THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Electric Power and Heat Production using Renewable Biogas
APPLICATION:	Combined Heat and Power System
TECHNOLOGY NAME:	CAT 379 engine/generator set with integrated Martin Machinery CHP system
COMPANY:	Patterson Farm
ADDRESS:	1131 Aurelius Springport Townline Rd. Auburn, NY 13021
WEB ADDRESS:	http://chp.nyserda.org/facilities/details.cfm?facility=70

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 a Caterpillar Model G379 internal combustion engine and generator - combined heat and power (CHP) system manufactured by Martin Machinery and fueled with biogas generated at a dairy farm. The system is owned and operated by Patterson Farms near Auburn, New York.

TECHNOLOGY DESCRIPTION

The Patterson Farm is a dairy farm in upstate New York housing approximately 1,725 cows and heifers. Farm operations generate approximately 50,000 gallons per day of manure and process water. This waste is collected and pumped to a complete mix anaerobic digester designed by RCM Digesters of Berkeley, California. The digester's dimensions are approximately 135 by 125 by 16 feet deep with a total waste capacity of approximately 270,000 cubic feet. Following the digester, solids are separated and composted in a solids removal system. Composted solids are later used as animal bedding and separated liquids are stored in a lagoon until used in the fields.

In addition to farm waste, operators also feed cheese whey waste generated off-site into the digester. The anaerobic digestion system produces biogas that is typically about 45 percent methane and has an average lower heating value (LHV) of approximately 525 Btu/scf. Approximately 4,800 cfh of the biogas is used to fuel an on-site DG/CHP system, and the remainder is flared. The DG/CHP system consists of a Caterpillar Model 379, 200 kW engine-generator set with integrated heat recovery capability. The engine tested was not equipped with any add-on emission control equipment

Prior to being used as fuel, the wet biogas is passed through two Filtration Systems, Inc. Model G82308 water filtration units arranged in series to remove moisture from the gas. Dry biogas is then metered and delivered to the engine. During normal farm operations, the engine generates nominal 187 kW power at an electrical efficiency of approximately 22 percent. The facility is equipped with net power metering so that excess power generated on-site can be exported to the grid and credited. The engine is equipped with a heat recovery system that recovers heat to warm the digester. Excess heat is dissipated through a radiator. Water with trace amounts of rust inhibitor is used as the heat transfer fluid. The farm has plans to expand engine heat use by supplying hot water to the milking parlor in the future. This expansion would increase biogas utilization at the site, decrease flare emissions, and improve thermal efficiency of the CHP system.

VERIFICATION DESCRIPTION

Field testing was conducted from May 2, 2007 through May 26, 2007. The defined system under test (SUT) was tested to determine performance for the following verification parameters:

- Electrical Performance
- Electrical Efficiency
- CHP Thermal Performance
- Emissions Performance
- NO_X and CO_2 Emission Offsets

The verification included a series of controlled test periods on May 2, 2007 in which the GHG Center maintained steady system operations for three one-hour test periods at three loads: 100%, 75%, and 50% of capacity (200, 150, and 100 kW, respectively) to evaluate electrical and CHP efficiency and emissions performance. The controlled tests were followed by a 7-day period of continuous monitoring to examine heat and power output, power quality, efficiency, and estimated annual emission reductions.

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) 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 – Electric Power and Heat Production Using Renewable Biogas at Patterson Farms.*

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 a representative portion 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 the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan.

VERIFICATION OF PERFORMANCE

Electrical and Thermal Performance

Table S-1. Patterson Farms DG/CHP System Electrical and Thermal Performance

Test ID		Heat Input (MBtu/h)	Electrical Power Generation Performance		Digester Loop Heat Recovery Performance		CHP Efficiency (%)	Radiator Loop Heat Rejected (MBtu/h)
			Power Generated (kW)	Electrical Efficiency (%)	Heat Recovered (MBtu/h)	Thermal Efficiency (%)		
200 kW	Run 1	2.45	192	26.8	0.164	6.72	33.5	1.60
	Run 2	2.44	191	26.6	0.215	8.77	35.4	1.34
	Run 3	2.44	190	26.6	0.218	8.94	35.5	1.34
	Avg.	**2.45**	**191**	**26.7**	**0.199**	**8.14**	**34.8**	**1.42**
150 kW	Run 1	2.39	153	21.8	0.0907	3.79	25.6	2.21
	Run 2	2.40	153	21.8	0.142	5.93	27.7	1.60
	Run 3	2.39	153	21.9	0.141	5.89	27.8	1.59
	Avg.	**2.39**	**153**	**21.8**	**0.125**	**5.20**	**27.0**	**1.80**
100 kW	Run 1	2.36	104	15.0	0.114	4.84	19.9	1.73
	Run 2	2.36	104	15.0	0.0237	1.00	16.0	6.15
	Run 3	2.37	104	15.0	0.0131	0.553	15.5	7.63
	Avg.	**2.36**	**104**	**15.0**	**0.0502**	**2.13**	**17.1**	**5.17**

- Electrical efficiency averaged approximately 26.7 percent at this site at 200 kW, 21.8 percent at 150 kW, and 15.0 percent at 100 kW.

- Heat recovery and use during the controlled test periods averaged 0.199 MBtu/h at 200 kW, 0.125 MBtu/h at 150 kW, and 0.00502 MBtu/h at 100 kW. Due to low thermal demand in the digester, the majority of heat generated by the CHP system was dissipated through the radiator loop. Thermal efficiency for the digester loop at this site averaged 8.14 percent at 200 kW, 5.20 percent at 150 kW, and 2.13 percent at 100 kW.

- Runs 2 and 3 at 50% load (100 kW) showed substantially lower heat recovered and thermal efficiency for the digester loop than that measured during Run 1. Examining the data showed that water flow in the digester loop dropped significantly during Runs 2 and 3. During these runs, it appears that heat stopped going to the digester and was instead dumped to the radiator, as shown by the increased radiator loop heat rejected. Run 1 is more representative of normal heat recovery performance for the digester at 50% load.

- During the 7-day monitoring period, the system operated for a total of total of approximately 167 hours, or 99 percent of the time. During this time, a total of 32,239 kWh of electricity was generated. Net electrical efficiency during the monitoring period averaged 28 percent and thermal efficiency for the digester heat recovery loop averaged 18 percent, for a total CHP efficiency of 46 percent.

Emissions Performance

Table S-2. Patterson Farms DG/CHP System Emissions during Controlled Tests

Test ID		Power (kW)	CO Emissions			CO_2 Emissions		
			ppm	lb/h	lb/kWh	ppm	lb/h	lb/kWh
200 kW	Run 1	192	182	0.389	0.00202	127000	271	1.41
	Run 2	191	354	0.755	0.00396	128000	274	1.44
	Run 3	190	337	0.718	0.00378	129000	276	1.45
	Avg.	**191**	**291**	**0.621**	**0.00325**	**128000**	**274**	**1.44**
150 kW	Run 1	153	21600	40.1	0.262	129000	240	1.57
	Run 2	153	22300	41.5	0.272	131000	243	1.59
	Run 3	153	22400	41.7	0.272	131000	243	1.59
	Avg.	**153**	**22100**	**41.1**	**0.269**	**130000**	**242**	**1.58**
100 kW	Run 1	104	29700	52.5	0.506	123000	217	2.09
	Run 2	104	29900	52.9	0.509	124000	219	2.11
	Run 3	104	30300	53.5	0.516	124000	220	2.12
	Avg.	**104**	**30000**	**53.0**	**0.510**	**123000**	**218**	**2.10**

- The average CO emission rate normalized to power output was 0.00325 lb/kWh for the 100% load tests, 0.269 lb/kWh at the 75% load tests, and 0.510 lb/kWh for the 50% load tests. THC emissions averaged 0.0202 lb/kWh at 100% load, 0.0359 lb/kWh at 75% load, and 0.0539 lb/kWh at 50% load. NO_x emissions averaged 0.0213 lb/kWh at 100% load, 0.00521 lb/kWh at 75% load, and 0.00123 lb/kWh at 50% load.

Table S-2 continued. Patterson Farms DG/CHP System Emissions during Controlled Tests

Test ID		Power (kW)	THC Emissions			NOx Emissions		
			ppm	lb/h	lb/kWh	ppm	lb/h	lb/kWh
200 kW	Run 1	192	1840	3.92	0.0204	1870	3.99	0.0208
	Run 2	191	1810	3.86	0.0203	1890	4.04	0.0212
	Run 3	190	1790	3.81	0.0200	1950	4.17	0.0219
	Avg.	**191**	**1810**	**3.87**	**0.0202**	**1910**	**4.07**	**0.0213**
150 kW	Run 1	153	2950	5.49	0.0359	409	0.760	0.00497
	Run 2	153	2920	5.44	0.0355	430	0.800	0.00523
	Run 3	153	2960	5.50	0.0359	447	0.832	0.00543
	Avg.	**153**	**2950**	**5.48**	**0.0359**	**429**	**0.797**	**0.00521**
100 kW	Run 1	104	3220	5.70	0.0549	71.9	0.127	0.00123
	Run 2	104	3170	5.61	0.0540	73.3	0.130	0.00125
	Run 3	104	3100	5.48	0.0529	70.8	0.125	0.00121
	Avg.	**104**	**3160**	**5.59**	**0.0539**	**72.0**	**0.127**	**0.00123**

- Compared to the EGrid baseline emissions scenarios for the New York State and national grid regions, changes in annual NO_X emissions caused by use of the SUT are estimated to be about 31,700 lb/y higher for New York State and 29,300 lb/y higher for the national scenario. CO_2 emission rates averaged 1.44 lb/kWh at 100% load, 1.58 lb/kWh at 75% load, and 2.10 lb/kWh at 50% load. For CO_2, reductions in estimated annual emissions for the New York State and national grid (including CO_2 equivalent emissions eliminated through the use of waste CH_4 at the farm), are 13,613,000 lb/y 14,272,000 lb/y, respectively.

Power Quality Performance

- Average electrical frequency was 60.0 Hz and average power factor was 99.7 percent.
- The average current THD was 5.90 percent and the average voltage THD was 3.14 percent. The IEEE recommended threshold for THD is 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 – Electric Power and Heat Production Using Renewable Biogas at Patterson Farms* (Southern 2007). Detailed results of the verification are presented in the final report titled *Environmental Technology Verification Report – Electric Power and Heat Production Using Renewable Biogas at Patterson Farms* (Southern 2007). 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 Sally Gutierrez (10/09/2007)

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Signed by Tim Hansen (09/26/2007)

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