THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Biogas-Fired Microturbine Combined With Heat Recovery System
APPLICATION:	Distributed Electrical Power and Heat Generation
TECHNOLOGY NAME:	Capstone 30 kW Microturbine System
COMPANY:	Colorado Pork, LLC
ADDRESS:	Lamar, Colorado

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective 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), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. A technology of interest to GHG Center stakeholders is the use of microturbines and engines as distributed generation sources. Distributed generation (DG) refers to power-generation equipment that provides electric power at a site much closer to customers than central station generation. Recently, biogas production from livestock manure management facilities has become a promising alternative for fueling DG technologies. These technologies, commonly referred to as anaerobic digesters, decompose manure in a controlled environment and recover methane produced from the manure digestion. The recovered methane can fuel power generators to produce electricity, heat, and hot water. Digesters also reduce foul odor and can reduce the risk of ground- and surface-water pollution.

The GHG Center collaborated with the Colorado Governor's Office of Energy Management and Conservation (OEMC) to evaluate the performance of two combined heat and power systems (CHP systems) that operate on biogas recovered from swine waste generated at the Colorado Pork facility in Lamar, Colorado. This verification statement provides a summary of the test results for the Capstone 30 kW Microturbine CHP system.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by Capstone and OEMC and does not represent verified information. The microturbine system tested at Colorado Pork consists of a Capstone Model 330 Microturbine and a heat-recovery system developed by Cain Industries. The CHP system also includes a CompAir gas compressor which is needed to boost the gas pressure to about 100 psig. A permanent magnet generator produces high-frequency alternating current which is rectified, inverted, and filtered by the line power unit into conditioned 480 volts alternating current (VAC). The unit supplies an electrical frequency of 60 hertz (Hz) and is equipped with a control system that allows for automatic and unattended operation. An active filter in the generator is reported by the turbine manufacturer to provide power free of spikes and unwanted harmonics. All operations, including startup, setting of programmable interlocks, grid synchronization, operational setting, dispatch, and shutdown, can be performed manually or remotely using the internal power-controller system.

The gas booster compressor is a CompAir Hydrovane Model 704PKGS with a nominal volume capacity of 48 standard cubic feet per minute (scfm) and the capability of compressing gas from inlet pressures ranging from 0.25 to 15 pounds per square inch gauge (psig) to outlet pressures of 60 to 100 psig. The compressor is boosting gas pressure from approximately 1 to 100 psig in this application. The compressor imposes a parasitic load of approximately 4 kW on the overall CHP system generating capacity.

Waste heat from the microturbine exhaust is recovered using a Cain Industries heat recovery and control system. It is a steel fin-and-tube Heat Recovery Silencer (HRS) radial heat exchanger and silencer (Model 112B28.SSS) suitable for up to 700 °F exhaust gas. Potable water is used as the heat-transfer media to recover energy from the microturbine exhaust gas. The water is circulated at a rate of approximately 28 gallons per minute (gpm). A digital controller monitors the water outlet temperature. When the temperature exceeds the user set point, a damper automatically opens and allows the hot exhaust gas to bypass the heat exchanger and release the heat through the stack. The damper allows hot gas to circulate through the heat exchanger when heat recovery is required (i.e., the water outlet temperature is less than user setpoint). This design allows the system to protect the heat recovery components from the full heat of the turbine exhaust while still maintaining full electrical generation from the microturbine.

The Colorado Pork facility is a sow farrow-to-wean farm in Lamar, Colorado that began operation in 1999 and houses up to 5,000 sows. The facility employs a complete mix anaerobic digester to reduce odor and meet water quality regulations mandated by the Colorado Department of Public Health and Environment. The anaerobic digester promotes bacterial decomposition of volatile solids in animal wastes. The resulting effluent stream consists of mostly water, which is allowed to evaporate from a secondary lagoon. Solids produced by the process accumulate in the digester and are manually removed. Recovered heat from the microturbine CHP is circulated through the waste in the digester to maintain the digester temperature at approximately 100 °F. Cool water returning from the digester remains relatively constant throughout the year. A temperature sensor continuously monitors this temperature, and in the event this temperature exceeds 105 °F, an automated mixing valve reduces the flow of hot water entering the digester.

VERIFICATION DESCRIPTION

Testing was conducted on February 14 and 15, 2004. The verification included a series of controlled test periods in which the GHG Center intentionally controlled the unit to produce electricity at nominal power output levels of 30, 24, 20, and 15 kW. Three replicate test runs were conducted at each setting. A 7-day extended monitoring period was planned to verify power and heat production, power quality performance, and emissions offsets during normal site operations. However, this could not be completed due to system startup and shakedown delays that resulted in GHG Center scheduling conflicts. Instead, the CHP performance was monitored continuously for a period of approximately 35 hours to evaluate power and heat production and power quality. In light of this, the emission offsets analysis was not conducted and the completeness data quality objective of 7-days was not met. During all test periods, waste heat was recovered and routed through the digester at temperatures of approximately 100 °F. The classes of verification parameters evaluated were:

- **Heat and Power Production Performance**
- **Emissions Performance (NO_x, CO, THC, CH_4, SO_2, TRS, TPM, NH_3, and CO_2)**
- **Power Quality Performance**

Evaluation of heat and power production performance included verification of power output, heat recovery rate, electrical efficiency, thermal efficiency, and total system efficiency. Electrical efficiency was determined according to the ASME Performance Test Code for Gas Turbines (ASME PTC-22). Tests consisted of direct measurement of fuel flow rate, fuel lower heating value (LHV), and power output. Heat recovery rate and thermal efficiency were determined according to ANSI/ASHRAE test methods and consisted of direct measurement of heat-transfer fluid flow rate and differential temperatures. Ambient temperature, barometric pressure, and relative humidity measurements were also collected to characterize the condition of the combustion air used by the microturbine. All measurements were recorded as 1-minute averages during the controlled test periods and throughout the 7-day monitoring period.

The evaluation of emissions performance occurred simultaneously with efficiency testing. Pollutant concentration and emission rate measurements for nitrogen oxides (NO_X), carbon monoxide (CO), total hydrocarbons (THC), methane (CH_4), sulfur dioxide (SO_2), total reduced sulfur (TRS), total particulate matter (TPM), ammonia (NH_3), and carbon dioxide (CO_2) were conducted in the turbine exhaust stack. All test procedures used in the verification were U.S. EPA reference methods recorded in the Code of Federal Regulations (CFR). Pollutant emissions are reported as concentrations in parts per million volume, dry (ppmvd) corrected to 15-percent oxygen (O_2), and as mass per unit time (lb/hr). The mass emission rates are also normalized to microturbine power output and reported as pounds per kilowatt hour (lb/kWh).

Electrical power quality parameters, including electrical frequency and voltage output, were measured during the controlled tests and the 35-hour monitoring period. Current and voltage total harmonic distortions (THD) and power factors were also monitored to characterize the quality of electricity supplied to the end user. The guidelines listed in "The Institute of Electrical and Electronics Engineers' (IEEE) Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" were used to perform power quality testing.

Quality Assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). The GHG Center's QA Manager conducted an audit of data quality on at least 10 percent of 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 (for data generated by subcontractors), the project manager, and the QA manager. Through these activities, the QA manager has concluded that, with the exception of the extended monitoring completeness goal described earlier, the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan.

VERIFICATION OF PERFORMANCE

Heat and Power Production Performance

MICROTURBINE CHP HEAT AND POWER PRODUCTION					
Test Condition (Power Command)	Electrical Power Generation		Heat Recovery Performance		Total CHP System Efficiency (%)
	Net Power Delivered (kW)	Net Efficiency (%)	Heat Recovery (10^3Btu/hr)	Thermal Efficiency (%)	
30 kW	19.9	20.4	111	33.3	53.7
24 kW	19.3	20.3	116	35.8	56.2
20 kW	15.0	18.6	108	39.2	57.7
15 kW	10.1	15.7	96.9	44.1	59.8

- The relatively high altitude of the facility (roughly 3,700 feet) and the parasitic load introduced by the gas compressor limit the turbine's power output performance. At the full power output command of 30 kW, the average net power delivered to the facility was 19.9 kW. Corresponding electrical efficiency at full load was 20.4 percent.

- Average electrical efficiencies at the reduced power commands of 24, 20, and 15 kW decreased to 20.3, 18.6, and 15.7 percent, respectively.

- Total CHP efficiency during the controlled test periods ranged from a low of 53.7 percent at the 30 kW load to a high of 59.8 percent at 15 kW. Normal heat recovery operations were maintained during the controlled test periods with the system configured to maintain the digester temperature at approximately 100°F.

Emissions Performance

MICROTURBINE EMISSIONS (lb/kWh)									
Power Command	NO_X	CO	THC	CH_4	SO_2	TRS	TPM	NH_3	CO_2
30 kW	8.21×10^{-5}	0.009	0.0027	0.0022	0.037	0.0008	0.0006	6.07×10^{-7}	3.45
24 kW	9.47×10^{-5}	0.010	0.0032	0.0027	0.039	0.0002	Not tested	Not tested	3.61
20 kW	1.95×10^{-3}	0.010	0.0035	0.0028	0.040	0.0005	Not tested	Not tested	3.79
15 kW	2.19×10^{-3}	0.017	0.0105	0.0087	0.042	0.0002	Not tested	Not tested	3.90

- NO_X emissions at 30 kW were 8.21×10^{-5} lb/kWh and increased as power output decreased. CO emissions averaged 0.009 lb/kWh at 30 kW and also increased slightly at the reduced loads.

- THC emissions at full load averaged 2.69 x 10^{-3}lb/kWh and increased as the power output was decreased. CH_4 emissions were similar, averaging 2.23 x 10^{-3} at full load, and representing approximately 80 percent of the THC emission rate.

- Emissions of SO_2 and TRS averaged 0.037 and 0.0008 lb/kWh respectively at full load and were not significantly impacted by load changes. Emissions of TPM and NH_3 were very low during the full load tests.

NO_X emissions per unit electrical power output at 30 kW (0.00008 lb/kWh), were well below the published weighted average U.S. and Colorado regional fossil fuel emission factors of 0.0066 and 0.0077 lb/kWh. The generator system CO_2 emission rate at full load is higher than the weighted average fossil fuel emission factors for both the U.S. and Colorado regional grids (2.02 and 2.13 lb/kWh, respectively). This indicates a likely increase in annual CO_2 emissions for power production from this system, based solely on electrical generation. Due to the reduction in the extended monitoring period, a true estimation of annual emissions offsets could not be completed.

Power Quality Performance

- Average electrical frequency was 59.999 Hz and average voltage output was 487.25 volts.
- The power factor remained relatively constant at full load, averaging 94.53 percent.
- The average current total harmonic distortion was 3.21 percent and the average voltage THD was 1.89, both well below the threshold specified in IEEE 519 of ± 5 percent.

Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the Test plan titled *Test and Quality Assurance Plan for Swine Waste Electric Power and Heat Production Systems: Capstone Microturbine and Martin Machinery Internal Combustion Engine* (SRI 2002). Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report for Swine Waste Electric Power and Heat Production – Capstone 30 kW Microturbine System* (SRI 2004). Both can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

Signed by Lawrence W. Reiter, Ph.D. 9/27/04

Lawrence W. Reiter, Ph.D.
Acting Director
National Risk Management Research Laboratory
Office of Research and Development

Signed by Stephen D. Piccot 9/13/04

Stephen D. Piccot
Director
Greenhouse Gas Technology Center
Southern Research Institute