THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Molten Carbonate Fuel Cell
APPLICATION:	Combined Heat and Power System
TECHNOLOGY NAME:	DFC 300A Molten Carbonate Fuel Cell
COMPANY:	FuelCell Energy, Inc.
ADDRESS:	3 Great Pasture Rd. Danbury, CT 06813
WEB ADDRESS:	www.fce.com

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) capability. An added environmental benefit of some DG technologies is the ability to fuel these systems with renewable energy sources such as anaerobic digester

gas or landfill gas. These gases, when released to atmosphere, contribute millions of tons of methane emissions annually in the United States.

The GHG Center collaborated with the New York State Energy Research and Development Authority (NYSERDA) to evaluate the performance the FuelCell Energy, Inc. (FCE) DFC 300A molten carbonate fuel cell CHP system currently in use at the State University of New York, College of Environmental Science and Forestry (SUNY-ESF) located in Syracuse, New York

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by FCE and does not represent verified information. The DFC 300A is a natural gas fueled molten carbonate fuel cell from which excess heat is recovered for use on-site. This technology provides a maximum 250 kW electrical output at 480 V three phase in parallel with the utility supply. Some of the waste heat produced by the fuel cell is recovered from the exhaust gases and supplied to the host sites' space heating system. Table S-1 summarizes the physical and electrical specifications for the unit.

Table S-1. FuelCell Energy DFC 300A Specifications

Physical Specifications	Width	9.0 ft
	Length	28.1 ft
	Height	10.5 ft
	Weight	90,000 lb
Electrical Specifications	Electrical Input	Interconnection of DC conversion + inverter
	Electrical Output	250 kW, 480 V, three phase; decline 10 % over 3 years
	Generator Type	Solid state inverter
	Power Generating Efficiency	45 % ; decline 4.5 % over 3 years
	Total CHP Efficiency	60 – 80 %

The performance verification of the DFC 300A took place at the SUNY-ESF, located in Syracuse, New York. The DFC 300A is located outdoors next to Walters Hall on the SUNY-ESF campus. The DFC 300A provides a 250 kW electrical output to the building in parallel with the utility supply. It is also used to provide supplemental water heating for a reheat loop in Walters Hall's air distribution system. The reheat loop helps control room temperature in Walters Hall.

The fuel cell is fueled with natural gas provided by National Grid. Hot exhaust gases exiting the fuel cell are directed to a Cain Industries heat recovery unit. If the water temperature in the reheat loop from Walters Hall is sufficiently high (approximately 155 ^{o}F or more), a valve in the heat recovery unit vents the exhaust gas to atmosphere. When reheat loop temperatures are below approximately 155 ^{o}F, the exhaust gas from the fuel cell is directed through a heat exchanger and heats the water in the reheat loop. A 1 hp pump located in Walters Hall circulates water through the reheat loop.

VERIFICATION DESCRIPTION

Field testing was conducted from March 13, 2007 through March 22, 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 March 13 and 14 in which the GHG Center maintained steady system operations for three one-hour test periods at two loads (250 kW and 200 kW) to evaluate electrical and CHP efficiency and emissions performance. The controlled tests were followed by a 7-day period of continuous monitoring to examine 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 are detailed in the Test and Quality Assurance Plan titled *Test and Quality Assurance Plan – FuelCell Energy, Inc. DFC 300A Molten Carbonate Fuel Cell Combined Heat and Power System.*

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 audits, 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-2. DFC 300A Electrical and Thermal Performance

Test ID		Heat Input (MBtu/h)	Electrical Power Generation Performance		Heat Recovery Performance		Total CHP System Efficiency (%)	Ambient Conditions	
			Power Generated by DFC 300A (kW)	Electrical Efficiency (%)	Heat Recovered (MBtu/h)	Thermal Efficiency (%)		Temp (^oF)	Pbar (psia)
250 kW	Run 1	1.76	250	48.4	0.302	17.2	65.6	50.9	14.6
	Run 2	1.76	250	48.5	0.305	17.4	65.9	54.7	14.6
	Run 3	1.76	249	48.3	0.305	17.4	65.7	58.0	14.6
	Avg.	**1.76**	**250**	**48.4**	**0.304**	**17.3**	**65.7**	**54.5**	**14.6**
200 kW	Run 1	1.44	210	49.9	0.267	18.6	68.5	65.0	14.5
	Run 2	1.45	210	49.6	0.272	18.8	68.4	59.2	14.5
	Run 3	1.45	211	49.7	0.271	18.7	68.4	60.9	14.5
	Avg.	**1.44**	**210**	**49.7**	**0.270**	**18.7**	**68.4**	**61.7**	**14.5**

- Electrical efficiency averaged approximately 48 percent at this site at 250 kW and 50 percent at 200 kW.

- The amount of heat recovered and used averaged 0.304 million Btu per hour (MBtu/h) at 250 kW and 0.270 MBtu/h at 200 kW. Corresponding thermal efficiency was 17.3 percent at 250 kW and 18.7 percent at 200 kW. Site personnel confirmed that, in some cases, DFC 300A heat recovery rates exceed Walters Hall demand, necessitating venting of the exhaust gas to atmosphere. Determination of the total potential heat recovery from the DFC 300A was not included in this verification, but rather the actual heat recovery and use at this site. Total potential heat recovery from the DFC 300A, and therefore thermal efficiency, may be higher than that reported here for users with higher heat demand. Total CHP efficiency (electrical and thermal combined) averaged 65.7 percent at 250 kW and 68.4 percent at 200 kW at this site under these conditions.

- During the 7-day monitoring period, the DFC 300A generated a total of 41,900 kWh of electricity and mean electrical efficiency was 48 percent. The GHG Center intended to collect heat recovery data over the extended test period, but the data logger malfunctioned during logging and no heat recovery data was recorded other than during the controlled test periods on March 13 and 14.

Emissions Performance

Table S-3. DFC 300A Emissions during Controlled Test Periods

Test ID		Power (kW)	CO Emissions			NOx Emissions			CO_2 Emissions		
			ppm, dry	lb/hr	lb/kWh	ppm, dry	lb/hr	lb/kWh	ppm, dry	lb/hr	lb/kWh
250 kW	Run 1	250	< 0.5	< 0.002	< 7E-06	< 0.5	< 0.003	< 1E-05	47800	264	1.06
	Run 2	250	< 0.5	< 0.002	< 7E-06	< 0.5	< 0.003	< 1E-05	47400	255	1.02
	Run 3	249	< 0.5	< 0.002	< 7E-06	< 0.5	< 0.003	< 1E-05	47200	252	1.01
	Avg.	**250**	**< 0.5**	**< 0.002**	**< 7E-06**	**< 0.5**	**< 0.003**	**< 1E-05**	**47500**	**257**	**1.03**
200 kW	Run 1	210	< 0.5	< 0.001	< 7E-06	< 0.5	< 0.002	< 1E-05	48000	219	1.04
	Run 2	210	< 0.5	< 0.001	< 7E-06	< 0.5	< 0.002	< 1E-05	47700	220.0	1.05
	Run 3	211	< 0.5	< 0.001	< 7E-06	< 0.5	< 0.002	< 1E-05	48100	221	1.05
	Avg.	**210**	**< 0.5**	**< 0.001**	**< 7E-06**	**< 0.5**	**< 0.002**	**< 1E-05**	**47900**	**220.0**	**1.04**

Table S-3 (continued). DFC 300A Emissions during Controlled Test Periods

Test ID		Power (kW)	TNMHC (as propane) Emissions			THC (as methane) Emissions		
			ppm, dry	lb/hr	lb/kWh	ppm, wet	lb/hr	lb/kWh
250 kW	Run 1	250	0.909	0.00502	2.01E-05	176	0.354	1.42E-03
	Run 2	250	0.830	0.00447	1.79E-05	184	0.360	1.44E-03
	Run 3	249	2.64	0.0141	5.66E-05	176	0.341	1.37E-03
	Avg.	**250**	**1.46**	**0.00786**	**3.15E-05**	**179**	**0.352**	**1.41E-03**
200 kW	Run 1	210	1.22	0.00557	2.65E-05	136	0.226	1.07E-03
	Run 2	210	1.42	0.00657	3.13E-05	128	0.215	1.02E-03
	Run 3	211	1.55	0.00713	3.38E-05	143	0.238	1.13E-03
	Avg.	**210**	**1.40**	**0.00642**	**3.05E-05**	**136**	**0.226**	**1.08E-03**

- NO_X and CO emissions were consistently low throughout the testing and averaged less than 1E-05 lb/kWh and less than 7E-06 lb/kWh, respectively at 250 kW. CO_2 emissions averaged 1.03 lb/kWh at 250 kW.

- Emissions of TNMHC (as propane) averaged 3.15E-05 lb/kWh at 250 kW. Emissions of THC (as methane) averaged 1.41E-03 lb/kWh at 250 kW.

- Compared to the baseline emissions scenarios for the New York State and national grid, annual NO_X emissions are estimated to be reduced by 1.97 tons per year (tpy) for New York State and reduced by 3.52 tpy for the national scenario. For CO_2, estimated annual emissions are expected to reduce by 588 tpy for New York State and by 1,020 tpy for the national grid.

Power Quality Performance

- Average electrical frequency was 60.0 Hz and average power factor was 99.9 percent.
- The average voltage THD was 1.63 percent, well within the IEEE recommended threshold of 5 percent on all occasions. Current THD was not able to be measured.

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 – FuelCell Energy, Inc. DFC 300A Molten Carbonate Fuel Cell Combined Heat and Power System* (Southern 2007). Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report for FuelCell Energy, Inc. DFC 300A Molten Carbonate Fuel Cell Combined Heat and Power System* (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)

Sally Gutierrez
Director
National Risk Management Research Laboratory
Office of Research and Development

Signed by Tim Hansen (09/26/2007)

Tim Hansen
Director
Greenhouse Gas Technology Center
Southern Research Institute