

Combined Heat and Power Case Study

Site Description

The City of Rochester Wastewater Reclamation Plant (WWRP) serves the residential, commercial and industrial residents of the City of Rochester, Minnesota. The city has a population of approximately 100,000 people, and the plant has the capacity of processing approximately 24 million gallons per day (MGD) of sewage and wastewater. The incoming waste stream (influent) is pumped to a higher elevation with the plant's preliminary, primary, secondary, and advanced treatment processes fed by gravity flow. The solids handling system utilizes anaerobic digestion which produces the treated solids that are trucked from the facility as well as the biogas that is stored and utilized on-site as fuel for both heating and electrical generation. The processed water goes through a final chlorination stage and is then pumped to a local river.

Preliminary Treatment:

The Preliminary Treatment process utilizes influent screens and grit removal chambers. The output (for the most part rags and grit) are washed and disposed of either at a waste-to-energy incinerator or at a local landfill.

Primary and Secondary Treatment:

The plant consists of two parallel treatment processes. The influent is divided, with approximately 4 MGD flowing through the more conventional Aeration Basin Complex (ABC) and approximately 19 MGD flowing through the High Purity Oxygen Activated Sludge (HPO) complex. The HPO complex has organic removal in the first stage and nitrification in the second stage. The ABC complex accomplishes both organic removal and nitrification in a single stage. The treated wastewater from the two complexes is recombined prior to being

Rochester Wastewater Reclamation Plant

2,000 kW CHP and Anaerobic Digester
Project



**Figure 1: City of Rochester Water Reclamation
Plant**

chlorinated, disinfected, and then discharged to the Zumbro River.

Solids Handling:

The biological treatment process used to treat the wastewater produces waste activated sludge. This sludge is thickened on gravity belt thickeners, blended with the primary sludge, and the resultant mixture flows through the digester system. The biogas produced by the digesters contains approximately 66% methane gas. The solids removed from the digesters, now referred to as biosolids, are thickened on the gravity belt thickeners and stored prior to being trucked to farm fields where they are land applied as a fertilizer. The biosolids are high in nitrogen and phosphorous and the digestion process significantly reduces pathogens and the potential to create odors.

Biogas Production and Usage

Anaerobic Digesters: The plant presently utilizes two continuous complete mix anaerobic digesters with a total capacity of

3.7 million gallons (installed in 1992). Each of the 1.85 million gallon capacity digesters is 90 feet in diameter, is mesophilic (operate at 98^o F), and operate with a detention time of approximately 34 days. The operation of the digesters has been fairly stable over the years. Table 1 provides some of the operating characteristics of the digesters in 2006, 2007 and 2008 as well as the average since 1994. The methane content of the gas is approximately 66% with a relatively low hydrogen sulfide (H₂S) content of approximately 50 ppmv.

Table 1: Digester Operating Data

Year	Digester Feed		Gas Cu Ft/Day	Time (Days)	VSS FED %	VSS Digested %	% Destroyed
	GPD	#/Day					
2006	130,320	48,257	369,916	28.5	80.21	60.50	62.21
2007	136,247	47,156	337,883	27.2	81.22	60.46	64.64
2008	123,704	43,022	316,241	30.0	81.30	63.22	60.46
Average since 1994	109,047	43,996	317,033	37.47	78.95	58.99	61.74

Note: VSS = Volatile Suspended Solids



Figure 2: Anaerobic Digester and Gas Sphere

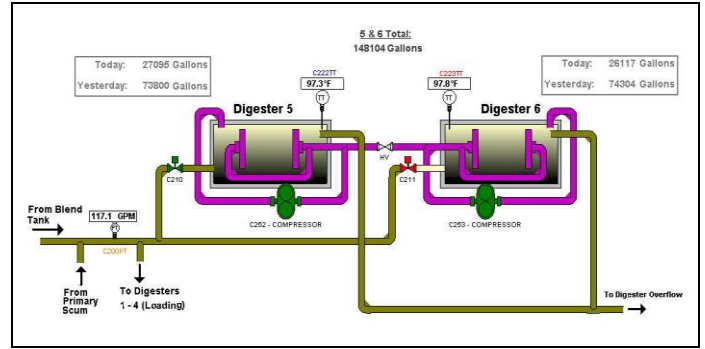


Figure 3: Digester Feed (thickened WAS enters from the left portion of the diagram and the primary sludge enters from the lower portion of the diagram)

Combined Heat and Power System

Electricity Generation: The original combined heat and power (CHP) system was installed in 1982 and consisted of two 440 kW bio-gas engine generators with both jacket water and exhaust gas heat recovery heat exchangers.

In 2002, a two phase project was initiated to upgrade the existing CHP system. In 2002, one of the original engines was replaced with a new 1,000 kW dual fueled engine (bio-gas and natural gas) generator with upgraded jacket water and exhaust heat exchangers. In 2008, the project was completed when the second original engine was replaced with a second new 1,000 kW dual fueled engine generator with heat recovery. Today, the plant has two 1,000 kW Waukesha engines installed. The engines are turbo-charged, lean burn, 20% more efficient than the original engines, and have dual fuel capability (operate on either digester/biogas or natural gas).

The installed capacity of 2,000 kW is more than sufficient to handle the amount of biogas generated by the digesters today. For example, the average flow of 338,000 cu ft/day of 66% methane biogas produced in 2007 can generate approximately 700 kW to 850kW of electric power (depending on the time of year). All the electricity generated by the CHP system is utilized on-site to base load the electrical requirements of the facility. In 2007, the CHP system

generated 2,021,481 kWh of electricity, totaling 11.7% of the wastewater reclamation plant's entire electric load. Table 2 below (Electrical Savings) shows the electrical cost savings in 2007 resulting from operating the CHP system at an average monthly generating capacity of 500 to 800 kW.

The electrical savings are recovered not only from the generated electricity displacing electricity procured from the utility, but also through interruptible savings, load factor credit, and long term service credit.

- The electric energy generated with the CHP system is greater in the summer than in the winter months. This operating mode provides max overall savings by utilizing more of the biogas in the plant boilers to meet the high heating demands in the winter months.

Combined Heat and Power System Recovered Heat: When operating the CHP system, the engine generator set produces recoverable heat in the form of hot water through both the engine jacket water and an exhaust heat recovery boiler. The total recoverable heat is transferred to the plant's main hot water loop and the digester heating loop at temperatures between 180°F and 190°F. Both heating loops have

Table 2: Electrical Savings

Month	Purchased Energy (kWh)	Generated Energy (kWh)	Total Electric Costs (\$)	Savings				
				Generator Energy Savings (\$)	Interruptible Savings (\$)	Load Factor Credit (\$)	Long Term Service* (\$)	Total Savings (\$)
Jan-07	1,316,395	3,838	\$74,632	\$150	\$2,241	\$1,063	\$6,390	\$9,844
Feb-07	1,226,127	2,758	\$71,455	\$108	\$2,077	\$1,184	\$6,918	\$10,287
Mar-07	1,331,017	41,848	\$77,208	\$1,638	\$2,225	\$797	\$6,983	\$11,644
Apr-07	1,321,301	92,977	\$80,481	\$3,640	\$2,225	\$1,048	\$6,984	\$13,898
May-07	1,251,218	333,504	\$90,435	\$16,165	\$2,225	\$1,689	\$6,736	\$26,815
Jun-07	1,156,777	313,407	\$84,274	\$15,872	\$2,151	\$1,520	\$7,238	\$26,780
Jul-07	1,233,702	210,004	\$81,904	\$8,222	\$2,225	\$1,157	\$6,684	\$18,288
Aug-07	1,104,265	393,856	\$88,269	\$20,007	\$2,225	\$294	\$7,973	\$30,500
Sep-07	1,158,124	302,161	\$83,063	\$11,830	\$2,225	\$1,187	\$6,155	\$21,396
Oct-07	1,292,913	227,417	\$85,599	\$8,903	\$2,225	\$1,353	\$6,323	\$18,804
Nov-07	1,336,830	98,052	\$81,812	\$3,839	\$2,225	\$1,601	\$7,600	\$15,265
Dec-07	1,486,972	1,659	\$83,351	\$65	\$2,254	\$846	\$10,985	\$14,149
Total	15,215,641	2,021,481	\$982,483	\$90,439	\$26,523	\$13,739	\$86,969	\$217,670
Average	1,267,970	168,457	\$81,874	\$7,537	\$2,210	\$1,145	\$7,247	\$18,139

* Credit expires end of 2009

Notes for Table 2:

- Generator Energy Savings – result from producing electricity with the CHP system rather than purchase from the utility
- Interruptible Savings – program with the utility where the plant agrees to interrupt 300 kW when requested
- Load Factor Credit – The CHP system allows the plant to control the energy purchased from the utility to maximize the load factor credit
- Long Term Service Credit – expires the end of 2009

external boilers (dual fueled – biogas or natural gas) available to supplement the recovered heat when required or to provide all the required heat if the CHP system is not operating.

Each of the 1,000 kW engine generators can produce a maximum of 4.46 MMBtu/hr of thermal energy (2.46 MMBtu/hr from the engine jacket water, and 2.0 MMBtu/hr from the engine exhaust). When considering the

CHP system is operating on average between 500 kW and 800 kW, the recovered heat delivered from the CHP system totals between 2.23 MMBtu/hr and 3.57 MMBtu/hr.

Optimum Utilization of Biogas:

During the extremely cold Minnesota winters, it has been determined that a greater financial return can result from reducing the operating time and/or capacity of the CHP system and utilizing the produced biogas first as a direct fuel into the existing boilers to meet process and building heating requirements. Any biogas not used in the boiler system during those months is then utilized to generate electricity in the CHP system. Table 3 provides the monthly summary for 2007 of the MMBtus required versus the MMBtus provided (CHP recovered heat, Biogas fueled boiler, Natural Gas fueled boiler). By operating in this mode, the total Btu savings for the year (2007) resulted in a cost savings of \$366,945.

Electricity and Recovered Heat: Finally, Table 4 pulls the numbers together in terms of both the 2007 Btu savings and the electrical savings. Please note that the electrical savings in this table are slightly lower than in Table 2. This is due to factoring such costs as maintenance of the CHP system. The total benefit or savings of utilizing the biogas to operate both the CHP system and plant boilers on the above schedule is approximately \$564,400, of which 41% is provided by the CHP system. Figure 4 graphically shows the contributions to the total monthly savings by biogas generated boiler Btus, biogas generated CHP kWhs and the resulting CHP generated Btus. What is interesting is the optimization of the use of the Biogas between the boilers and CHP system to maximize total savings.

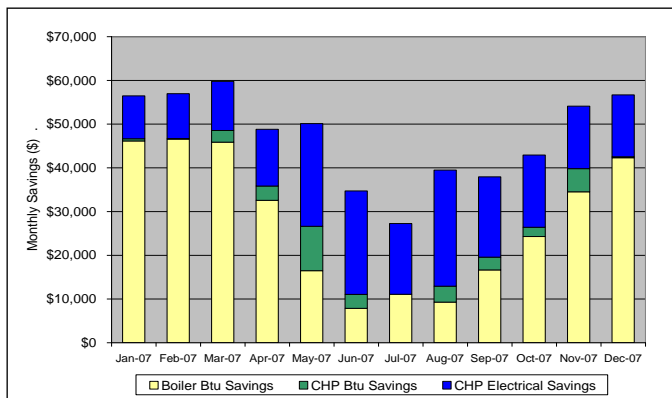
Table 3: Thermal Btu Savings (\$)

Month	Digester Gas Produced (SCF)	Heat Demand (MMBtu)	Generated or Produced (MMBtu)	Boiler Produced (MMBtu)	Purchased (MMBtu)	Gas Purchased (SCF)	Btu Savings (\$)
Jan-07	10,458,044	8,629	49	4,614	3,966	3,966,061	\$46,632
Feb-07	10,394,413	6,905	11	4,657	2,237	2,237,055	\$46,680
Mar-07	11,308,724	5,305	268	4,587	451	450,554	\$48,549
Apr-07	9,920,054	3,583	534	3,463	(413)		\$35,834
May-07	10,312,813	2,663	1,395	2,026	(757)		\$26,630
Jun-07	9,903,415	1,106	1,388	1,854	(2,136)		\$11,059
Jul-07	9,899,308	1,034	1,139	2,320	(2,425)		\$10,336
Aug-07	10,537,595	1,293	1,453	2,017	(2,177)		\$12,927
Sep-07	10,521,626	1,955	1,168	2,544	(1,757)		\$19,554
Oct-07	10,690,887	2,640	901	3,121	(1,383)		\$26,396
Nov-07	9,878,770	4,029	530	3,452	47	47,010	\$39,816
Dec-07	9,498,684	7,848	24	4,229	3,595	3,595,236	\$42,531
Total	123,324,333	46,990	8,860	38,884	(752)	10,295,916	\$366,944
Average	10,277,028	3,916	738	3,240	(63)	2,059,183	\$30,579

	Generator BTU Savings	Boiler BTU Savings	Total BTU Savings	Electrical Savings	Total Savings
Month	(\$)	(\$)	(\$)	(\$)	(\$)
Jan-07	\$490	\$46,142	\$46,632	\$9,806	\$56,438
Feb-07	\$108	\$46,572	\$46,680	\$10,259	\$56,939
Mar-07	\$2,675	\$45,873	\$48,549	\$11,225	\$59,774
Apr-07	\$3,273	\$32,561	\$35,834	\$12,968	\$48,802
May-07	\$10,159	\$16,472	\$26,630	\$23,480	\$50,110
Jun-07	\$3,203	\$7,856	\$11,059	\$23,645	\$34,704
Jul-07	(\$738)	\$11,074	\$10,336	\$16,188	\$26,524
Aug-07	\$3,648	\$9,279	\$12,927	\$26,561	\$39,488
Sep-07	\$2,900	\$16,654	\$19,554	\$18,374	\$37,928
Oct-07	\$2,102	\$24,294	\$26,396	\$16,530	\$42,926
Nov-07	\$5,301	\$34,515	\$39,816	\$14,285	\$54,101
Dec-07	\$244	\$42,287	\$42,531	\$14,132	\$56,663
Total	\$33,365	\$333,580	\$366,945	\$197,453	\$564,398
Average	\$2,780	\$27,798	\$30,579	\$16,454	\$47,033

Table 4: Total Savings

Figure 4: Total Savings



Digester Biogas Storage:

The plant also contains a 50 ft-diameter spherical gas storage tank which can store up to 208,000 cu. ft. of compressed (46 psig) biogas. By supplementing the biogas produced during the normal operation of the plant with the stored biogas from the sphere, the plant has the flexibility to operate the CHP system at significantly higher capacities during utility outages and utility on-peak periods. Also since the engines are dual fueled, the CHP system

can be operated on natural gas if required. These features provide reliability options for the plant during prolonged electric utility outages.

Project Specific Benefits

The main purpose for the City of Rochester to invest and install the 2,000kW CHP system was to provide adequate emergency power. A CHP system was selected to fill this need to provide the added benefit of producing base load electric power and recovered heat to offset the need for purchased utilities (electricity and natural gas). The total cost of the 2,000 kW CHP system was approximately \$4.0 million. With the present levels of biogas production at the plant, the first unit installed (1,000 kW in 2002) will be paid back from savings in approximately 6 years. No direct payback is expected on the second unit. That unit was installed as an emergency power source, a standby unit for utilization during maintenance / downtime periods required of the first unit, and for utilization as the plant grows in biogas production.

System Operation History

Overall, the operation of the total system (digesters, engine generators, and heat

recovery) has been satisfactory. Care is taken to monitor operation of the system and planned maintenance schedules are adhered to.

Additional Digester Capabilities:

The plant has two older digesters (750,000 gallon capacity each) and has the ability to operate at least one if necessary during any planned or unplanned outages of either of the main digesters.

Digester Biogas Conditioning:

The plant removes sulfur content from the produced biogas utilizing an iron scrubber and water is removed from the biogas utilizing drip holes. To date, the plant has not installed a siloxane removal system. A financial analysis was done on the need to invest in a siloxane removal system, and it was determined that investing in periodic major engine overhauls was less expensive than investing in a siloxane removal system. Recent experience shows that the time between major overhauls (due to siloxane buildup) has increased from 8,000 hours to over 16,000 hours and based on current engine conditions, the wastewater treatment facility manager expects to increase major overhaul interval by another 4,000 to 8,000 hours.



Figure 5: Waukesha 1,000 kW Lean Burn Turbo-Charged Dual Fueled Gas Engine Generator Set

Lessons Learned

CHP systems can be fairly complex and control intensive

- Be alert for unforeseen project startup issues

- Provide additional training for operations and maintenance personnel
- Systems can operate on a relatively stand-alone basis if tied into a SCADA or other monitoring and control system

CHP projects require due diligence from design through operation and maintenance

- Proper sizing of equipment
- Proper control system design
- Proper training
- Need for biogas analysis and possible gas cleanup
- Proper digester maintenance

The CHP system provides the opportunity to better control energy usage, provides measurable energy savings, and provides good public relations (energy and environmental stewardship)

The CHP system, in the case of the City of Rochester, provided two solutions in one package

- Source of Emergency Backup power
- Renewable energy source to offset purchased energy from utilities

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