US EPA ARCHIVE DOCUMENT

US EPA ARCHIVE DOCUMENT

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Natural-Gas-Fired Microturbine Combined With Heat Recovery System**
APPLICATION:	**Distributed Electrical Power and Heat Generation**
TECHNOLOGY NAME:	**Heat PlusPower™ System**
COMPANY:	**Mariah Energy Corporation**
ADDRESS:	**Box 6044, Station A, Calgary, Alberta, Canada T2H 2L3**
E-MAIL:	**pliddy@mariahpower.com**

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 substantially 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. The GHG Center has recently evaluated the performance of the Heat PlusPower™ System (Mariah CHP System). This verification statement provides a summary of the test results for the Mariah CHP System, which is offered by Mariah Energy Corporation of Calgary, Alberta.

TECHNOLOGY DESCRIPTION

Large- and medium-scale gas-fired turbines have been used to generate electricity since the 1950s. Technical and manufacturing developments during the last decade have enabled the introduction of microturbines, with generation capacities ranging from 30 to 200 kW. The Mariah CHP System is one of the first cogeneration installations that integrate microturbine technology with a heat recovery system.

Electric power is generated with a Capstone MicroTurbine™ Model 330, with a nominal power output of 30 kW_e (60 ^oF, sea level). The system incorporates an air compressor, recuperator, combustor, turbine, and permanent-magnet generator. Filtered air is pressurized in the compressor, and then enters the combustor where it is mixed with fuel and heated further by combustion. The resulting hot gas is allowed to expand through the turbine section to perform work, rotating the turbine blades to turn a generator that produces electricity. The inverter-based electronics enable the generator to operate at high speeds and frequencies, so the need for a gearbox and associated moving parts is eliminated. The rotating components are mounted on a single shaft, supported by patented air bearings that rotate at over 96,000 rpm (full load). The exhaust gas exits the turbine and enters the recuperator, which transfers waste heat from the combustor into the combustion air stream, improving the overall efficiency of the system. The exhaust gas then exits the recuperator through a muffler and enters Mariah's heat recovery unit. Mariah provides an optional muffler system to further reduce sound levels at installations requiring quieter operation. The standard turbine requires a natural gas supply pressure of 52 to 60 psig. Capstone offers an optional booster compressor for sites where high pressure gas is not available. The use of a booster compressor will decrease overall electrical efficiency.

The Mariah CHP System uses the Capstone industrial housing which required no structural modifications to support the weight of an overhead heat recovery unit. The housing was modified to alter the exhaust flow path, and for improved sound attenuation. The heat recovery system consists of a fin-and-tube heat exchanger, which circulates a 15 to 17 percent propylene glycol (PG) mixture through the heat exchanger at approximately 20 gallons per minute. The primary heating loop is driven by a pump, which circulates the heat to building areas where hot water and comfort heating are needed. After the heat transfer is complete, the PG mixture is circulated back to the fin-and-tube heat exchanger, energy is exchanged between the hot turbine exhaust gas and the PG mixture, and the circulation loop is repeated. If the heat demand is significantly lower than the heat recovered with the Mariah CHP System, such that overheating of the glycol loop could occur, the system will automatically shut off. The thermal control system, monitoring the supply and return temperatures of the PG mixture, is programmable. The maximum return temperature is set to not exceed 203 ^oF. The exhaust gases leave the heat recovery unit at less than 212 ^oF, and are vented through the stack.

The permanent-magnet generator produces high-frequency alternating current which is rectified, inverted, and filtered by the line power unit into conditioned alternating current at 480 VAC. The unit can select an electrical frequency of 50 or 60 hertz (Hz), and is supplied with a control system which allows for automatic and unattended operation. An active filter in the turbine 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 settings, dispatch, and shutdown, can be performed manually or remotely using an internal power controller system. The Mariah CHP System runs parallel with the local power utility. If the site power demand exceeds the available capacity of the turbine, additional power is drawn from the grid. In the event of a power grid failure, the system is designed to automatically disconnect from the grid and run stand-alone, which isolates the on-site electrical system from grid faults. The control system is also designed to automatically shed lower priority loads, if necessary, to ensure that local loads do not exceed stand-alone generator capacity. When grid power is restored, the Mariah CHP System can either automatically reconnect, or await a manual command.

US EPA ARCHIVE DOCUMENT

VERIFICATION DESCRIPTION

Verification of the Mariah CHP System was conducted at the Walker Court condominium site in Inglewood, Calgary (elevation 3,370 ft). The site is a live/work arrangement consisting of 12 units that combine a street-level retail/office space with a two-level residence above. A single Mariah CHP System unit, connected in parallel with the Alberta grid, provides on-site electricity, hot water, and space heating. An external voltage transformer converts 480 VAC output to 220 VAC. Excess electricity, not consumed at the site, is exported to the grid. The Mariah CHP System is sized to meet all of Walker Court's thermal energy needs, except during peak heating seasons, when supplementary heat may be needed. An on-site natural-gas-fired boiler serves as a backup heat source for cold winter months. The natural gas supplied is of sufficient pressure such that an optional booster compressor is not needed.

Testing commenced on April 2, 2001, and was completed on May 25, 2001. It consisted of a series of short periods of "load testing," in which the GHG Center intentionally modulated the unit to produce electricity at 100, 90, 75, and 50 percent of rated power (30 kW nominal). These 4 days of load testing were followed by 38 days of extended monitoring to verify electric power production, heat recovery, and power quality performance. The Mariah CHP System was operating 24 hours per day at maximum electrical power output and heat recovery rate. Because Walker Court was new and had achieved only a 25 percent occupancy during the test period, the demand for heat was low. To verify the heat recovery potential of the Mariah CHP System, heat was discarded through open windows and doorways, simulating higher energy demand. As such, the verification results reported here represent maximum heat recovery and thermal energy performance. The specific verification factors are:

Heat and Power Production Performance
Emissions Performance (NO_x, CO, THC, CO_2, and CH_4)
Power Quality Performance

Evaluation of heat and power production performance includes verification of power output, heat recovery rate, electrical efficiency, thermal efficiency, and total system efficiency loads. Electrical efficiency was determined according to the ASME Performance Test Code for Gas Turbines (PTC-22), and consisted of direct measurements of fuel flow rate, fuel heating value, and power output. Heat recovery rate and thermal efficiency were determined according to ANSI/ASHRAE test methods, and consisted of direct measurements of heat transfer fluid flow rate, differential temperatures, and specific heat of the heat transfer fluid. Ambient temperature, barometric pressure, and relative humidity measurements were also collected to characterize the condition of the combustion air.

The evaluation of emissions performance occurred simultaneously with efficiency determination at the four load conditions cited. Pollutant concentration and emission rate measurements for nitrogen oxides (NO_x), carbon monoxide (CO), total hydrocarbons (THC), carbon dioxide (CO_2), and methane (CH_4) were conducted in the turbine exhaust stack. All test procedures used in the verification were U.S. EPA Federal Reference Methods. Pollutant concentrations in the exhaust gas are reported in two sets of units; parts per million volume, dry (ppmvd) corrected to 15 percent oxygen (O_2), and mass per unit time (lb/hr). The mass emission rates are also normalized to turbine power output and reported as pounds per kilowatt hour (lb/kWh).

NO_x and CO_2 emissions reductions for the Mariah CHP System are estimated by comparing measured lb/kWh emission rates with corresponding emissions levels for baseline power and heat production systems (i.e., systems that would be used if the Mariah CHP System were not present). For the test site, baseline systems include electricity supplied from the Alberta grid and heat from a standard natural gas boiler (73 percent efficiency, derated for elevation). Baseline emissions from the Alberta grid are based on real-time hourly average plant specific emissions from Alberta power plants (90 percent are coal fired), and were compiled by the KEFI-Exchange. Emissions from heat production are based on EPA emission factors for residential-scale gas-fired boilers.

US EPA ARCHIVE DOCUMENT

Electrical power quality parameters, such as electrical frequency and voltage output, were also measured during the 38-day extended test. Other performance parameters, such as current and voltage total harmonic distortions (THD) and power factor, were monitored to characterize the quality of electricity supplied to the end user. The guidelines listed in the Institute of Electrical and Electronics Engineers' Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems were used to perform power quality testing.

VERIFICATION OF PERFORMANCE

Heat and Power Production Performance

- All load tests occurred at similar operating conditions (ambient temperatures: 40.90 to 43.96 ^{o}F; barometric pressure: 12.90 to 13.11 psia; relative humidity: 44 to 54 percent).

- At full load, 28.39 ± 0.01 kW of electric power was generated. Maximum heat recovery rate was 186.9 ± 5 MBtu/hr.

- At full load, electrical efficiency was 24.6 percent, thermal efficiency was 47.2 percent, and total CHP system efficiency was 71.7 percent. Total CHP system efficiency remained relatively constant at all loads tested.

HEAT AND POWER PRODUCTION						
Test Condition		Electrical Power Generation Potential		Maximum Heat Recovery Potential		Total Mariah CHP System Efficiency (%)
% of Rated Power	Power Command (kW_e)	Power Delivered[a] (kW_e)	Electrical Efficiency[a] (%)	Heat Recovery Rate (MBtu/hr)	Thermal Efficiency (%)	
100	30	28.39	24.6	186.9	47.2	71.7
90	27	26.44	24.6	171.4	46.7	71.2
75	22.5	22.04	24.0	149.3	46.9	70.5
50	15	14.54	21.9	113.4	50.1	71.9

[a] Includes energy consumed by 220 volt transformer

- Heat input at full load was 393.7 MBtu/hr, or 7.17 scfm natural gas. Heat rate at full load was 13,865 Btu/kWh_e.

Emissions Performance

- At full load, average NO_x concentration was 4.27 ppmvd @ 15 percent O_2, which equates to a mass emission rate of 0.00603 lb/hr. NO_x concentrations were less than 5 ppmvd at the 90 and 75 percent load conditions. Based on a series of short-term non-standard emission measurements, NO_x concentrations remained at this level down to near the half load condition. At the 50 percent load condition, average NO_x concentrations increased abruptly to 70.09 ppmvd, and remained at this elevated level down to the 40 percent load condition.

- CO emissions were also low (4.96 ppmvd) at full power, and increased to 25.04 ppmvd at 50 percent load condition. During a series of non-standard test runs executed in 1 kW power command increments, CO concentrations peaked to > 200 ppmvd at the 55 percent load condition.

US EPA ARCHIVE DOCUMENT

- Emissions of THC were lower than the sensitivity of the sampling system (< 2 ppmvd) at the three highest loads tested. At the 50 percent load condition, maximum THC concentration of 2.47 ppmvd (quantified as propane) was measured.

- At full load, NO_x emissions per unit electrical power output were 0.000212 lb/kWh, well below the levels reported for the Alberta grid (0.0068 lb/kWh). The hourly average CO_2 emission rate for the Alberta grid was 2.18 lb/kWh, which is significantly higher than for the Mariah CHP System. Maximum possible NO_x and CO_2 reductions at the test site are estimated to be 97 and 55 percent, respectively.

CRITERIA POLLUTANT AND GHG EMISSIONS								
Test Condition		**(ppmvd @ 15% O_2)**			**(lb/kWh$_e$)**			
% of Rated Power	Power Command (kW$_e$)	NO_X	CO	THC	NO_x	CO	THC	CO_2
100	30	4.27	4.96	0.35	2.12E-04	1.50E-04	1.8E-05	1.54
90	27	3.50	5.80	1.70	1.75E-04	1.77E-04	8.89E-05	1.41
75	22.5	2.65	10.73	1.90	1.36E-04	3.343E-04	1.02E-04	1.34
50	15	79.09	25.04	1.40	4.480E-03	8.634E-04	8.250E-05	1.44

Power Quality Performance

- Throughout the 38-day test period, the Mariah CHP System maintained continuous synchronization with the utility grid. Average electrical frequency was 60.000 Hz, and average voltage output was 215.21 volts.
- The power factor remained relatively constant for all monitoring days (99.13 percent).
- Current and voltage THDs were consistently below the ± 5 percent threshold specified in IEEE 519. The average current THD was 3.37 percent, and the average voltage THD was 0.94 percent.

Original signed by:

E. Timothy Oppelt
Director
National Risk Management Research Laboratory
Office of Research and Development

Original signed by:

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

Notice: GHG Center verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The EPA and Southern Research Institute make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and Local requirements. Mention of commercial product names does not imply endorsement or recommendation.

US EPA ARCHIVE DOCUMENT