoming	5.0	5.4	7.3	6.4	6.0	8.3	5.1	4.0	3.2

*Includes thermal credit as described in Section 4.2.3

Average industrial electricity prices taken from Energy Information Administration (EIA), "Monthly Electric Sales and Revenue Report with State Distributions Report," year to date through December 2010.

Average industrial natural gas prices taken from EIA, available at: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

Net Cost to Generate Electricity with Digester Gas (Case 3 – Full Thermal Credit)

State	Average Industrial Electricity Price[1] (cents/kWh)	Average Industrial Natural Gas Price[2] ($/1000 scf)	Cost to Generate (cents/kWh)						
			Small Rich-Burn Engine (1-5 MGD)	Microturbine (1-10 MGD)	Rich-Burn Engine (5-15 MGD)	Fuel Cell (10-80 MGD)	Small Lean-Burn Engine (12-40 MGD)	Lean-Burn Engine (40-160 MGD)	Combustion Turbine (>160 MGD)
Alaska	14.1	4.2	5.0	4.8	4.0	7.2	3.5	2.6	1.6
Alabama	6.1	6.4	4.9	4.2	3.9	6.6	3.2	2.1	1.3
Arkansas	5.4	7.6	3.9	3.1	3.0	6.0	2.3	1.2	0.4
Arizona	6.7	8.2	4.0	3.3	3.1	6.1	2.4	1.3	0.5
California	10.9	7.0	4.7	3.9	3.7	6.5	2.9	1.8	1.0
Colorado	6.9	5.8	4.0	3.5	3.1	6.3	2.3	1.5	0.4
Connecticut	14.4	9.6	3.2	3.1	2.5	6.0	1.7	1.1	0.0
Delaware	9.6	14.0	1.9	1.6	1.2	5.0	0.4	0.0	0.0
Florida	8.9	9.4	4.0	3.3	3.0	5.9	2.5	1.4	0.6
Georgia	6.2	6.7	4.8	4.2	3.7	6.4	3.1	2.1	1.2
Hawaii	21.9	24.2	0.2	0.0	0.0	3.2	0.0	0.0	0.0
Iowa	5.4	6.1	4.4	4.1	3.5	6.7	2.7	2.0	0.9
Idaho	5.1	6.4	3.5	3.7	2.7	6.4	2.3	1.6	0.5
Illinois	6.7	7.3	3.8	3.6	3.0	6.3	2.2	1.5	0.4
Indiana	6.0	5.5	4.3	4.0	3.4	6.6	2.6	1.9	0.8
Kansas	6.2	5.3	5.4	4.8	4.4	7.2	3.5	2.6	1.6
Kentucky	5.1	5.3	4.8	4.2	3.8	6.8	2.9	2.1	1.0
Louisiana	5.8	4.6	5.7	4.9	4.5	7.1	3.8	2.7	1.9
Massachusetts	13.2	12.1	0.0	0.1	0.0	3.9	0.0	0.0	0.0
Maryland	9.5	8.6	2.6	2.2	1.8	5.4	1.0	0.4	0.0
Maine	8.8	9.1	0.5	1.5	0.1	4.9	0.0	0.0	0.0
Michigan	7.2	9.2	2.1	2.6	1.5	5.7	1.2	0.7	0.0
Minnesota	6.3	5.7	4.2	4.2	3.3	6.8	2.8	2.1	1.0
Missouri	5.5	9.6	3.1	2.7	2.3	5.7	1.5	0.8	0.0
Mississippi	6.4	5.9	4.9	4.2	3.9	6.6	3.2	2.1	1.3
Montana	5.6	9.1	2.4	2.9	1.8	5.9	1.5	0.9	0.0
North Carolina	6.1	8.1	4.0	3.2	3.0	6.1	2.3	1.2	0.4
North Dakota	5.7	5.2	4.5	4.4	3.6	6.9	3.0	2.2	1.2
Nebraska	5.9	5.7	4.4	4.1	3.5	6.7	2.7	2.0	0.9
New Hampshire	12.8	12.1	0.0	0.3	0.0	4.0	0.0	0.0	0.0
New Jersey	11.6	9.7	3.0	2.9	2.3	5.9	1.6	1.0	0.0
New Mexico	6.0	6.0	5.3	4.4	4.2	6.9	3.4	2.3	1.5
Nevada	7.4	10.5	1.9	2.0	1.3	5.3	0.6	0.2	0.0
New York	9.7	9.5	1.5	2.2	1.0	5.4	0.8	0.3	0.0
Ohio	6.3	8.9	2.6	2.5	1.9	5.6	1.1	0.6	0.0
Oklahoma	5.2	12.6	3.5	2.8	2.6	5.8	2.0	0.9	0.1
Oregon	5.5	7.3	3.7	3.2	2.8	6.1	2.0	1.2	0.1
Pennsylvania	7.6	10.2	1.9	2.0	1.3	5.3	0.6	0.2	0.0
Rhode Island	12.8	12.6	1.3	1.5	0.8	4.9	0.1	0.0	0.0
South Carolina	5.7	6.1	4.7	3.9	3.7	6.6	2.9	1.8	1.0
South Dakota	5.9	5.9	4.1	4.1	3.2	6.7	2.7	2.0	0.9
Tennessee	6.7	6.2	4.3	3.5	3.3	6.3	2.6	1.5	0.7
Texas	6.3	4.6	5.4	4.6	4.3	6.9	3.6	2.5	1.7
Utah	4.9	5.5	4.5	4.1	3.5	6.7	2.7	2.0	0.9
Virginia	6.7	7.1	4.3	3.7	3.3	6.5	2.5	1.7	0.6
Vermont	9.5	6.6	3.5	3.7	2.7	6.4	2.3	1.6	0.5
Washington	4.0	9.4	3.1	3.0	2.3	5.9	1.6	1.0	0.0
Wisconsin	6.8	7.6	3.1	3.4	2.4	6.2	2.0	1.4	0.2
West Virginia	5.9	5.4	4.7	4.1	3.7	6.7	2.8	2.0	0.9
Wyoming	5.0	5.4	4.7	4.5	3.8	7.0	3.2	2.4	1.3

*Includes thermal credit as described in Section 4.2.3

Average industrial electricity prices taken from Energy Information Administration (EIA), "Monthly Electric Sales and Revenue Report with State Distributions Report," year to date through December 2010.

Average industrial natural gas prices taken from EIA, available at: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

Appendix E: Additional Reference Resources

EPA Combined Heat and Power Partnership (CHPP)

The CHPP is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. The CHPP works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new projects and promote their energy, environmental, and economic benefits.

Website: www.epa.gov/chp/

The CHPP offers a number of tools and resources that can help a WWTF implement a CHP system. These include:

- Description of the CHP project development process, including information on key questions for each stage of the process along with specific tools and resources.
  Website: www.epa.gov/chp/project-development/index.html.

- The CHP funding database with bi-weekly updates of new state and federal incentive opportunities.
  Website: www.epa.gov/chp/funding/funding.html.

- The CHP Catalog of Technologies, which describes performance and cost characteristics of CHP technologies.
  Website: www.epa.gov/chp/basic/catalog.html.

- The Biomass CHP Catalog of Technologies, which provides detailed technology characterization of biomass CHP systems.
  Website: www.epa.gov/chp/basic/catalog.html.

Reports

The following reports about CHP at WWTFs are available for download:

Brown & Caldwell, “Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities,” December 2010. Available at: http://water.epa.gov/scitech/wastetech/publications.cfm.

Association of State Energy Research & Technology Transfer Institutions, “Strategic CHP Deployment Assistance for Wastewater Treatment Facilities,” October 2009. Available at: http://www.asertti.org/wastewater/index.html.

California Energy Commission, “Combined Heat and Power Potential at California’s Wastewater Treatment Plants,” September 2009. Available at: http://www.energy.ca.gov/2009publications/CEC-200-2009-014/CEC-200-2009-014-SF.PDF.

Organizations

The following organizations work closely with the wastewater treatment industry and offer a wealth of knowledge concerning wastewater treatment and the use of anaerobic digestion.

EPA Office of Wastewater Management (OWM) – The OWM oversees a range of programs contributing to the well-being of the nation's waters and watersheds.
Website: www.epa.gov/owm/

National Association of Clean Water Agencies (NACWA) – NACWA represents the interests of more than 300 public agencies and organizations. NACWA members serve the majority of the sewered population in the United States and collectively treat and reclaim more than 18 billion gallons of wastewater daily.
Website: www.nacwa.org/

Water Environment Federation (WEF) – Founded in 1928, the WEF is a not-for-profit technical and educational organization with members from varied disciplines who work toward the organization's vision of preserving and enhancing the global water environment.
Website: www.wef.org/Home

Water Environment Research Foundation (WERF) – WERF helps improve the water environment and protect human health by providing sound, reliable science and innovative, effective, cost-saving technologies for improved management of water resources.
Website: www.werf.org

Air and Waste Management Association (A&WMA) – A&WMA is a not-for-profit, non-partisan professional organization that provides training, information, and networking opportunities to thousands of environmental professionals in 65 countries.
Website: www.awma.org/

Other

Database of State Incentives for Renewables and Efficiency (DSIRE) – DSIRE is a comprehensive source of information on federal, state, local, and utility incentives and policies that promote renewable energy and energy efficiency.
Website: http://www.dsireusa.org/

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Office of Air and Radiation (6202J)
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