THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Electric Power and Heat Production using Natural Gas
APPLICATION:	Combined Heat and Power System
TECHNOLOGY NAME:	Tecogen Model CM-100
COMPANY:	Tecogen
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The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of ETV is to further environmental protection by accelerating the acceptance and use of improved and innovative environmental technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Greenhouse Gas Technology Center (GHG Center), operated by Southern Research Institute (Southern), is one of six verification organizations operating under the ETV program. A technology area of interest to some GHG Center stakeholders is distributed electrical power generation (DG), particularly with combined heat and power (CHP) capabilities.

The GHG Center collaborated with the New York State Energy Research and Development Authority (NYSERDA) to evaluate the performance of an array of six Tecogen Model CM-100 units - combined heat and power (CHP) system manufactured by Tecogen and fueled with natural gas. The system is owned and operated by BOCES in Verona, New York.

TECHNOLOGY DESCRIPTION

The following information has been supplied by the vendor and has not been verified. Building Energy Solutions (BES) has installed six natural gas-fired Tecogen Model CM-100 Premium Power CHP modules as part of a DG / CHP upgrade at the Madison-Oneida Board of Cooperative Educational Services (BOCES) campus located in Verona, NY. The technical basis for the technology is as follows.

The Tecogen system utilizes natural gas fuel, combusted in an internal combustion engine, which is used to drive an electric generator. Thermal energy in the engine's exhaust heat and other heat sources is recovered and used for various purposes. The CHP array operates in response to the site's electrical demand; power is not exported to the grid. Management of the host facility's peak electrical demand is a fundamental economic driver for the system.

The installation recovers thermal energy from the IC engine jacket coolant, oil cooler, and exhaust. The recovered energy is designed to supply up to 4.4 million British thermal units per hour (MMBtu/h) from the array of six units to the following district heating and cooling applications:

- year-round domestic hot water (DHW)
- heat supply to two 100-ton absorption chillers for air-conditioning during warm weather
- hydronic space heating during cold weather

The facility also incorporates two 7500-gallon insulated thermal storage tanks. Their function is to provide approximately 2.5 MMBtu carry-through capacity for space heating and DHW needs during cold weather periods when electrical demand is low.

The CHP heating and cooling applications displace fuel consumption by five existing natural gas-fired boilers rated at1.94 MMBtu/h each. Two of the boilers are located adjacent to the CHP installation while the remaining three are located elsewhere on the campus. Hydronic heating, DHW, and chilled water piping is generally located in the ceiling spaces and corridors which connect the various building sections. The electrical generators, panel boards, circulation pumps, and most other parasitic loads are connected to the main service bus located in the building "Section H" mechanical room.

VERIFICATION DESCRIPTION

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in the draft ETV Generic Verification Protocol (GVP) [3] for DG/CHP verifications developed by the GHG Center. Site specific information and details regarding instrumentation, procedures, and measurements specific to this verification were detailed in the Test and Quality Assurance Plan titled *Test and Quality Assurance Plan – Building Energy Soulutions, LLC Tecogen DG / CHP Installation.* Both can be downloaded from the ETV Program web-site (www.epa.gov/etv).

Controlled Testing

Controlled testing for the field testing was conducted on September 9, 2009 through September 11th, 2009. The defined system under test (SUT) was tested to determine performance for the following verification parameters:

- Electrical Performance
- Electrical Efficiency
- CHP Thermal Performance
- CHP Thermal Efficiency
- Atmospheric Emissions (controlled test period only).
- NO_x and CO_2 emissions reductions (offsets) relative to baseline conditions

Electrical and thermal performance and efficiency were quantified following the rationale and approaches detailed in the GVP. Specifically, electrical generation efficiency can also be termed the "fuel-to-electricity conversion efficiency." It is the net amount of energy a system produces as electricity compared to the amount of energy input to the system in the fuel. Heat rate expresses electrical generation efficiency in terms of British thermal units per kW-hour (Btu/kWh). For determination of thermal performance, applicable CHP devices use a circulating liquid heat transfer fluid for heating or chilling. The CHP equipment itself is considered to be within the SUT boundary. The balance of plant (BoP) equipment, which employs the heating or chilling effect, is outside the system boundary. The GVP does not consider how efficiently the BoP uses the heating or chilling effect. Actual thermal performance is the heat transferred out of the SUT boundary to the BoP for both CHP heaters and chillers. Actual thermal efficiency in heating service is the ratio of the thermal performance to total heat input in the fuel. Detailed definitions and equations appear in Appendix C of the GVP.

The verification included a series of controlled test periods on September 10, 2009 in which the GHG Center maintained steady system operations for three test periods at loads of 100%, 75%, and 50% of capacity (100, 75, and 50 kW, respectively) on one of the six Tecogen CM 100 units. Equipment tag name, Cogen 4 was selected from the six units to evaluate electrical and CHP efficiency and emissions performance. Testing took place at night so it would not interfere with normal operations of the facility. Five of the six units were shutdown during the controlled test period and temporary installation of independent electrical power analyzers were placed on the Cogen 4 output bus. The analyzers recorded the electrical performance parameters at 1-minute intervals. Water serves as the CHP heat transfer fluid. Southern installed supply and return temperature sensors and an ultrasonic fluid flow meter to determine heat recovery from the CHP system heat recovery loop.

Emissions data were recorded from the Cogen 4 exhaust stack on the roof of the mechanical room. Southern's Horiba OBS-2200 PEMS (Portable Emissions Monitoring System) was installed on the exhaust stack to measure atmospheric emissions including THC, CO, CO_2, and NO_x. Other parameters including exhaust flow, exhaust temperature, exhaust pressure, moisture, ambient temperature, and ambient pressure were also collected from the OBS-2200 to allow for computing exhaust gas flow at dry, standard conditions. Fuel gas consumption was determined by a data logger connected to a revenue-grade gas meter. Southern installed a Dresser brand Roots meter (model 11M175) in the CHP array gas line. The meter incorporates a high-frequency pulse output for flow rate determinations. Test personnel connected the meter output to the data logger and recorded the gas flow rate at least once per minute during all test periods. Testing personnel also temporarily installed ports for collecting natural gas samples for lower heating value (LHV) analysis.

Long-term Monitoring
The controlled tests were followed by a 1 year period of continuous monitoring to determine heat recovery and power output, electrical and thermal efficiency, and estimated annual emission reductions on the full array of six CHP units under normal operation.

Quality Assurance

Quality assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). On September 10th 2009, the EPA conducted a Technical Systems Audit on site. Bob Wright from EPA and David Gratson from Neptune and Company, Inc conducted the audit while controlled testing was underway. The GHG Center's QA manager conducted an audit of data quality on the data generated during this verification and a review of this report. Data review and validation was conducted at three levels including the field team leader, the project manager, and the QA manager.

VERIFICATION OF PERFORMANCE

Electrical and Thermal Performance – Controlled Test Period

Gross and net electrical performance and efficiency as measured during the controlled test period are presented in Table 1. Net electrical performance is exclusive of power consumed by CHP system electrical loads required for system operation (parasitic loads). Parasitic loads are disproportionally high during the controlled test period when only one unit is operating as compared to normal operations when up to six cogeneration units may be operating. Parasitic loads during the controlled test period averaged about 7 percent of gross power output, whereas during the long term monitoring, parasitic loads averaged only 2-4 percent of gross power output (depending on load conditions). Uncertainties given in table 1 were determined by measurement error propagation as detailed in Section 7 of the GVP.

Thermal performance as measured during the controlled test period is not reported. The thermal performance measurements are not considered representative for several reasons. The heat recovery fluid flow measurement is not considered reliable because the flow velocities with only a single unit operating were at or below the velocity at which the instrument accuracy rapidly deteriorates. Heat losses with only a single unit operating are disproportionately high compared to normal operations with up to six units operating. System controls, which seek to maintain the return temperature to the cogeneration array at a constant level, did not appear to be able to operate as intended with only a single unit operating, resulting in cycling of flow rate and return temperature. A detailed assessment of these factors is provided in section 3.2.3 of the full verification report.

Table 1. Controlled Test Electrical and Thermal Performance

Test ID		Heat Input (MMBtu/h)	Electrical Power Generation Performance			
			Net Power Generated (kW)	**Net Electrical Efficiency (%)**	**Gross Power Generated (kW)**	**Gross Electrical Efficiency (%)**
100 kW	Run 1	1.18	91.8	26.5	98.0	28.3
	Run 2	1.17	91.2	26.6	97.3	28.4
	Run 3	1.17	91.4	26.6	97.7	28.4
	Avg.	**1.18**	**91.5**	**26.6**	**97.7**	**28.4**
	+/-	**1.8%**	**0.7%**	**3.0%**	**0.7%**	**3.0%**
75 kW	Run 1	0.85	66.2	26.5	72.3	28.9
	Run 2	0.85	66.1	26.4	72.3	28.9
	Run 3	0.86	66.5	26.4	72.6	28.8
	Avg.	**0.86**	**66.3**	**26.4**	**72.4**	**28.9**
	+/-	**1.8%**	**0.7%**	**3.0%**	**0.7%**	**3.0%**
50 kW	Run 1	0.57	41.6	24.7	47.3	28.1
	Run 2	0.57	41.4	24.6	47.2	28.0
	Run 3	0.58	42.8	25.2	47.5	28.0
	Avg.	**0.58**	**41.9**	**24.8**	**47.3**	**28.0**
	+/-	**1.8%**	**0.7%**	**3.0%**	**0.7%**	**3.0%**

Reported uncertainties by measurement error propagation per GVP in percentage of reported value. Net electrical performance is exclusive of electrical loads required for system operation (parasitic loads). Parasitic loads are disproportionately high during the controlled test conditions as described above.

Emissions Performance – Controlled Test Period
Table 2 summarizes emissions performance of the Cogen 4 unit during the controlled test period.

THC and NO_x emissions at the 50kW load condition are elevated. This is due to poor engine performance at partial load – an abnormal operating condition. In normal operations, the units are run at greater than 60 percent load and individual units are taken on and off line in response to facility electrical demand.

Uncertainties given in this table were determined by calculating a 95 percent confidence interval over the mean of all three runs at each load condition. The higher uncertainty for CO emissions at the 75kW load conditions is due to a greater degree of fluctuation in CO concentration at the lower load conditions. CO emissions measurements for the 50kW load condition were invalidated and are not reported. The analyzer failed the span drift check at the conclusion of the test run, and examination of the data showed that negative values were frequently reported.

Power Quality Performance – Controlled Test Period
Power quality was not monitored during the controlled test period due to a malfunction of data logging equipment. This is not considered to have a significant impact on the quality of the performance verification as power quality is proven to be sufficient for grid interconnect.

Electrical and Thermal Performance – Long Term Monitoring Period
Measurements necessary to determine electrical and thermal performance and efficiency were collected over a period from September 2009 through September 2010. Table 3 provides a summary of the results. During normal operations at the BOCES facility, the cogeneration array operates in response to electrical demand. As such, the array typically operates at nearly full load during weekdays, with partial load at nights and on weekends. Full load conditions are characterized by power generation rates over 300kW, and night/weekend conditions are characterized by generation rates less than 300 kW. The cogeneration array operated nearly continuously throughout the year of monitoring, with only one brief period of down time (43 hours) in late June 2010.

Gross electrical efficiency during the extended test was 24.1 percent on an annual basis, 26.4 percent at full load conditions, and 22 percent at partial load conditions. Parasitic loads accounted for 2 to 4 percent of power production depending on load conditions.

As can be seen in Table 3, the electrical and thermal efficiency of the system is somewhat lower at partial load than at full load. The lower thermal efficiency at partial load may be due to system heat losses - which amount to a greater proportion of the total heat recovered at partial load than at full load.

The lower electrical efficiency at partial load is not fully explained by the data. However, at the very lowest loads (occurring during weekend daytimes), fuel consumption was consistently observed to increase as power output decreased. This could be due to the cogeneration array running in an inefficient operating range at the lowest load conditions. During the controlled tests with only one of six units operating, electrical efficiency decreased slightly at the 50 percent load condition, but not as much as was observed during extended monitoring of the full cogeneration array.

Table 2. Tecogen Emissions During Controlled Test Periods

Test ID		Gross Power (kW)	CO Emissions			CO2 Emissions		
			ppm	lb/hr	lb/MWh	Volume %	lb/hr	lb/MWh
100kW	Run 1	98	175	0.17	1.8	9.3	91	930
	Run 2	97	162	0.16	1.6	9.2	90	927
	Run 3	98	168	0.16	1.7	9.2	91	928
	Avg.	**98**	**168**	**0.17**	**1.7**	**9.2**	**91**	**928**
	95% CI		**1.7%**			**0.02%**		
75 kW	Run 1	72	44	0.04	0.5	9.1	80	1113
	Run 2	72	81	0.08	1.1	9.1	85	1182
	Run 3	73	96	0.09	1.2	9.1	86	1180
	Avg.	**72**	**74**	**0.07**	**0.9**	**9.1**	**84**	**1158**
	95% CI		**5.3%**			**0.06%**		
50 kW	Run 1	47	not reported*	0.06	1.4	9.2	52	1095
	Run 2	47	not reported*	0.08	1.7	9.2	59	1250
	Run 3	48	not reported*	0.09	1.8	9.2	63	1328
	Avg.	**47**		**0.08**	**1.6**	**9.2**	**58**	**1224**
	95% CI					**0.07%**		
Test ID		**Gross Power (kW)**	**THC Emissions**			**NOx Emissions**		
			ppm	**lb/hr**	**lb/MWh**	**ppm**	**lb/hr**	**lb/MWh**
100kW	Run 1	98	5.7	0.006	0.06	12.8	0.013	0.1
	Run 2	97	4.8	0.005	0.05	12.9	0.013	0.1
	Run 3	98	4.9	0.005	0.05	13.1	0.013	0.1
	Avg.	**98**	**5.1**	**0.005**	**0.05**	**12.9**	**0.013**	**0.1**
	95% CI		**1.2%**			**2.5%**		
75 kW	Run 1	72	8.8	0.008	0.11	8.4	0.007	0.1
	Run 2	72	8.5	0.008	0.11	8.3	0.008	0.1
	Run 3	73	8.7	0.008	0.11	7.8	0.007	0.1
	Avg.	**72**	**5.8**	**0.008**	**0.11**	**5.6**	**0.008**	**0.1**
	95% CI		**2.3%**			**4.0%**		
50 kW	Run 1	47	273	0.154	3.2	843	0.475	10.0
	Run 2	47	288	0.185	3.9	881	0.567	12.0
	Run 3	48	292	0.201	4.2	881	0.608	12.8
	Avg.	**47**	**284**	**0.180**	**3.8**	**869**	**0.550**	**11.6**
	95% CI		**1.5%**			**1.6%**		

*Carbon monoxide results for the 50 percent load condition are not reported because the instrument failed the span drift check at the conclusion of the testing at this condition and the results appeared suspect upon examination (concentrations during the run were frequently recorded as negative values).

Table 3. Extended Test Results Summary

	Average Net Power Output (kW)	**+/-**	**Average Heat Recovery (MMBtu/hr)**	**+/-**	**Average Thermal Efficiency (%)**	**+/-**	**Average *Net* Electrical Efficiency (%)**	**+/-**	**Average Total Efficiency (%)**	**+/-**
Annual Average	293	0.7%	2.26	4.4%	53.7	4.9%	23.5	3.0%	77.2	3.5%
Full Load - (Weekday) (>=300kW)	394	0.7%	2.98	4.4%	60.4	4.9%	25.8	3.0%	86.2	3.5%
Partial Load - (Night) (<300kW)	211	0.7%	1.68	4.4%	48.2	4.9%	21.3	3.0%	69.5	3.5%

Reported uncertainties by measurement error propagation per GVP.

Signed by Cynthia Sonich-Mullin (3/7/2013)

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