**THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM**

U.S. Environmental Protection Agency

# ETV Joint Verification Statement

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| TECHNOLOGY TYPE: | Carbon Based Digester or Sour Gas Processing System |
| APPLICATION: | Anaerobic Digester Gas |
| TECHNOLOGY NAME: | Gas Processing Unit (GPU) |
| COMPANY: | US Filter/Westates Carbon |
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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. The GHG Center has collaborated with the New York State Energy and Development Authority (NYSERDA) to evaluate the performance of several combined heat and power (CHP) systems. One such technology is the PC25CC Fuel Cell Power Plant (PC25CC) offered by United Technologies Corporation (UTC) Fuel Cells. 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 fueled by anaerobic digester gas (ADG) produced at a water pollution control plant (WPCP). The PC25C tested includes a gas processing unit (GPU) that treats the ADG prior to use as a fuel. Under a partnership between NYSERDA, New York Power Authority (NYPA), and others, a total of eight fully interconnected PC25C systems are being installed at four WPCPs in Brooklyn, New York. Each system will be fueled with ADG generated from anaerobic digestion of sewage sludge, and each system will incorporate a dedicated GPU to process the gas. The GPUs used by UTC Fuel Cells are manufactured by US Filter/Westates Carbon. This verification statement provides the results of the GPU performance verification. A separate verification statement and report was issued for the PC25C performance evaluation.

## TECHNOLOGY DESCRIPTION

The PC25C fuel cell 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. Electrical efficiency of the PC25C averages 35 to 40 percent, but total system efficiency can rise to over 80 percent if the waste heat is reused in a cogeneration system. A detailed description of the PC25C fuel cell system and power module can be found in both the Test and Quality Assurance Plan and the PC25C Verification Report. The following GPU description is based on information provided by UTC Fuel Cells and US Filter/Westates and does not represent verified information

Prior to use as a fuel, the raw ADG is processed using an integrated GPU. The GPU is electrically integrated with the PC25C such that the fuel cell provides power and startup and shutdown control to the GPU. The GPU includes a variable speed gas blower that is used to pressurize low pressure ADG fuel supply as needed to overcome the GPU pressure drop. PC25C fuel pressure sensors and electronics are used to control GPU blower speed. The GPU is designed primarily to remove hydrogen sulfide ($H_2S$) from the ADG because its presence in concentrations greater than 6 ppm can be damaging to the PC25C. The GPU can also remove other potentially harmful ADG components such as other sulfur species and hydrocarbons.

The GPU consists of three major components including a coalescing filter, activated carbon beds, and the blower. The coalescing filter removes water vapor and entrained particulates from the raw gas. The GPU is equipped with liquid traps to remove condensed water from the fuel supply line. Collected and condensed water is piped back into the waste water treatment system at the plant.

The dry ADG is then directed to two 1,200 lb carbon beds in series to capture $H_2S$ and other harmful contaminants. Each bed is designed to operate for approximately six months with ADG containing up to 200 ppm $H_2S$. The system is configured with the capability to operate using a single bed when a bed needs to be changed out. Periodic monitoring of the $H_2S$ levels in the raw and processed ADG is conducted manually by system operators. Additionally, periodic sampling of the carbon beds is conducted to evaluate the condition of the carbon.

## VERIFICATION DESCRIPTION

Testing was conducted at the Red Hook WPCP – a 60-million gallon per day secondary wastewater treatment facility in Brooklyn, New York. Two PC25C fuel cell systems were installed at the Red Hook WPCP in May of 2003 to provide on-site generation of power and hot water.

The ADG is produced at the Red Hook facility using a series of anaerobic sludge digesters and is typically composed of 60 to 65 percent methane with a lower heating value (LHV) of 550 to 650 Btu/cf. The system is designed to switch to natural gas fuel whenever ADG methane concentrations are less than

around 50 percent, or ADG pressure is below 3 inches water column. Gas production rates at the facility vary depending on daily plant wastewater flow rates and ambient temperatures. Peak production rates during the summer months can approach 750 cubic feet per minute. Approximately 6,000 cubic feet per hour of the ADG is needed to operate both PC25C's at this site at full power. During times when ADG production rates at the plant exceed this level, the excess gas is combusted using an enclosed flare.

Testing was conducted on May 19 and 20, 2004. Testing was conducted to evaluate GPU performance by comparing the composition and quality of raw ADG to that of processed ADG. The following gas compositional and quality criteria were evaluated on six raw and six corresponding processed ADG samples:

- Gas properties (gross and net heating value, density, and compressibility)
- Gas composition ($N_2$, $O_2$, $CO_2$, and $C_1$ through $C_6$)
- Sulfur compounds
- Volatile Organic Compounds (VOCs) and total halides
- Moisture content

Corresponding ADG samples were collected on both the upstream and downstream sides of the GPU and submitted for analysis. Results of the analyses were used to evaluate GPU removal efficiency for moisture, $H_2S$ and sulfur compounds, VOCs, and halides. The results also allowed the center to evaluate the effects on ADG composition and heating value.

The GPU performance verification testing was completed in conjunction with the CHP efficiency testing that was conducted on the PC25C. The efficiency testing was performed at three different fuel cell power output commands including full power (about 193 kW), 150 kW, and 100 kW.

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 the 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

### ADG Composition and Heating Value (Table S-1)

- There was very little variation in the composition and physical properties of both the raw and processed ADG samples. The raw ADG was almost entirely $CH_4$ and $CO_2$ (62.25 and 37.60 percent-dry basis, respectively), with a small amount of $N_2$ (0.14 percent) and trace levels of $H_2S$ (93 ppm) and VOCs. The data indicate that the GPU introduces a slight dilution of ADG with air (required for $H_2S$ removal), but the basic gas composition is otherwise unchanged.

- The slight dilution of the gas reduces the average $CH_4$ concentration by about 1.4 percent, and subsequently, the fuel heating value is reduced by the same amount on a volumetric basis. The gas compositional changes are consistent across the range of ADG flow rates measured during the three different test conditions. The density and compressibility of the gas is virtually unchanged by processing.

**Table S-1. Composition and Properties of Raw and Processed ADG (dry basis)**

| | Gas Composition (%) | | | Heat Content (Btu/scf) | | | |
|---|---|---|---|---|---|---|---|
| Sample ID | $CH_4$ | $CO_2$ | $N_2$ | HHV | LHV | Relative Density | Compres-sibility |
| Raw ADG 1 | 62.39 | 37.45 | 0.15 | 622.6 | 560.4 | 0.919 | 0.9969 |
| Processed ADG 1 | 61.66 | 37.27 | 0.88 | 615.3 | 553.8 | 0.921 | 0.9969 |
| Change (%) | -1.18 | -0.48 | 82.95 | -1.19 | -1.19 | 0.25 | 0.00 |
| Raw ADG 2 | 62.23 | 37.59 | 0.15 | 621.1 | 559.0 | 0.920 | 0.9969 |
| Processed ADG 2 | 60.87 | 36.76 | 1.89 | 607.4 | 546.7 | 0.922 | 0.9970 |
| Change (%) | -2.23 | -2.26 | 92.06 | -2.26 | -2.25 | 0.23 | 0.01 |
| Raw ADG 3 | 62.18 | 37.67 | 0.15 | 620.5 | 558.5 | 0.921 | 0.9969 |
| Processed ADG 3 | 61.55 | 37.17 | 1.04 | 614.2 | 552.8 | 0.921 | 0.9969 |
| Change (%) | -1.02 | -1.35 | 85.58 | -1.03 | -1.03 | 0.02 | 0.01 |
| Raw ADG 4 | 62.56 | 37.26 | 0.17 | 624.3 | 561.9 | 0.917 | 0.9969 |
| Processed ADG 4 | 61.83 | 36.89 | 1.04 | 617.0 | 555.3 | 0.918 | 0.9969 |
| Change (%) | -1.18 | -1.00 | 83.65 | -1.18 | -1.19 | 0.12 | 0.00 |
| Raw ADG 5 | 62.14 | 37.73 | 0.12 | 620.1 | 558.1 | 0.921 | 0.9969 |
| Processed ADG 5 | 61.20 | 37.17 | 1.31 | 610.7 | 549.7 | 0.923 | 0.9969 |
| Change (%) | -1.54 | -1.51 | 90.84 | -1.54 | -1.53 | 0.13 | 0.01 |
| Raw ADG 6 | 61.99 | 37.90 | 0.11 | 618.6 | 556.8 | 0.923 | 0.9968 |
| Processed ADG 6 | 61.13 | 37.35 | 1.23 | 610.0 | 549.1 | 0.924 | 0.9969 |
| Change (%) | -1.41 | -1.47 | 91.06 | -1.41 | -1.40 | 0.09 | 0.01 |
| **Avg. Raw ADG** | **62.24** | **37.60** | **0.14** | **621.2** | **559.1** | **0.920** | **0.9969** |
| **Avg. Processed ADG** | **61.37** | **37.10** | **1.23** | **612.4** | **551.2** | **0.921** | **0.9969** |
| **Avg. Change (%)** | **-1.43** | **-1.34** | **87.69** | **-1.43** | **-1.43** | **0.14** | **0.01** |

## Sulfur Compounds Removal Efficiency (Table S-2)

**Table S-2. GPU Removal Efficiency for Sulfur Compounds**

| | Sulfur Compounds Detected (concentrations in ppb) | |
|---|---|---|
| Sample ID | Hydrogen sulfide | Carbon disulfide |
| Raw ADG 1 | 83,000 | 1,200 |
| Processed ADG 1 | < 4.0 | 38 |
| Removal Efficiency (%) | > 99.995 | 96.8 |
| Raw ADG 2 | 100,000 | 1,400 |
| Processed ADG 2 | < 4.0 | 35 |
| Removal Efficiency (%) | > 99.996 | 97.5 |
| Raw ADG 3 | 96,500 | 800 |
| Processed ADG 3 | < 4.0 | 38 |
| Removal Efficiency (%) | > 99.996 | 95.3 |
| **Average Removal Efficiency (%)** | **> 99.996** | **96.5** |

- The only sulfur compounds detected in measurable quantities in the raw ADG samples were $H_2S$ and carbon disulfide.

- Concentrations of $H_2S$ ranged from 83 to 100 ppm. Based on processed ADG sample results below the analytical detection limit of 4.0 ppb for $H_2S$, the average removal efficiency is greater than 99.996 percent. GPU removal efficiency for carbon disulfide averaged 96.5 percent. Breakthrough of carbon disulfide was limited to 37 ppb.

**VOCs Removal Efficiency (Table S-3)**

- A total of 22 VOCs were detected in each of the raw ADG samples. Of these, 12 were found in concentrations of 50 ppb or greater, as summarized in Table S-3. Ten other VOCs were detected in low or trace amounts in the raw ADG samples. None of the 10 trace compounds were detectable in the processed ADG samples.

- Concentrations of toluene averaged approximately 2,200 ppb in the raw ADG and were higher than the remaining VOCs combined. GPU removal efficiency for toluene averaged 99.90 percent. Removal efficiencies for the nine remaining alkanes and alkenes detected in the raw ADG samples were generally greater than 96 percent.

- GPU removal efficiencies for vinyl chloride and acetone averaged 17.5 and 59.6 percent, respectively. Still, breakthrough of these two compounds was limited to 130 and 15 ppb, respectively. Vinyl chloride and 1,2-dichloroethene were the only two halides detected in the raw ADG samples. Total halide removal efficiency averaged 65 percent.

**ADG Moisture Content**

Raw and processed ADG temperatures were relatively low during the test periods ranging from 77 to 82 $^{o}$F. Subsequently, moisture content ranged from 15.5 to 23.0 milligrams per liter (mg/l). As such, removal of condensed water by the GPU was not required.

**Table S-3. GPU Removal Efficiency for Volatile Organic Compounds**

| | Primary Volatile Organic Compounds Detected (concentrations in ppb) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | **Vinyl chloride** | **Acetone** | **cis-1,2 Dichloroethene** | **Benzene** | **Heptane** | **Toluene** | **Ethyl benzene** | **m,p-Xylene** | **Propyl benzene** | **4-Ethyltoluene** | **1,3,5-Trimethylbenzene** | **1,2,4-Trimethylbenzene** |
| Raw ADG 1 | 160 | 25 | 100 | 46 | 65 | 1,700 | 80 | 44 | 40 | 210 | 61 | 84 |
| Processed ADG 1 | 125 | 17 | < 1.4 | < 1.4 | < 1.4 | 2.0 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Removal Efficiency (%) | 21.9 | 32.0 | > 98.6 | > 97.0 | > 97.8 | 99.9 | > 98.3 | > 96.8 | > 96.5 | > 99.3 | > 97.7 | > 98.3 |
| Raw ADG 2 | 140 | 40 | 110 | 52 | 69 | 2,500 | 93 | 49 | 55 | 285 | 96 | 160 |
| Processed ADG 2 | 130 | 17 | < 1.8 | < 1.8 | < 1.8 | 2.3 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 |
| Removal Efficiency (%) | 7.1 | 57.5 | > 98.4 | > 96.5 | > 97.4 | 99.9 | > 98.1 | > 96.3 | > 96.7 | > 99.4 | > 98.1 | > 98.9 |
| Raw ADG 3 | 170 | 120 | 120 | 51 | 72 | 2,500 | 100 | 54 | 56 | 310 | 100 | 180 |
| Processed ADG 3 | 130 | 13 | < 1.4 | < 1.4 | < 1.4 | 2.1 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Removal Efficiency (%) | 23.5 | 89.2 | > 98.8 | > 97.3 | > 98.1 | 99.9 | > 98.6 | > 97.4 | > 97.5 | > 99.5 | > 98.6 | > 99.2 |
| **Average Removal Efficiency (%)** | **17.5** | **59.6** | **> 98.6** | **> 96.9** | **> 97.8** | **99.9** | **> 98.3** | **> 96.9** | **> 96.9** | **> 99.4** | **> 98.1** | **> 98.8** |

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 Generation Using the UTC PC25C Fuel Cell 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 The UTC Fuel Cells PC25C Power Plant – Gas Processing Unit Performance for 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).

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