THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Proton Exchange Membrane Fuel Cell
APPLICATION:	Distributed Electrical Power Generation
TECHNOLOGY NAME:	Plug Power SU1 Fuel Cell System
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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 (SRI) in cooperation with EPA's National Risk Management Research Laboratory. The GHG Center has collaborated with the New York State Energy and Development Authority (NYSERDA) to evaluate the performance of the Stationary Unit 1

Demonstration Fuel Cell System (SU1 system) offered by Plug Power. This verification statement provides a summary of the test results for the SU1 system.

TECHNOLOGY DESCRIPTION

The following description of the SU1 system was provided by the vendor and does not represent verified information. The Plug Power SU1 is one of the first commercially available proton exchange membrane (PEM) fuel cell systems. The unit is designed to generate nominal 5 kW of electricity through a reaction between hydrogen (H_2), oxygen (O_2), and a solid electrolyte (the proton exchange membrane). This type of fuel cell operates at relatively low temperatures (about 175 °F) and can vary output fairly quickly to meet changes in demand. The basic principle of operation is to convert H_2 into electrical energy with an electrochemical reaction with O_2, generally supplied from ambient air.

Because pure H_2 is usually not readily available, a reformed fuel (reformate) rich in H_2 is derived from fuels such as natural gas, propane, methanol, or other petroleum products using a fuel processor. The SU1 system uses auto-thermal reforming (ATR) technology to generate reformate. The reformate created by fuel processing consists primarily of hydrogen (H_2), carbon dioxide (CO_2), nitrogen (N_2), and carbon monoxide (CO). The fuel processor also contains a CO cleanup component to remove or transform all or most of the CO to CO_2 and minimize CO damage to the system.

Direct current (DC) electricity is generated in the SU1 fuel cell stack. The stack consists of a series electrodes (an anode and cathode) separated by an ion-exchange membrane. The reformate is directed into the anode and air enters the system through the cathode during operation. The H_2 molecules in the reformate split into two protons and two electrons. The electrons flow through an external circuit creating a low-voltage direct electrical current (DC). The H^+ protons pass through the membrane and combine at the cathode with the electrons and O_2 from the air to form water, with waste heat as a by-product.

The SU1 also includes a power conditioner. This component uses an inverter to convert the low-voltage DC produced by the stack to alternating current (AC) power and a transformer to produce the desired voltage output. Specific power-conditioning transformers are unit-specific and vary depending on the size and generating capacity of the fuel cell. The SU1 system is equipped with 4 lead-acid batteries to provide auxiliary power during extended periods of peak demand that are higher than fuel cell output capacity, and to aid in starting the SU1 system.

VERIFICATION DESCRIPTION

Verification of the SU1 was conducted at a private residence in Lewiston, New York. The home is located in Niagara County, New York and includes 2,060 ft^2 of conventional living space and 700 ft^2 of basement space. The home was constructed in the early 1970's, and contains walls that are insulated at a typical R-11 level and ceilings that are R-19 rated. Natural gas is used to fuel the SU1, and space heating at the home is provided by a gas-fired boiler. In addition to standard electrical outlets and lighting fixtures throughout the home, it contains a hot tub, electrical washer, and gas dryer (dryer motor is electric), several ceiling fan/light units, a refrigerator, dishwasher, microwave, several television sets, computer, sump pump, freezer, and other miscellaneous electrical devices.

The SU1 fuel cell is not a load-following system, but is configured to operate at nominal power outputs of 2.5, 4.0, or 5.0 kW. Under the fuel cell interconnect contract with the local utility, all power generated by the fuel cell and not used by the residence is directed to the grid. Therefore, the system is normally set to operate at 2.5 kW. If the power demand exceeds the available capacity of the fuel cell, additional power is drawn from the grid. In the event of a grid power failure, the system is designed to automatically shut down, to isolate system from grid faults. When grid power is restored, the SU1 system can be restarted manually.

Testing commenced on April 10, 2003, and was completed on April 21, 2003. It consisted of a series of short periods of "controlled tests" in which the unit was operated at power output commands of 5, 4, and 2.5 kW respectively. Three test replicates were conducted at each power output command to determine power output, electrical efficiency, power quality, and emissions performance. These controlled test periods were followed by approximately 10 days of extended monitoring to verify electric power production and power quality performance during a period of normal site operations.

The classes of verification parameters evaluated are:

- **Power Production Performance**
- **Emissions Performance**
- **Power Quality Performance**

Evaluation of power production performance includes verification of power output and electrical efficiency. Electrical efficiency was determined according to the ASME Performance Test Code for Fuel Cell Power Systems (ASME PTC-50), and tests consisted of direct measurements of fuel flow rate, fuel heating value, and power output. Ambient temperature, barometric pressure, and relative humidity measurements were also collected to characterize the condition of the air used by the fuel cell.

The evaluation of emissions performance occurred simultaneously with efficiency determination at all power output settings. 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 SU1 exhaust stack. All emissions 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: (1) parts per million volume, dry (ppmvd) corrected to 15 percent O_2, and (2) mass per unit time (lb/hr). The mass emission rates are also normalized to power output and reported as pounds per kilowatt hour (lb/kWh).

Annual NO_X and CO_2 emissions reductions for the SU1 system at the test site are estimated by comparing measured lb/kWh emission rates with corresponding emission rates for the baseline power production systems (i.e., systems that would be used if the SU1 system were not present). The baseline system at this site is electricity supplied from the local utility grid (Niagara Mohawk). Baseline emissions for the electrical power were determined following Ozone Transport Commission guidelines.

Electrical power quality parameters, such as electrical frequency and voltage output, were also measured during the ten-day extended test. Other performance parameters, including 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.

Quality Assurance (QA) oversight of verification testing was provided following specifications in the ETV Quality Management Plan (QMP). GHG Center staff conducted one performance evaluation audit and an audit of data quality on at least 10 percent of the data generated during this verification.

VERIFICATION OF PERFORMANCE

Power Production Performance

- All controlled tests occurred at similar operating conditions (ambient temperatures 40 to 50 ^{o}F; barometric pressure: 14.39 to 14.58 psia; relative humidity: 52 to 69 percent).

- The following table shows the heat input, power output, heat rate, and efficiency of the SU1 at the three loads tested.

SU1 Power Production				
Power Command (kW)	**Power Delivered (kW)**	**Heat Input (MBtu/hr)**	**Heat Rate (MBtu/kWh)**	**Electrical Efficiency (%)**
5	4.75	68.05	14.33	23.8
4	3.91	53.90	13.78	24.7
2.5	2.57	35.84	13.94	24.5

- The SU1 generated 689 kWh electricity over an extended monitoring period of 233.5 hours. SU1 power output varied between nominal 2.5 and 5.0 kW as commanded by the system operator, but was stable at both set-points. A total of 61 hours of downtime were experienced during this period equating to a system availability of about 74 percent. The average generating rate during this period was 2.95 kW, including periods of downtime.

Emissions Performance

The following table summarizes the measured pollutant concentrations and emissions rates for the SU1 System at each of the three power outputs tested.

Criteria Pollutant And GHG Emissions									
Power Output (kW)	**(ppmvd at 15% O_2)**				**(lb/kWh_e)**				
	NO_X	CO	THC	CH_4	NO_X	CO	THC	CH_4	CO_2
4.75	<0.035	0.13	476	465	$<1.64 \times 10^{-6}$	4.18×10^{-6}	0.0087	0.0085	1.66
3.91	<0.020	0.10	488	485	$<6.97 \times 10^{-7}$	3.07×10^{-6}	0.0086	0.0086	1.61
2.57	<0.025	0.19	509	492	$<1.27 \times 10^{-6}$	6.04×10^{-6}	0.0091	0.0088	1.61

- NO_X concentrations were at or near the sensitivity limits of the sampling system during all testing. CO emissions were also very low during all test periods.

- Emissions of CO_2 averaged 1.63 lb/kWh over the fuel cell's range of power output.

- Emissions of CH_4 and THC were consistent at the three power outputs and average 0.0087 and 0.0088 lb/kWh, respectively.

- During normal fuel cell operations at the residence (power set-point of 2.5 kW), NO_X emissions per unit electrical power output were 1.27 x 10^{-6} lb/kWh, well below the average levels reported for the regional grid (0.0024 lb/kWh) by the Ozone Transport Commission (OTC). This resulted in an estimated annual NO_X emission reduction of 44.3 lbs (64 percent).

- This version of the SU1 (without heat recovery potential) is essentially a greenhouse gas neutral technology. The average CO_2 emissions for the regional grid are estimated at 1.53 lb/kWh which is slightly lower than the emission rate for the SU1 (1.61 lb/kWh), but since the SU1 eliminates the estimated 7.8 percent line losses associated with grid power, an average annual CO_2 emission reduction of 723 lbs (1.7 percent) is estimated. But these CO_2 reductions are likely offset by the level of methane emissions from the SU1, which are higher than the typical combustion generators at central power plants.

Power Quality Performance

- Throughout the ten-day test period, the SU1 system maintained synchronization with the utility grid during all operational periods. Average electrical frequency was 60.001 Hz and average voltage output was 120.98 volts.
- The power factor remained relatively constant for all monitoring days with an average of 99.9 percent and a range of 99.6 to 100.0 percent.
- The average current total harmonic distortion (THD) was 2.85 percent, and the average voltage THD was 2.69 percent, both well below the ±5 percent threshold specified in IEEE 519.

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 Residential Electric Power Generation Using the Plug Power SU1 Fuel Cell System* (SRI 2003). Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report for Residential Electric Power Generation Using the Plug Power SU1 Fuel Cell System* (SRI 2003). 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).

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