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Third-Party Technology Performance Verification Results
Data From A Stakeholder-Driven Technology Testing Program

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Abstract

The Greenhouse Gas (GHG) Technology Verification Center is one of 12 independently operated verification centers established by the U.S Environmental Protection Agency. The Center provides third-party performance data to stakeholders interested in environmental technologies that reduce or monitor greenhouse gases and other air pollutants. To ensure that broadly acceptable verifications are conducted, technology stakeholders, including purchasers, developers, policy experts, and vendors, routinely advise the Center on which technologies to test and how to test them. The Center has focused on verifying technologies that capture and make use of methane emissions that occur at natural gas facilities and solid waste disposal landfills. The Center is also beginning verifications of distributed electrical generation technologies. This paper presents a synopsis of four recent verifications conducted by the Center. Two technologies that capture and recover leaking methane at natural gas compressor stations have been tested at field sites in the U.S. Performance highlights for these two technologies are presented. Verification results for a new computer-software-based continuous emission monitor for gas-fired engines are also presented. Finally, a phosphoric acid fuel cell/gas pretreatment unit that produces electricity from raw landfill gas was evaluated at two landfill sites, and results of this performance evaluation are presented.

INTRODUCTION AND BACKGROUND

The ETV Program

Since the early 1990s, government and private groups in the U.S. have identified the lack of independent and credible performance data as a major impediment to the acceptance and use of innovative environmental technologies. It is recognized that technology buyers need such data to make informed technology purchase decisions. To satisfy this need, the President's environmental technology strategy, Bridge to a Sustainable Future(1), and the Vice-President's National Performance Review Report(2) contain initiatives geared to accelerate the adoption of environmental technology. One initiative, which is being implemented by the U.S. Environmental Protection Agency (EPA), provides verification and reporting of technology performance. This initiative is the Environmental Technology Verification (ETV) program. In 1997 an ETV strategy document(3) was prepared, based on the evolution of the program over its first 2 years, to specify the goals and operational features of the program.

Twelve individual verification organizations have been established under the ETV program, each with a unique technology focus and operation. Although different in many ways, each verification organization has common operating principles: participation is voluntary, only commercially available technologies can be verified, verification organizations do not "certify" or approve technologies, and verification tests must maintain a high degree of quality, transparency, and fairness. Another key principle each organization shares is that the entire process is stakeholder driven; that is, technology purchasers, developers, policy experts, vendors, and others advise the Center on which technologies to test and how to test them.

Since 1995, EPA, along with several private companies and national laboratories, has entered into partnerships to verify technologies in the drinking water, pollution prevention, monitoring, air pollution control, and other areas. One of these partnerships resulted in the formation of the GHG Technology Verification Center. The Center is operated as a partnership between Southern Research Institute (SRI) and the U.S. EPA's National Risk Management Research Laboratory.

Operation and Technology Focus of The Greenhouse Gas Technology Verification Center

It is estimated that carbon dioxide (CO_2) emissions account for about 60 percent of human-induced GHG warming, and that methane, halocarbons, and nitrous oxide account for 18, 13, and 4 percent, respectively. This makes a compelling case for the verification program to focus primarily on sources of CO_2, since it accounts for most of the GHG emissions, and the opportunities for reducing emissions would appear to be significant. However, in the absence of GHG regulations, market and other forces continue to play a dominant role in the development and implementation of commercial GHG mitigation and monitoring technologies. Technologies that have low capital requirements and strong potentials for profitable economic performance will continue to have the greatest commercialization potential in the next 2 to 5 years.

The Center has established and tested a process to identify the technologies most in need of performance verification, to encourage vendors of those technologies to participate in the ETV program, and to produce high quality verification reports. The strategy, developed with input from industry, government, vendor, and other technology stakeholders, identified eight industries where independent verification testing could facilitate the adoption of promising new technologies. These areas were presented to the Executive Stakeholder Group, the Center's independent oversight panel made up of technology experts, industry representatives, policy experts, and others. The Executive Stakeholder Group recommended that the Center focus initial efforts on technologies applicable to the oil and gas industries and the landfill industry.

In 1997, methane emissions accounted for about 10 percent of total GHG emissions in the U.S.[4]. Figure 1 shows the distribution of methane emissions by industry. From this figure, it can be seen that the Center's initial technology focus areas (the natural gas and landfill industries) are among the most significant sources of methane emissions in the U.S. (19 and 37 percent, respectively).

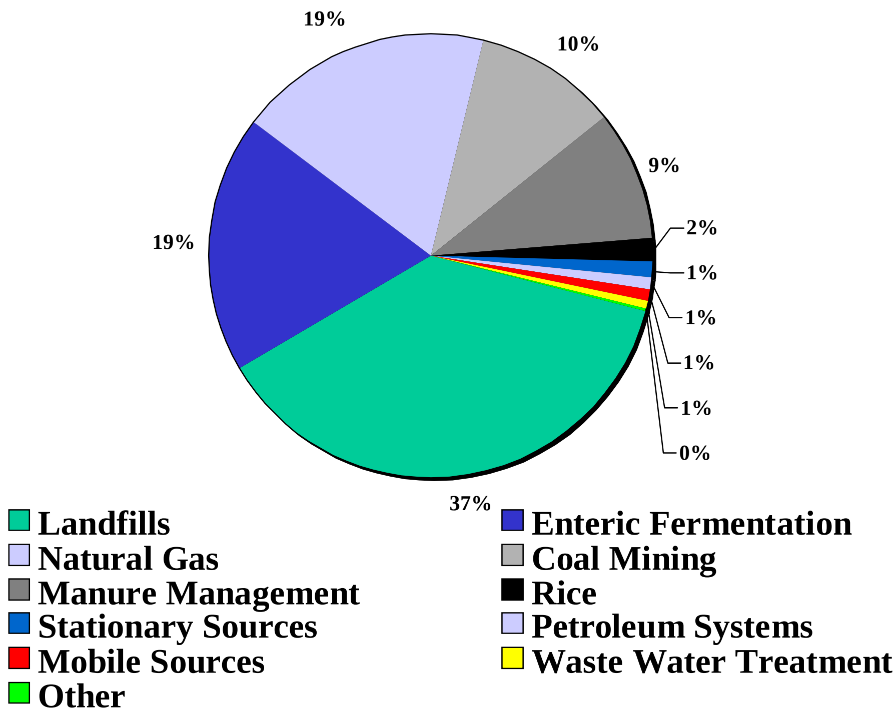

Figure 1. 1997 methane emissions in the U.S. by source type (percent of U.S. methane emissions).

After receiving input from the Executive Stakeholders, an Oil and Gas Industries Stakeholder Group was established. This group included industry representatives, services providers, technology vendors, trade organization representatives, and government groups. The group's first meeting was held on June 23 and 24, 1998, in Houston, Texas. During this meeting, the group identified seven high priority technologies in need of verification, voiced support for the Center's mission, and identified broadly acceptable verification strategies. The group also emphasized that the verification of technology cost and economic payback is critical for industry acceptance of new products. After the Houston meeting, vendors of GHG mitigation devices were solicited in several top-rated technology areas, and verification testing was started on various natural gas compressor leak mitigation and other devices. Testing was also started on technologies for which vendors had approached the Center and requested testing be conducted. In 1999, a second industry-specific group was formed, the Electricity Generation Stakeholder Group, to support the

Center's more recent activities in distributed electrical power systems. Figure 2 illustrates the range of verifications occurring in 1998 and 1999, and the location of each field test.

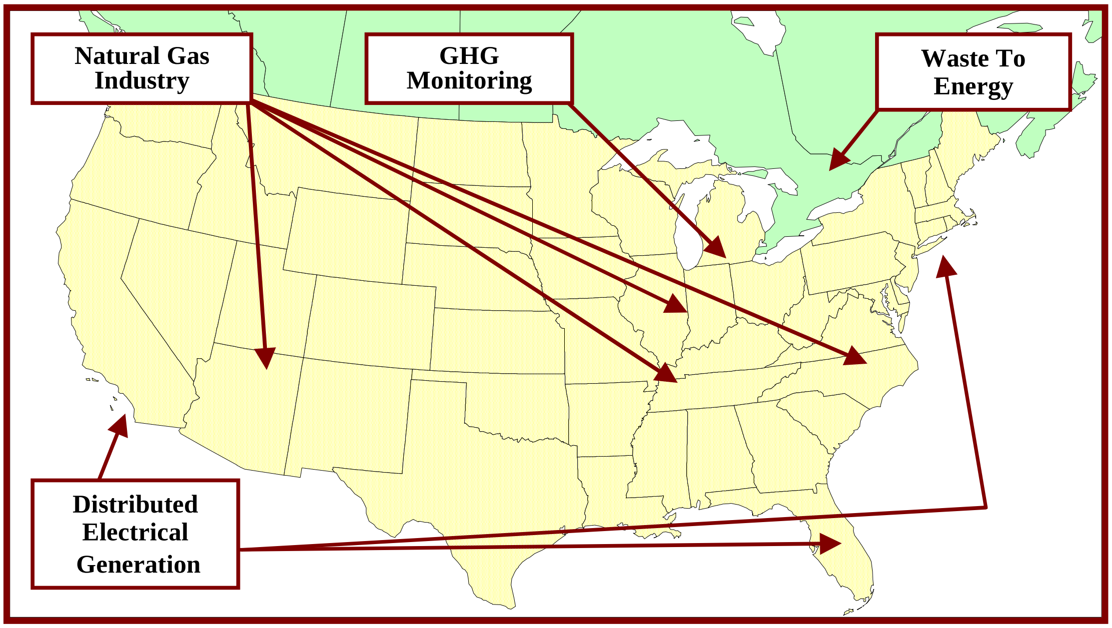

Figure 2. Verifications completed or underway at the Center.

The Center's verification process consists of: 1) inviting vendors to submit pretest applications, 2) conducting engineering evaluations to determine their readiness for testing, 3) locating host test sites and preparing initial test plans based on input from the stakeholders, vendors, and the host site, 4) negotiating and signing testing commitment letters, 5) preparing and publishing verification test plans, 6) obtaining independent reviews of these plans, 7) performing verification tests, and 8) reporting and distributing performance results. Verification results are reported in two formats: the Verification Report and the Verification Statement. Both documents are made public in printed form and through posting on two worldwide Web sites: the ETV Program Web site (http://www.epa.gov/etv) and the GHG Center's Web site (http://www.sri-rtp.com).

Verification Results

In the landfill industry, methane mitigation activities have focused on the recovery and combustion or conversion of landfill gas into electricity. The Center has examined such technologies, but is also evaluating new solid-waste-to-energy concepts. Verification results for a landfill-gas-to-electricity technology (fuel cell) are presented below.

In the natural gas industry, gas leaks and releases from reciprocating compressors are significant and most often associated with blowdown valves, compressor rod packing, unit isolation valves, pressure relief valves, blowdown operations, and other small fugitive sources. A large source of these emissions is the leakage associated with compressor rod packing at gas transmission stations. Two technologies that reduce emissions from leaking natural gas compressor rod packing have been verified by the Center and are discussed below. Finally, verification results for a low cost continuous emissions monitor for internal combustion (IC) engines are discussed. This novel new technology provides for continuous emissions monitoring of IC engine emissions without the use of expensive continuous monitoring hardware.

A&A Environmental Seals Seal Assist System

The Seal Assist System (SAS) is a secondary emission containment device designed to prevent compressor rod packing leaks from escaping into the atmosphere on reciprocating natural gas compressors. The SAS allows existing rod packing leaks to continue, but the leaking gas is contained within a secondary emission containment gland. The contained gas is then collected, recompressed, and routed into the compressor engine fuel line for use.

The SAS consists of three primary components: the Emission Containment Gland (ECG), a set of Jets which provide the motive force to move collected emissions through the systems piping, and an Eductor/Compressor system which repressurizes the collected gas for introduction into the engine fuel line. The primary function of the ECG, attached to an existing rod seal packing case, is to collect rod emissions and prevent them from entering the atmosphere. Figure 3 presents a simplified diagram of the SAS and shows points at which the Center collected process flow and other measurements related to SAS performance.

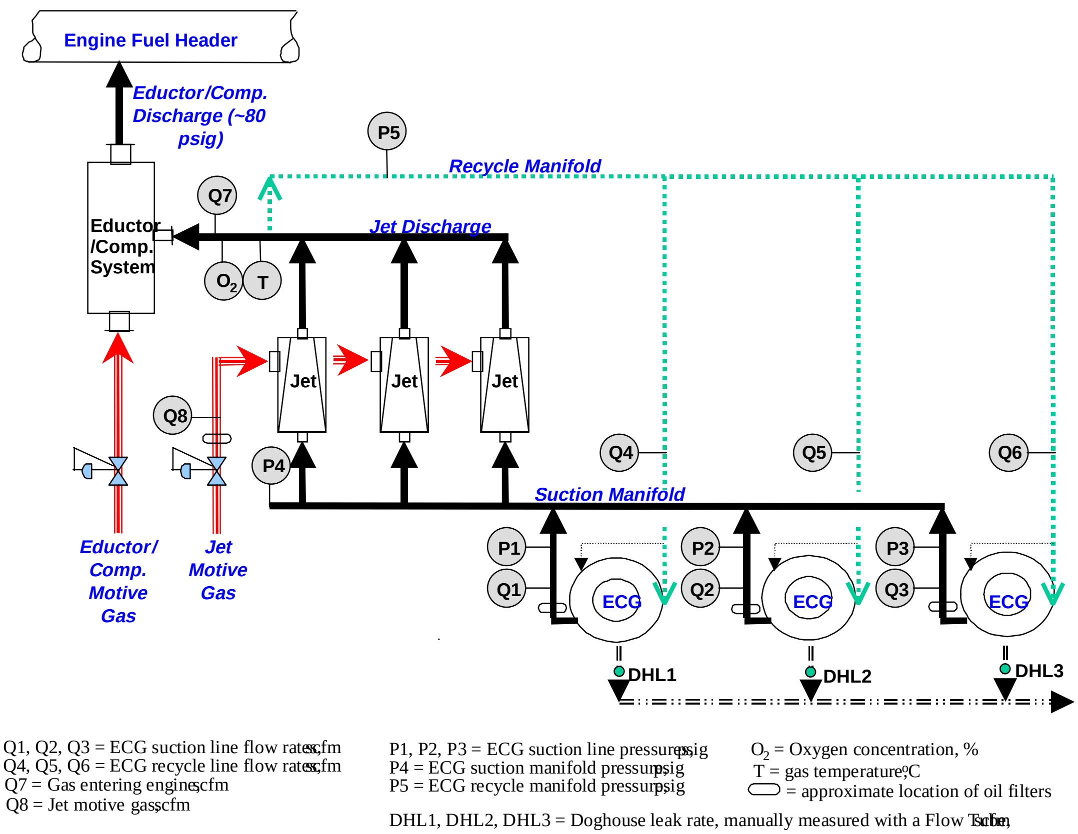

Figure 3. The as-built SAS and measurement system at test site.

The SAS was verified at a natural gas compressor station operated by Transwestern Pipeline Company -- Enron Gas Pipeline Group. Three ECGs were installed on three 4.5 inch compressor rods, and the SAS system was installed to provide fuel to the compressor's 4000 hp gas-fired IC engine. Specific verification goals were to measure and verify SAS leak tightness, gas recovery rates, and methane emission reduction performance. SAS installation and operating requirements and costs were also verified. Verification findings are outlined below.

- SAS Leak Tightness: The SAS assembly was leak tight except for the ECGs. Based on 12 individual measurements, total system leaks of 0 to 5.7 scfm methane were measured.

- Gas Recovery: The SAS recovered from 3.7 to 11.6 scfm gas, and injected it into the engine fuel line. The average recovery rate over the test period was 7.2 ± 0.22 scfm gas (an approximate leak capture efficiency of 70 percent).

- Methane Emission Reduction Potential: Due to operation problems at the site, reliable emission estimates could not be obtained. The Center is collecting additional verification data in a Phase II test.

- Initial Costs: The equipment cost for the SAS system was $30,933, and the labor cost was $11,841. The total installed cost was $42,774.

- Optimum Performance: Maximum gas recovery was achieved when ECG suction pressures were negative. The SAS was unable to maintain design operational pressures because fluctuations in engine load caused system pressure variations. This caused a tertiary seal located on the ECG to leak continuously. The impact of pressure on the leak rate of these tertiary seals can be seen in Figure 4. According to A&A, new seal designs are being developed to mitigate this leakage.

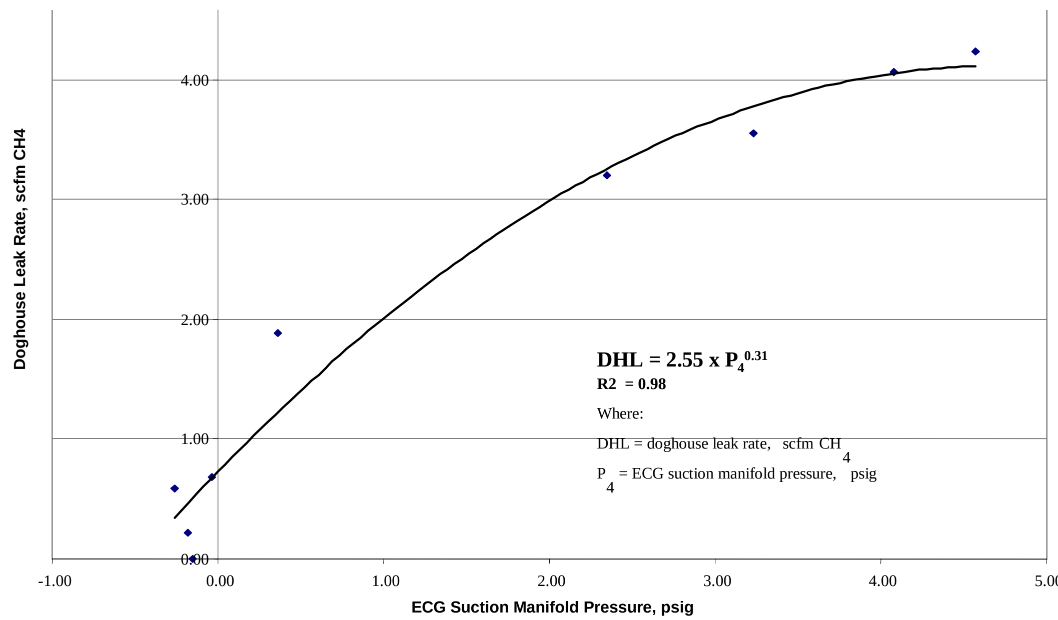

Figure 4. Leak rate versus ECG suction pressure.

A Phase II effort is underway to characterize additional performance parameters, and to calculate the economic pay back period for the SAS installed at the test site.

C. Lee Cook Static Pac™

Gas can leak from compressor rod packing while the compressor is either in operation or, in some cases, in a standby mode. The standby operating mode is commonly encountered in industry, and ensures that compressors can quickly return to operation in response to changing pipeline demand. If rod leaks during standby operations are reduced or eliminated, significant gas savings and emissions reductions could occur.

The C. Lee Cook Static Pac™ is a gas leak containment device designed to prevent rod packing leaks during pressurized compressor standby periods. The Static Pac system is installed in a conventional packing case by replacing several rings (typically two) in the low-pressure side of the packing case or by slightly extending the case length. Upon shutdown of the compressor, a control system activates the Static Pac, causing pressurized gas to move a piston along the outer shell of the Static Pac seal, wedging a lip seal into contact with the rod. When the actuating pressure is lowered, the piston retracts, releasing the Static Pac seal.

The Static Pac was verified at a natural gas compressor station operated by ANR Pipeline Company. The test was carried out on two engines (8-cylinder, 2000 hp), each equipped with two reciprocating compressors (4-inch rods). The goals of the verification test were to: 1) measure and verify Static Pac gas savings, and 2) document installation costs and installation requirements. To accomplish this, the Static Pac was installed on a single compressor rod on each of the two ANR engines. The remaining rods, equipped with new conventional packing, served as Control Rods against which Static Pac performance was compared. The bullets below summarize the verification test results.

- Methane Emissions During Standby: The Static Pac reduced 96 percent of the rod packing emissions while the compressor was in an idle, pressurized state. The overall average methane emission reduction achieved was 0.66 scfm.

- Methane Emissions During Compressor Operation: The Static Pac requires removing a rod seal to make room for the Static Pac components, resulting in a “missing seal” compared to a conventional packing case. No differences in operating rod emissions were measured between the Test Rods and Control Rods, indicating that the missing seal does not increase normal operating emissions after initial installation.

- Gas Savings for a Compressor that Normally Remains Pressurized During Standby Periods: The Static Pac-equipped rods provided gas savings of 4,733 scf natural gas over 116 standby hours, equivalent to 41 scf natural gas savings/standby hour per rod.

- Gas Savings for a Compressor that Normally Depressurizes and Blows Down to Atmospheric Pressure: As a result of installing the Static Pac, a pressurized idle state is established, increasing emissions from some fugitive sources (e.g., valves and seals) and decreasing emissions from others. Net gas savings were 61,217 scf natural gas for a standby period of 116 hours and three blowdown occurrences (528 scf natural gas/standby hour per rod). The change in operating characteristics, particularly the elimination of blowdowns due to compressor depressurization, provided the most significant benefits.

- Initial Costs: The equipment cost for the Static Pac system was $2,638/rod greater than that for a conventional packing case. Installation of the Static Pac required 13 hours/rod more than for conventional packing. The total incremental cost for modifying a conventional packing case with the Static Pac was $3,483/rod.

The Static Pac will be tested continuously for an additional 4 months, after which a Phase II document reporting medium-term technical and economic payback performance will be issued.

ANR Pipeline Parametric Emission Monitoring System

In the natural gas industry, interstate gas pipeline operators use large gas-fired engines to provide the mechanical energy needed to drive pipeline gas compressors. ANR Pipeline Company of Detroit, Michigan, has developed a parametric emissions monitoring system (PEMS) which provides continuous monitoring of air emissions from gas-fired IC engines. The patented PEMS approach provides an alternative to instrumental continuous emissions monitoring systems (CEMS), and has a potential to be a more cost-effective approach. In addition to monitoring emissions of CO_2, carbon monoxide (CO), total hydrocarbons (THCs), oxygen (O_2), and nitrogen oxides (NO_x), the ANR PEMS provides feedback on engine operating conditions that influence continuous emissions.

The PEMS approach to monitoring exhaust emissions is based on establishing relationships between engine operating parameters, as determined by existing engine sensors, and exhaust emissions. As such, PEMS are fundamentally computerized algorithms that describe the relationships between operating parameters and emission rates, and which estimate emissions without the use of CEMS. Table 1 identifies the engine sensors that provided input to the ANR PEMS during verification testing.

Table 1. Engine Parameters/Sensors Used by PEMS

Sensor	Model	Specified Accuracy (%)	Calibration Check	Operating Range
Ignition Timing	Altronic #DI-1401P	± 1 of full scale	Annual	45° BTDC[1] to 45° ATDC[2]
Fuel DP (flow)	Rosemount #1151DP-4-S-12-MI-B1 transducer	± 0.25	Annual	0-100 in. water
Fuel Temperature	Rosemount #444RL1U11A2NA RTD	± 0.25	Annual	0-125 °F
Air Manifold Pressure	Electronic Creations #EB-010-50-1-0-40/N transducer	± 0.25	Annual	0-25 psig
Air Manifold Temperature	Rosemount 0068-F-11-C-30-A-025-T34 RTD	± 1	Annual	0-150 °F

(1) before top dead center
(2) after top dead center

PEMS performance was assessed by comparing predicted emissions under normal engine operating conditions, to measured emissions determined using calibrated instrumental methods specified by the U.S.EPA[5]. The key verification parameter is relative accuracy (RA), which represents the accuracy of the PEMS relative to the instrumental methods. A total of 12 test runs, each 21 minutes in duration, were conducted in order to determine the RA for each gas. Since engine speed and torque are primary determinants of engine emissions, tests were conducted while operating the engine at four different engine-operating conditions within the normal operating range of the test engine. The engine/compressor selected for this evaluation is a gas-fired reciprocating, 4-cycle IC engine (Ingersoll-Rand model KVR-616: 16 cylinder, 6000 hp).

The RA test results were determined based on two types of emission units: grains per brake horsepower-hour and parts per million by volume. The RA results are presented in Table 2. Based on the 12 runs, the RA is defined as the run-average difference between actual emissions (reference method value) and predicted emissions (PEMS output) divided by the reference method value and multiplied by 100. Table 2 also presents the mean absolute differences in emissions between the Reference Method data and the PEMS predictions, and the standard deviation of the differences.

Table 2. Relative Accuracy Test Results						
	Emissions (gr/bhp-hr)			**Emissions (ppm -- % for CO_2)**		
Parameter	**Mean Diff.**	**Std. Dev.**	**RA (%)**	**Mean Diff.**	**Std. Dev.**	**RA (%)**
NO_x	0.60	0.14	11.1	71.4	26.9	11.2
CO_2	10.9	7.41	3.90	-0.36	0.08	8.18
CO	-0.07	0.05	6.78	-12.9	9.61	6.38
THC	-0.63	0.12	34.2	-220	52.0	33.6

The calculated RA for NO_x, CO, and CO_2 were well within the U.S. EPA's Performance Specification for CEMS (20 percent). This indicates that the PEMS has excellent emission prediction capabilities for these pollutants, at least as good as CEMS. The calculated RA for THC was well outside the 20 percent value, but some difference between PEMS and reference method values was expected due to a significant offset observed between the data used by ANR to parameterize the PEMS and the verification measurement data.

International Fuel Cells PC25™ Fuel Cell

International Fuel Cells (IFC) Corporation has developed a commercially available phosphoric acid fuel cell (PC25) to generate electricity from natural gas, and offers a system that can be used at municipal solid waste landfills to convert landfill gas (LFG) into electric power. This application requires a supplemental gas pretreatment unit (GPU) to remove sulfur and halide compounds present in the LFG. The combined GPU and PC25 fuel cell system provides a means for utilizing waste landfill gas, thus reducing methane and other air pollutants.

In the system design evaluated, raw LFG is first treated in an impregnated carbon adsorber which removes hydrogen sulfide, followed by the removal of water, heavy hydrocarbons, sulfides, and other contaminants by a dryer bed, low temperature cooler, carbon bed, and particulate filter. The impregnated carbon and dryer beds are purged routinely to remove contaminants, and the resulting waste gas stream is routed to a flare for combustion. The PC25 fuel cell consists of a fuel processing section, an electrical conversion section, and a thermal management system. In the fuel processing section, treated LFG is converted to hydrogen (H_2) and CO_2 for introduction into the fuel cell stack. The fuel treatment process consists of low temperature removal of residual contaminants, a fuel reformer, and a low temperature shift converter. The H_2 from the process fuel stream is then combined electrochemically with O_2 from the air to produce electricity in the fuel cell stacks. The direct current produced is converted into alternating current in a power-conditioning package. The PC25 is designed to produce 200 kW of electric power from natural gas. LFG has a lower heating value, so the unit generates less power when using LFG.

Verification testing of the combined GPU and fuel cell system was conducted at two sites in the U.S.: the Penrose Landfill in Los Angeles, California, and the Groton Landfill in Groton, Connecticut. The information below summarizes key verification findings.

Performance of the GPU:

- Halide and Sulfur Removal Efficiency: The fuel cell requires total halogen and total sulfur levels to be <3 ppmv in the GPU outlet stream. At both sites, the GPU exceeded the removal requirements of both contaminants (total halides and total sulfur are <0.05 ppmv).

- Estimated Flare Destruction Efficiency and CO/NO_x Concentrations: The destruction efficiencies of non-methane organic compounds, volatile organic compounds, and sulfur compounds were estimated to be 99 percent. This is based, in part, on estimations because measured flow rates were below the EPA Method 2 detection limit. The NO_x and CO concentrations at the flare outlet averaged 10.4 and 3.0 ppmv, respectively.

- Operational Availability: The GPU availability averaged 70 percent at Groton and 87 percent at the Penrose site.

Performance of the PC25 Fuel Cell:

- Electrical Output: At the Penrose site, a nominal output of 140 kW was expected using the LFG containing 44 percent methane (heating value of 446 Btu/scf). The test verified a maximum output of 137 kW. The heating value of the Groton LFG was higher, 581 Btu/scf and 57 percent methane, resulting in higher power production from the fuel cell (165 kW).

- Energy Conversion Efficiency: The fuel cell system energy conversion efficiency, based on lower LFG heating values, was determined to be 37.1 percent at Penrose and 38.0 percent at Groton.

- Operational Availability: The adjusted availability for the fuel cell, which compensates for shutdowns not caused by the fuel cell, was over 96 percent at both test sites.

- Stack Emissions: The average emissions measured are (dry gas, corrected to 15 percent O_2): NO_x = 0.12 ppmv or 0.29 g/hr, SO_2 was not detectable (0.23 ppmv detection limit) or <0.78 g/hr, and CO = 0.77 ppmv or 1.15 g/hr.

NEW VERIFICATIONS IN PROCESS

Microturbine Power Generator

Honeywell Power Systems, Inc. of Albuquerque, New Mexico, in cooperation with Enron Gas Pipeline Group in Houston, Texas, is participating in an independent performance verification of

Honeywell's 75 kW Parallon™ 75 turbogenerator. The test will be conducted at an Enron-operated gas transmission station in Melbourne, Florida.

Microturbines are relatively new and, although based on well-established turbine technology designs, have been applied at natural gas transmission stations on a limited basis.

The test will address a range of technical, economic, emissions, and operational performance characteristics. A phased approach will be used to initially verify the performance of a single commercial unit (Phase I) in a peak shaving mode. If the Phase I results meet site acceptance criteria established jointly by Honeywell and Enron, then several new microturbines will be installed, and the Phase II verification monitoring will begin.

The primary objectives of Phase I are to verify: 1) energy production and conversion efficiency performance, 2) capital, installation, and O&M costs, 3) emission rates of several criteria pollutants, including GHGs, 4) installation and startup requirements, and 5) compatibility with existing electrical systems. The Phase I and II efforts have similar objectives, but a more long-term perspective will be provided and overall economic performance and GHG emission reductions will be verified.

Solid Waste To Energy Technology

In September 1999, the Center entered into an agreement with Eastern Power of Ontario, Canada, the parent company of Super Blue Box Recycling Corp., to verify the GHG reduction performance of their new municipal solid waste (MSW) to electricity technology. The technology, referred to as Super Blue Box Recycling or SUBBOR, converts MSW into biogas and a suite of saleable recycled materials including metals, plastics, and peat. The biogas, which according to the vendor is higher quality than competing MSW to biogas conversion processes, is used to produce electricity for onsite use and/or sale to the grid. The verification will be conducted by the Center at the SUBBOR facility under construction at Guelph, Ontario, Canada.

The Center will conduct a focused verification to quantify the GHG emission and emission reduction performance of the SUBBOR technology. The analysis will characterize, via measurements and other means, the GHG emissions from all significant release points within the process. These emissions will then be compared to the GHG emissions estimated for conventional landfill technologies and other MSW management strategies to determine emission reductions from baseline. A life cycle analysis will be conducted to ensure that all primary and secondary GHG-related sources of emissions have been taken into account. Criteria pollutant and organic species emission rates of interest to potential purchasers and regulators will also be verified.

Summary

The U.S. EPA has initiated a program to accelerate the adoption of environmental technology through objective verification and reporting of technology performance. Under this program, referred to as the Environmental Technology Verification (ETV) program, 12 verification organizations have been established to provide independent technology verification in a wide range of areas. The Greenhouse Gas Technology Verification Center (the Center) is one of these verification organizations, and since 1998 the Center has focused on verifying technologies which capture and use methane emissions associated with natural gas facilities and solid waste disposal landfills.

This paper describes the verification results associated with four technologies examined by the Center. Two technologies evaluated allow the capture and recovery of methane leaks from rod packing seals used on reciprocating natural gas compressors. In addition to verifying the installation costs for each technology under actual field conditions, leak tightness and gas recovery rates for each were measured. The seal assist system offered by A&A Environmental Seals of La Marque, Texas, recovered about 70 percent of the leaked gas. The Static Pac^{TM} offered by C. Lee Cook of Louisville, Kentucky, is applicable to compressors placed under standby operating conditions. During testing, the system recovered about 96 percent of the gas that would have leaked had the Static Pac not been applied.

The Center recently completed an evaluation of a Parametric Emission Monitoring System (PEMS) used to monitor continuous emissions of several pollutant species on large gas-fired IC engines. PEMS offers an advantage over a conventional Continuous Emission Monitoring System (CEMS) in that no CEM hardware is required (PEMS are essentially computerized prediction algorithms). The system is offered by ANR Pipeline of Detroit, Michigan and, based on field testing conducted by the Center, it was concluded that for NO_x, CO, and CO_2, the ANR PEMS is well within U.S. EPA's performance specification of 20 percent relative accuracy for a standard CEMS. The accuracy for THCs was found to be well outside this 20 percent guideline, but some difference between PEMS and reference method values were expected due to a bias measured by the Center in data used to paramaterize the PEMS.

The Center also evaluated International Fuel Cells Corporation's phosphoric acid fuel cell (PC25™). The PC25 fuel cell, designed to generate electricity from raw landfill gas (LFG), was tested at two landfill sites in the U.S. to verify energy conversion efficiency, availability, and other performance characteristics. In general, the system's gas pretreatment unit adequately removed LFG contaminants that could harm the fuel cell stack, but the unit’s availability was moderate (70 to 80 percent). On the other hand, fuel cell availability was over 96 percent, and the energy conversion efficiency ranged from 37 to 38 percent.

Two new technology verifications underway at the time this paper was written were briefly described: Honeywell's new 75 kW Parallon^{TM} 75 turbogenerator, and a new municipal solid waste to energy process developed and offered by Eastern Power/Super Blue Box Recycling Corp. of Toronto, Canada.

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