THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NYSERDA

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Phosphoric Acid Fuel Cell Combined With Heat Recovery System
APPLICATION:	Distributed Electrical Power and Heat Generation Using UTC Fuel Cells' PC25C Power Plant and Anaerobic Digester Gas
TECHNOLOGY NAME:	PC25C Fuel Cell Power Plant – Model C
COMPANY:	UTC Fuel Cells, LLC
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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 in cooperation with EPA's National Risk Management Research Laboratory. A technology of interest to GHG Center stakeholders is the use of fuel cells as distributed generation (DG) sources. DG refers to power-generation equipment that provides electric power at a site much closer to customers than central station generation. An added environmental benefit of some DG technologies is the ability to fuel these systems with renewable energy sources such as anaerobic digester gas (ADG) or landfill gas. These gases, if released to atmosphere, contribute millions of tons of methane emissions annually in the U.S. Cost-effective technologies are available that can significantly reduce these emissions by recovering methane and using it as an energy source. Recently, ADG production from waste management facilities has become a promising alternative for fueling DG technologies. The recovered methane can fuel power generators to produce electricity, heat, and hot water. The improved efficiency of combined heat and power DG systems and the ability to use renewable fuels make them a viable alternative to traditional power generation technologies.

The GHG Center collaborated with the New York State Energy Research and Development Authority (NYSERDA) to evaluate the performance of the PC25C Model C Fuel Cell Power Plant (PC25C) offered by United Technologies Corporation Fuel Cells (UTC). The PC25C is a phosphoric acid fuel cell capable of producing nominal 200 kW of electrical power with the potential to produce an additional 205 kW of heat. The PC25C selected for this verification is owned and operated by the New York Power Authority (NYPA). It is located at the Red Hook Water Pollution Control Plant (WPCP) operated by the New York City Department of Environmental Protection. The system is fueled by ADG produced at the Red Hook facility.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by UTC and NYPA and does not represent verified information. The PC25C is a phosphoric acid fuel cell (PAFC) that generates electricity through an electrochemical process in which the energy stored in a fuel is converted into alternating current (AC) electricity. The unit has a rated generating capacity of nominal 200 kW at 480 volts. System specifications state that electrical efficiency of the PC25C averages 35 to 40 percent, but total system efficiency can rise to about 80 percent if the waste heat is reused in a cogeneration system. The PC25C system consists of three major components including: (1) the gas processing unit (GPU), (2) the power module, and (3) the cooling module.

Prior to use as a fuel, the raw ADG is processed using an integrated GPU. The GPU is manufactured by US Filter and specifically designed for integration with the PC25C. The GPU is designed primarily to remove hydrogen sulfide (H_2S) from the ADG, as its presence is damaging to the PC25C. The GPU will also remove other potentially harmful ADG components such as other sulfur species and volatile organic compounds. A separate verification statement and report titled *Environmental Technology Verification Report – UTC PC25C Fuel Cell Power Plant – Gas Processing Unit Performance for Anaerobic Digester Gas* provides results of GPU performance testing.

The PC25C Power Module consists of three components including: (1) the fuel processor, (2) the fuel cell stack, and (3) the power conditioner. The PC25C uses catalytic steam reforming (CSR) to produce a reformed fuel (reformate) rich in H_2 from the ADG. According to UTC, the CSR reforming process yields higher H_2 per unit of fuel compared to other reforming processes, boosting fuel quality and fuel cell efficiency. The fuel cell stack uses a phosphoric acid electrolyte to generate direct current (DC) power from reformate. After the fuel cell stack, the spent reformed fuel sent to the CSR burner to provide heat for the endothermic reforming process. The reformer exhaust is combined in the condenser along with the spent air from the fuel cell stack. There, water is recovered and sent back to the cooling water loop, and uncondensed water vapor is exhausted to the atmosphere. A power conditioner converts the DC power to AC using an inverter.

Two PC25C systems are installed at the Red Hook plant, providing a potential 400 kW of power to offset power purchased from the utility grid. The PC25C systems will also offset a portion of the heat provided to Red Hook by a large neighboring cogeneration facility. Both fuel cells are configured to use either natural gas or ADG produced at the site as fuel. ADG is the primary fuel under normal site operations with natural gas used only during fuel cell startup or as a backup fuel during digester upset conditions. When the fuel cells are not in service or excess ADG is produced, it is combusted in an enclosed flare.

VERIFICATION DESCRIPTION

Testing was conducted from May 19 through June 19, 2004. The verification included a series of controlled test periods in which the GHG Center intentionally modulated the unit to produce electricity at nominal power output commands of 200, 150, and 100 kW. Three replicate test runs were conducted at each point. The controlled test periods were followed by 30 days of continuous monitoring to verify electric power production, heat recovery, and power quality performance over an extended period. The classes of verification parameters evaluated were:

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

Evaluation of heat and power production performance included verification of power output, heat production, electrical efficiency, thermal efficiency, and total system efficiency. Electrical efficiency was determined according to the ASME Performance Test Code for Fuel Cells (ASME PTC-50). Tests consisted of direct measurements 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 fuel cell. All measurements were recorded as one-minute averages.

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), and carbon dioxide (CO_2) were conducted in the PC25C 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 by volume, dry (ppmv) corrected to 15-percent oxygen (O_2), and as mass per unit time (lb/hr). The mass emission rates are also normalized to power output and reported as pounds per megawatt hour (lb/MWh).

Annual NO_X and CO_2 emissions reductions resulting from the use of the PC25C were estimated by comparing measured emission rates with corresponding emission rates for the baseline scenario for the Red Hook plant. The baseline scenario consists of emissions associated with generation of an amount of power by utilities equivalent to that produced by the fuel cell (based on average regional grid emission factors for New York State) plus estimated emissions from combustion of an amount of ADG using the flare equivalent to that consumed by the fuel cell.

Electrical power quality parameters, including electrical frequency and voltage output, were measured during the controlled and 30-day extended tests. 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 the data quality objectives specified in the Test and Quality Assurance Plan were met with the exception of the efficiency determinations. Due to a conservative uncertainty estimate in the heat input determination, the efficiency DQOs were slightly exceeded.

VERIFICATION OF PERFORMANCE

Heat and Power Production Performance

PC25C HEAT AND POWER PRODUCTION					
Test Condition (Power Command)	Electrical Power Generation		Heat Production Performance		Potential CHP System Efficiency (%)
	Power Delivered (kW)	Efficiency (%)	Heat Production (10^3Btu/hr)	Potential Thermal Efficiency (%)	
200 kW	193.1	36.8	1,018	56.9	93.8
150 kW	152.3	38.2	700	51.5	89.8
100 kW	101.5	37.4	478	51.7	89.0

- Electrical efficiency averaged approximately 37.5 percent over the range of PC25C operation.

- The Red Hook WPCP does not have demand for the heat generated by the PC25C. All heat produced by the fuel cell is removed through the unit's cooling module loop. The heat production rates summarized in the table represent the total heat removed at the cooling module. Based on these heat removal rates, potential thermal efficiency at full load was 56.9 percent and potential combined heat and power system efficiency averaged 93.8 percent.

- During the 30-day monitoring period, the PC25C operated on ADG for a total of 165 hours. During this time, a total of 27,748 kWhr electricity was generated at an average rate of 166 kW, and 120.4 million Btu (35,296 kWh) of heat was removed through the cooling module at an average heat recovery rate of 730 MBtu/hr. Numerous power upsets at the Red Hook facility during the verification period reduced the amount of PC25C run time during the verification period. Testing conducted by the GHG Center on a different PC25C showed an availability of 97 percent.

Emissions Performance

PC25C EMISSIONS (lb/MWh)					
Power Command	**NO_X**	**CO**	**THC**	**CH_4**	**CO_2**
200 kW	0.013	0.029	0.78	0.80	1,437
150 kW	0.013	0.051	1.36	1.40	1,314
100 kW	0.013	0.078	1.37	1.19	1,451

- NO_X emissions were consistent at all three loads tested and averaged 0.013 lb/MWh. CO emissions averaged 0.029 lb/MWh at full load and increased slightly as power output was reduced.

- THC emissions ranged from 0.78 lb/MWh at full load to 1.37 lb/MWh at the 100 kW power demand. The PC25C ventilation system draws ambient air through the exhaust duct and also into the fuel cell stack. Background hydrocarbons in the room air were measured and used to correct the measured exhaust stack emissions. Even after this correction for background hydrocarbons, reported THC levels are much higher than has been reported for three other PC25C tests. Further information is available in the Verification Report.

- Compared to the baseline emissions scenario (regional grid emission factors plus flare emissions), annual NO_X emission reductions are estimated to be 0.45 tons when operating the PC25C for an average 165 hours per month (as observed during the verification period). At an estimated PC25C availability rate of 97 percent (based on previous testing by the GHG Center), estimated annual NO_X emission reductions increase to 1.82 tons. For CO_2, estimated annual emission reductions at the operating conditions observed during the period are 337 tons. At the expected 97 percent availability, annual CO_2 emission reductions increase to an estimated 1,346 tons.

Power Quality Performance

- Average electrical frequency was 60.00 Hz and average voltage output was 487.6 volts.
- During the first half of the verification period, power factor remained relatively constant at 99.9 percent. However, power factor reversed to approximately -87 percent following a long period of downtime. The cause of this reversal is not clear.
- The average current THD was 12.5 percent and the average voltage THD was 2.3 percent. Current THD exceeded the IEEE recommended threshold of 5 percent on several occasions.

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 the UTC Fuel Cells PC25C Power Plant and Anaerobic Digester Gas* (SRI 2004). Detailed results of the verification are presented in the final report titled *Environmental Technology Verification Report for Electric Power and Heat Production Using the UTC Fuel Cells PC25C Power Plant and Anaerobic Digester Gas* (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. 9/22/04

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