SRI/USEPA-GHG-QAP-37
July 2005

Test and Quality Assurance Plan

Aisin Seiki 6.0 kW Natural Gas-Fired Engine Cogeneration Unit

Prepared by:

Greenhouse Gas Technology Center

Operated by
Southern Research Institute

Under a Cooperative Agreement With
U.S. Environmental Protection Agency

and

Under Agreement With
New York State Energy Research and Development Authority

EPA REVIEW NOTICE

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A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

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Aisin Seiki 6.0 kW Natural Gas-Fired Cogeneration Unit

This Test and Quality Assurance Plan has been reviewed and approved by the Greenhouse Gas Technology Center Project Manager and Center Director, the U.S. EPA APPCD Project Officer, and the U.S. EPA APPCD Quality Assurance Manager.

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Test Plan Final: July 2005

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1.0 INTRODUCTION

1.1 BACKGROUND

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 the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and innovative environmental technologies. Congress funds ETV in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. With performance data developed under this program, technology buyers, financiers, and permitters in the United States and abroad will be better equipped to make informed decisions regarding environmental technology purchase and use.

The Greenhouse Gas Technology Center (GHG Center) is one of six verification organizations operating under the ETV program. The GHG Center is managed by EPA's partner verification organization, Southern Research Institute (Southern), which conducts verification testing of promising GHG mitigation and monitoring technologies. The GHG Center's verification process consists of developing verification protocols, conducting field tests, collecting and interpreting field and other data, obtaining independent peer-review input, and reporting findings. Performance evaluations are conducted according to externally reviewed verification Test and Quality Assurance Plans (Test Plan) and established protocols for quality assurance (QA).

The GHG Center is guided by volunteer groups of stakeholders. The GHG Center's Executive Stakeholder Group consists of national and international experts in the areas of climate science and environmental policy, technology, and regulation. It also includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested groups. The GHG Center's activities are also guided by industry specific stakeholders who provide guidance on the verification testing strategy related to their area of expertise and peer-review key documents prepared by the GHG Center.

In recent years, a primary area of interest to GHG Center stakeholders has been distributed electrical power generation systems. Distributed generation (DG) refers to equipment, typically ranging from 5 to 1,000 kilowatts (kW) that provide electric power at a site closer to customers than central station generation. A distributed power unit can be connected directly to the customer or to a utility's transmission and distribution system. Examples of technologies available for DG includes gas turbine generators, internal combustion engine generators, photovoltaics, wind turbines, fuel cells, and microturbines. DG technologies provide customers one or more of the following main services: standby generation, peak shaving generation, baseload generation, or cogeneration.

Since 2002, the GHG Center and the New York State Energy Research and Development Authority (NYSERDA) have collaborated and shared the cost of verifying several new DG technologies throughout the state of New York under NYSERDA-sponsored programs. The verification described in this document will evaluate the performance of one such DG system: an Aisin Seiki G60 6.0 kW natural gas fired engine cogeneration unit currently in use at the Hooligans Bar and Grille in Liverpool, New York. The Aisin system is manufactured in Japan. ECO Technology Solutions, LLC. (ECOTS) serves as Aisin's primary agent in the U.S. and manages the installation and operation of the Aisin system at

Hooligans. The GHG Center will be evaluating the performance of this system in collaboration with NYSERDA.

In partnership with the Association of State Energy Research and Technology Transfer Institutions (ASERTTI), Southern was contracted to develop and validate a nationally recognized distributed generation and combined heat and power field testing protocol. In December 2004 ASERTTI issued the DG/CHP Distributed Generation and Combined Heat and Power Performance Protocol for Field Testing [1]. The ETV GHG Center has used portions of this protocol and procedures developed during past ETV verifications to develop a draft generic verification protocol (GVP) for ETV verifications of DG/CHP technologies. This ETV performance verification of the Aisin system will be based on the draft GVP. A final GVP will be issued in 2006 with any revisions based on this and other field validations and feedback from various users and stakeholders.

This document is the site specific Test Plan for this performance verification. This Test Plan does not repeat the rationale for the selection of verification parameters, the verification approach, data quality objectives (DQOs), and Quality Assurance/Quality Control (QA/QC) procedures specified in the GVP. Instead, this plan includes descriptions of the Aisin Seiki G60 system, its integration at the Hooligan's facility, site specific measurements and instrumentation, and site specific exceptions to the GVP. This performance verification will include evaluation of the following parameters:

– electrical performance
– electrical efficiency
– CHP performance
– atmospheric emissions
– NO_X and CO_2 emission offsets

This Test Plan has been reviewed by NYSERDA, ECOTS and Aisin representatives, and the EPA QA team. Once approved, as evidenced by the signature sheet at the front of this document, it will meet the requirements of the GHG Center's Quality Management Plan (QMP) and thereby satisfy the ETV QMP requirements and conform to EPA's standard for environmental testing. This Test Plan has been prepared to guide implementation of the test and to document planned test operations. Once testing is completed, the GHG Center will prepare a Technology Verification Report and Verification Statement, which will first be reviewed by NYSERDA and ECOTS. Once all comments are addressed, the report will be reviewed by the EPA QA team. Once completed, the GHG Center Director and the EPA Laboratory Director will sign the Verification Statement, and the final Report will be posted on the Web sites maintained by the GHG Center (www.sri-rtp.com) and ETV program (www.epa.gov/etv).

1.2 AISIN SEIKI G60 TECHNOLOGY DESCRIPTION

The Aisin Seiki G60 6.0 kW natural gas fired engine cogeneration unit is a natural gas-fueled engine driven generator from which excess heat is recovered for use on-site. This technology provides a maximum 6.0 kW electrical output at 120v single phase in parallel with the utility supply. The engine is a water-cooled 4-cycle, 3-cylinder overhead valve unit that drives a synchronous generator. Some of the waste heat produced by the engine (approximately 46,000 Btu) is recovered from the exhaust gases and supplied to an indirect fired water heater and storage system to provide first stage water heating for the host site's hot water system. A heat transfer fluid (water for this system) is circulated through the Aisin heat recovery system by an external circulation pump to provide heat for use in the facility. Table 1-1 summarizes the physical and electrical specifications for the unit.

Table 1-1. Aisin Seiki G60 Specifications

(Source: Aisin Seiki Co., Ltd.)

Physical Specifications	Width	1,100 mm
	Depth	660 mm
	Height	1,500 mm
	Weight	465 kg
Electrical Specifications	Electrical Input	Interconnection of DC conversion + inverter
	Electrical Output	6.0 kW, 240 V, single phase, 2-wire
	Engine Type	Water-cooled vertical 4-cycle 3-cylinder OHV
	Generator Type	Permanent magnet rotating-field type synchronous
	Power Generating Efficiency	26.5 %
	Waste Heat Recovery Efficiency	59.5 %

1.3 TEST FACILITY DESCRIPTION

The performance verification of the Aisin Seiki G60 will take place at Hooligans Bar and Grille in Liverpool, New York. Hooligans is a sit-down restaurant and lounge with a seating capacity of 498 people. Being in upstate New York, the location provides a relatively cold climate at an altitude of approximately 500 feet. Average daily ambient temperatures in Liverpool range from 14°F in January to 82°F in July. Electric service is provided by Niagara Mohawk Power Corporation at 120/208v under service classification T&D SC3. Hooligans' annual peak electrical demand is 119 kW.

The site uses natural gas delivered by Niagara Mohawk Gas for hot water, space heating, and cooking utilities. Monthly thermal loads range from approximately 1,300 therms in summer months to over 2,500 therms per month in winter. The Aisin cogeneration unit is used to offset a small portion of the site's electrical demand and at the same time provide first stage water heating for the site's hot water system.

The Aisin cogeneration unit is located outdoors at the rear of the facility on a concrete pad with weather protection. Figure 1-1 shows the Aisin G60 as it is currently installed. It is fully integrated into the facility's existing domestic hot water and electrical distribution systems. The output of the cogeneration unit is 240v 60 Hz single phase. The restaurant has an 800 amp 120/208v three phase service. Installation of the Aisin G60 required the addition of a 240 X 120v isolation transformer in order for the restaurant service to properly accept the unit output. The connection was made to the phase with the highest normal load, so as to bring the load into greater balance.

As part of the control system, current transformers (CTs) are located on the neutral and the unit's connected phase. The output of these CTs are connected to the Aisin unit to monitor the power flow on the phase and neutral to provide signaling that prevents the unit from exporting power to the grid. This configuration causes all energy produced to be used on-site.

Prior to installation of the Aisin cogeneration unit, Hooligans used an 85 gallon gas-fired water heater to provide hot water at 150 °F. The existing water heater is an A.O. Smith Master Fit Model BTR 365104 with a rated heat input of 365 MBtu/hr. The kitchen's dishwasher has an internal electric heater that boosts water temperature to 185 °F for dish and silver washing. Installation of the Aisin cogeneration unit required the addition of a 120-gallon Amtrol indirect water heater with a double walled heat exchanger. The hot transfer fluid from the Aisin cogeneration unit is circulated through the Amtrol unit by an external 10 gallon per minute (gpm) pump. Cold water supply flows into the Amtrol water heater, where it is preheated to approximately 140 °F. The preheated water is then routed to the existing water heater, where it is further heated to approximately 150 °F.

Figure 1-1. Current Installation of Aisin G60 Cogeneration Unit at Hooligans

The hot water system is equipped with control circuits that interface with the storage tank aquastat and the circulating pump control relay. A thermocouple inserted into the Amtrol water heater provides temperature measurement for the aquastat. The unit is set for a cutout temperature of 140 °F, at which point the control circuit shuts down the Aisin unit and disconnects it from the grid. When the water heater temperature drops, the control circuit closes, causing the unit to restart and complete the interconnection process. The system is designed to be load following and therefore seeks to deliver its full capacity of 6.0 kW upon startup. This process is repeated throughout the day depending on hot water demand.

1.4 ORGANIZATION AND RESPONSIBILITIES

Figure 1-2 presents the project organization chart. The following section discusses functions, responsibilities, and lines of communications for the verification test participants.

Southern's GHG Center has overall responsibility for planning and ensuring the successful implementation of this verification test. The GHG Center will ensure that effective coordination occurs, schedules are developed and adhered to, effective planning occurs, and high-quality independent testing and reporting occur.

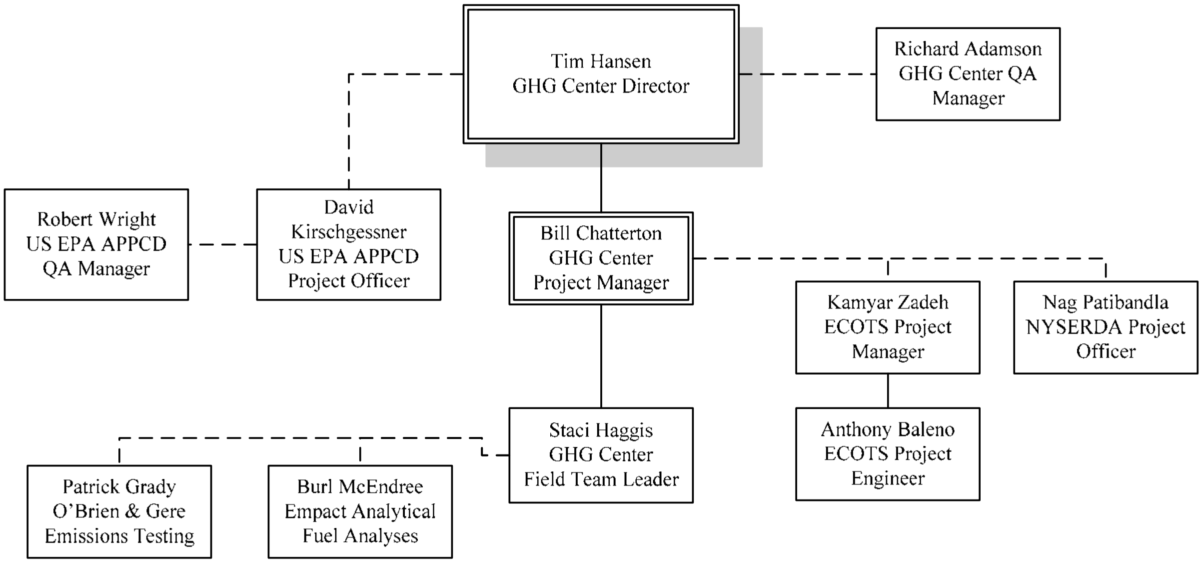

Figure 1-2. Project Organization

Tim Hansen is the GHG Center Director. He will ensure the staff and resources are available to complete this verification as defined in this Test Plan. He will review the Test Plan and Report to ensure they are consistent with ETV operating principles. He will oversee the activities of the GHG Center staff, and provide management support where needed. Mr. Hansen will sign the Verification Statement, along with the EPA-ORD Laboratory Director.

Bill Chatterton will serve as the Project Manager for the GHG Center. His responsibilities include:

- drafting the test plan and verification report;
- overseeing the field team leader's data collection activities, and
- ensuring that data quality objectives are met prior to completion of testing.

The project manager will have full authority to suspend testing should a situation arise that could affect the health or safety of any personnel. He will also have the authority to suspend testing if the data quality indicator goals are not being met. He may resume testing when problems are resolved in both cases. He will be responsible for maintaining communication with ECOTS, NYSERDA, and EPA. He also oversees and manages subcontractor activities and submittals.

Staci Haggis will serve as the Field Team Leader. Ms. Haggis will provide field support for activities related to all measurements and data collected. She will install and operate the measurement instruments, supervise and document activities conducted by the emissions testing contractor, collect gas samples and coordinate sample analysis with the laboratory, and ensure that QA/QC procedures outlined in this test plan are followed, including QA requirements for field subcontractors. She will submit all results to the Project Manager, such that it can be determined that the DQOs are met.

Southern's QA Manager, Richard Adamson, is responsible for ensuring that all verification tests are performed in compliance with the QA requirements of the GHG Center QMP, the GVP, and this test plan. He has reviewed and is familiar with each of these documents. He will also review the verification test results and ensure that applicable internal assessments are conducted as described in these documents. He will reconcile the DQOs at the conclusion of testing and will conduct or supervise an audit of data quality.

He is also responsible for review and validation of subcontractor activities, review of subcontractor generated data, and confirmation that subcontractor QA/QC requirements are met. Mr. Adamson will report all internal reviews, DQO reconciliation, the audit of data quality, and any corrective action results directly to the GHG Center Director, who will provide copies to the project manager for corrective action as applicable and citation in the final verification report. He will review and approve the final verification report and statement. He is administratively independent from the GHG Center Director and maintains stop work authority.

The verification will include the services of two subcontractors. Emissions testing will be conducted by O'Brien & Gere, Inc. of Syracuse, New York with Patrick Grady serving as project manager. Fuel gas analyses will be conducted by Empact Analytical of Brighton, Colorado under the management of Burl McEndree.

Kamyar Zadeh and Anthony Baleno of ECOTS and Nag Patibandla of NYSERDA will serve as the primary contact persons for the Aisin verification team. They will provide technical assistance, assist in the installation of measurement instruments, and coordinate operation of the cogeneration system at the test site. They will ensure the units are available and accessible to the GHG Center for the duration of the test. They will also review the Test Plan and Reports and provide written comments.

EPA-ORD will provide oversight and QA support for this verification. The APPCD Project Officer, Dr. David Kirchgessner, is responsible for obtaining final approval of the Test Plan and Report. The APPCD QA Manager reviews and approves the Test Plan and the final Report to ensure they meet the GHG Center QMP requirements and represent sound scientific practices.

1.5 SCHEDULE

The tentative schedule of activities for testing is:

Verification Test Plan Development	
GHG Center Internal Draft Development	March – April 29, 2005
NYSERDA and ECOTS Review/Revision	May 2 – 31, 2005
EPA Review/Revision	June 1 – 24, 2005
Final Test Plan Posted	July 1, 2005
Verification Testing and Analysis	
Measurement Instrument Installation/Shakedown	July 5 – 8, 2005
Field Testing	July 8 – 22, 2005
Data Validation and Analysis	July 8 – 29, 2005
Verification Report Development	
GHG Center Internal Draft Development	July 23 – August 5, 2005
NYSERDA and ECOTS Review/Revision	August 8 – 19, 2005
EPA Review/Revision	August 22 – 31, 2005
Final Report Posted	September 30, 2005

2.0 VERIFICATION APPROACH

This performance verification will be conducted following the guidelines and procedures specified in the GVP. This test plan includes site-specific information including the following:

- Definition of the system under test (SUT) boundary for this verification - **§2.1**,
- Summary of the Aisin Seiki verification parameters and references to the applicable measurements, procedures, and calculations from the GVP - **§2.2**, and
- Site specific instrumentation - **§2.3**.

Following the GVP, the verification will include evaluation of the Aisin system performance over a series of controlled test periods. The GVP specifies controlled tests be conducted at three different engine loads including 100, 75, and 50 percent of capacity. Because this unit is designed to operate at full load only, an exception to the GVP is required. Tests will only be conducted while the unit operates at nominal 6 kW. Procedures related to the load tests are summarized in §2.2.6 of this test plan and detailed in §7.1 through §7.4 of the GVP. In addition to the controlled test periods, the GHG Center will collect sufficient data to characterize the Aisin system's performance over normal facility operations. This will include up to 1 week of continuous monitoring of fuel consumption, power generation, power quality, and heat recovery rates.

2.1 SYSTEM BOUNDARY

The Aisin Seiki verification will be limited to the performance of the system under test (SUT) within a defined system boundary. Figure 2-1 illustrates the SUT boundary for this verification.

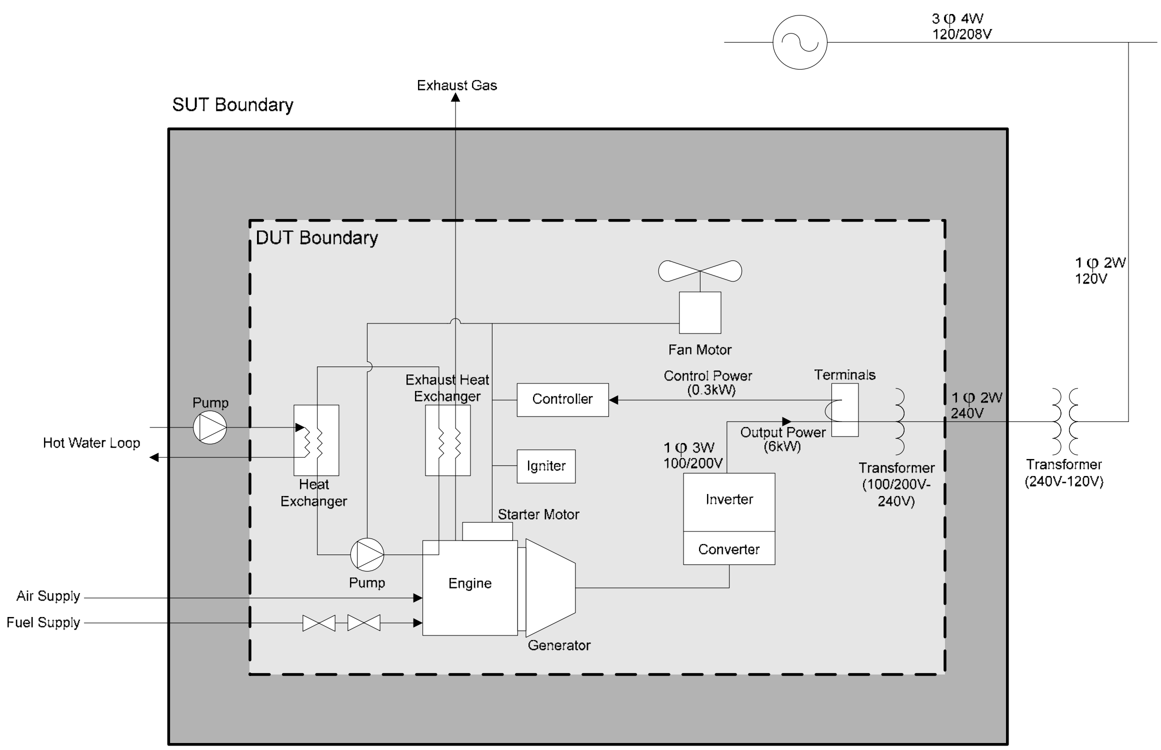

Figure 2-1. Aisin Seiki 6.0 kW Cogeneration System Boundary Diagram

The figure indicates two distinct boundaries. The device under test (DUT) or product boundary includes the Aisin Seiki 6.0 kW Cogeneration unit selected for this test including all of its internal components. The SUT includes the DUT as well as the heat transfer fluid circulation pump, the only significant external parasitic load on the system. Following the GVP, this verification will incorporate the system boundary into the performance evaluation.

2.2 VERIFICATION PARAMETERS

The defined SUT will be 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

Testing will be conducted at 100 percent of system capacity. The test sequences and durations will follow the guidelines specified in GVP §1.3. There will be three separate one-hour test runs conducted. Permissible measurement variability criteria for IC engines presented in GVP §2.2.1 will apply to this testing. In addition to these verification parameters, this verification will also include estimation of NO_X and greenhouse gas (CO_2) emissions reductions realized through use of the cogeneration system at this test location. The approach and methodology for these estimations are provided in §2.2.4 and Appendices A and B of this test plan.

The following sections identify the sections of the protocol that are applicable to the verification parameters for this test, identify site specific instrumentation for each (Table 2-1), and specify any exceptions or deviations.

2.2.1 Electrical Performance (GVP §2.0)

Determination of electrical performance will be conducted following §2.0 and Appendix D1.0 of the GVP. The following parameters will be measured:

- Real power, kW
- Apparent power, kVA
- Reactive power, kVAR
- Power factor, %
- Voltage total harmonic distortion, %
- Current total harmonic distortion, %
- Frequency, Hz
- Voltage, V
- Current, A

The verification parameters will be measured with a digital power meter manufactured by Power Measurements Ltd. (Model 7500 or 7600 ION). The meter scans all power parameters once per second and computes and records one-minute averages. Test personnel will install the power meter on the Aisin cogeneration unit. The meter will operate continuously, unattended, and will not require further adjustments after installation. The rated accuracy of the power meter is ± 0.1 percent, and the rated accuracy of the current transformers (CTs) needed to employ the meter at this site is ± 1.0 percent. Overall power measurement error is then ± 1.0 percent.

2.2.2 Electrical Efficiency (GVP §3.0)

Determination of electrical efficiency will be conducted following §3.0 and Appendix D2.0 of the GVP. The following parameters will be measured:

- Real power production, kW
- External parasitic load power consumption, kW
- Ambient temperature, ^{o}F
- Ambient barometric pressure, psia
- Fuel LHV, Btu/scf
- Fuel consumption, scfh

Real power production and external parasitic load consumption will be measured by the Power Measurements Ltd. Digital power meter, as described in §2.2.1 above. Ambient temperature will be recorded on the datalogger from a single Class A 4-wire RTD. The specified accuracy of the RTD will be ± 0.6 ^{o}F. Ambient barometric pressure will be measured by a Setra Model 280E ambient pressure sensor with a full scale (FS) of 0 – 25 psia and an accuracy of ± 1% FS.

Gas flow will be measured by a Model 8C175 Series B3 Roots Meter manufactured by Dresser Measurement with a specified accuracy of ± 1%. Gas temperature will be measured by a Class A 4-wire platinum resistance temperature detector (RTD). The specified accuracy of the RTD is ± 0.6 ^{o}F. Gas pressure will be measured by an Omega Model PX205 Pressure Transducer. The specified accuracy of the pressure transducer is ± 0.25% of reading over a range of 0 – 30 psia. At least three gas samples will be collected in 500 ml stainless steel canisters and shipped to subcontractor Empact Analytical of Brighton, Colorado for LHV analysis according to ASTM Method 1945. The QA Manager will confirm that the subcontractor satisfies the required QA elements of the method.

The external parasitic load introduced by the heat transfer fluid circulation pump will be monitored using a second digital power meter manufactured by Power Measurements Ltd. (Model 7500 or 7600 ION). Meter specifications and accuracy will be the same as those for the power meter described in §2.2.1 above.

2.2.3 CHP Thermal Performance (GVP §4.0)

Determination of CHP thermal performance will be conducted following §4.0 and Appendix D3.0 of the GVP. The following parameters will be quantified:

- Thermal performance in heating service, Btu/h
- Thermal efficiency in heating service, %
- Actual SUT efficiency in heating service as the sum of electrical and thermal efficiencies, %

To quantify these parameters, heat recovery rate will be measured throughout the verification. This verification will employ an Omega Model FTB-905 flow meter with a nominal linear range of 2.5 – 29 gpm. An Omega Model FSLC-64 transmitter will amplify the flow meter's pulse output. An Agilent / HP Model 34970A will totalize and log the pulse output. Accuracy of this system will be ± 1.0 % of reading. The nominal K factor for the flow meter is 1035 pulses per gallon, but a pretest calibration will document actual average K factor. Class A 4-wire platinum resistance temperature detectors (RTD) will be used to determine the transfer fluid supply and return temperatures. The specified accuracy of the RTDs, including an Agilent / HP Model 34970A datalogger, is ± 0.6 ^{o}F. Pretest calibrations will document the RTD performance.

2.2.4 Emissions Performance (GVP §5.0)

Determination of emissions performance will be conducted following §5.0 and Appendix D4.0 of the GVP. This verification will include emissions of NO_X, CO, CO_2, CH_4, and THC. The verification will not include emissions of SO_2 or acoustic emissions performance. Emissions testing will be performed by subcontractor O'Brien & Gere, Inc. of Syracuse, New York. A fully equipped mobile emissions testing laboratory will be transported to the facility to conduct the EPA Reference Methods emission testing. The field team leader will confirm that the subcontractor satisfies the required QA elements of the methods. Proposed analytical ranges for the gas analyzers are listed in Table 2-1. Results for each pollutant will be reported in units of ppm, ppm corrected to 15% O_2, lb/h, and lb/kWh.

2.2.5 Field Test Procedures and Site Specific Instrumentation

Field test procedures will follow the guidelines and procedures detailed in the following sections of the GVP:

- Electrical performance - §7.1
- Electrical efficiency - §7.2
- CHP thermal performance - §7.3
- Emissions performance - §7.4

Load tests will be conducted as three one-hour test replicates at a cogeneration power command of approximately 6.0 kW. Hot water will be dumped as needed to maintain demand and allow the Aisin unit to operate over the entire test period.

In addition to the controlled tests, system performance will be monitored continuously for a period of approximately one week while the unit operates under normal Hooligans facility operations. The Aisin unit will be allowed to cycle on and off during this period depending on facility demand. Continuous measurements will be recorded during the entire period including:

- Power output,
- Power quality parameters,
- Fuel consumption (gas flow, pressure, and temperature),
- Heat recovery rate (transfer fluid flow, supply temperature, and return temperature),
- Heat transfer fluid circulation pump power consumption, and
- Ambient conditions (temperature and pressure).

Using these data, the GHG Center can evaluate Aisin system performance and usage rates for Hooligans under typical facility operations.

Site specific measurement instrumentation is summarized in Table 2-1. The location of the instrumentation relative to the SUT is illustrated in Figures 2-2 and 2-3. All measurement instrumentation meets the GVP specifications.

Table 2-1. Site Specific Instrumentation for Aisin Seiki Cogeneration System Verification

Verification Parameter	Supporting Measurement	Expected Range of Measurement	Instrument	Instrument Range	Instrument Accuracy
Electrical Performance	Real power	0.0 – 6.0 kW	Power Measurements Ltd. ION power meter (Model 7600 or 7500)	0 – 260 kW	± 1% of reading
	Apparent power	0.0 – 6.3 kVA		0 – 260 kVA	± 1% of reading
	Reactive power	0.0 – 0.3 kVAR		0 – 260 kVAR	± 1% of reading
	Power factor	90 – 100 %		0 – 100 %	± 0.5% of reading
	Voltage THD	0 – 100 %		0 – 100 %	± 1% FS
	Current THD	0 – 100 %		0 – 100 %	± 1% FS
	Frequency	58 – 62 Hz		57 – 63 Hz	± 0.01% of reading
	Voltage	120 V		0 – 600 V	± 1% of reading
	Current	12 – 25 A		0 – 400 A	± 1% of reading
	Ambient temperature	40 – 80 °F	Omega Class A 4-wire RTD	0 – 250 °F	± 0.6 °F
	Barometric pressure	14.5 – 15.0 psia	Setra Model 280E	0 – 25 psia	± 0.1% FS
	Parasitic load	200 W	ION power meter (Model 7600 or 7500)	0 – 260 kW	± 1% of reading
Electrical Efficiency	Gas flow	0 – 70 cfh	Model 8C175 Roots Meter	0 – 800 cfh	± 1% of reading
	Gas pressure	15 – 20 psia	Omega PX205 Pressure Transducer	0-30 psia	± 0.25% of reading
	Gas temperature	30 – 80 °F	Omega Class A 4-wire RTD	0 – 250 °F	± 0.6 °F
CHP Thermal Performance	Transfer fluid flow	8 – 12 gpm	Omega Model FTB-905 turbine meter	2.5 – 29 gpm	± 1.0% of reading
	Transfer fluid supply temp.	140 – 160 °F	Omega Class A 4-wire RTD	0 – 250 °F	± 0.6 °F
	Transfer fluid return temp.	120 – 140 °F	Omega Class A 4-wire RTD	0 – 250 °F	± 0.6 °F
Emissions Performance	NO_X concentration	2 – 20 ppmv	Chemiluminescence	0 – 25 ppmv	± 2% FS
	CO concentration	10 – 50 ppmv	(NDIR)-gas filter correlation	0 – 100 ppmv	± 2% FS
	CO_2 concentration	5 – 10 %	NDIR	0 – 20 %	± 2% FS
	O_2 concentration	8 – 15 %	Paramagnetic or electrochemical cell	0 – 25 %	± 2% FS
	THC concentration	10 – 50 ppmv	Flame ionization detector (FID)	0 – 100 ppmv	± 2% FS
	CH_4 concentration	10 – 50 ppmv	Gas chromatograph with FID	0 – 100 ppmv	± 2% FS

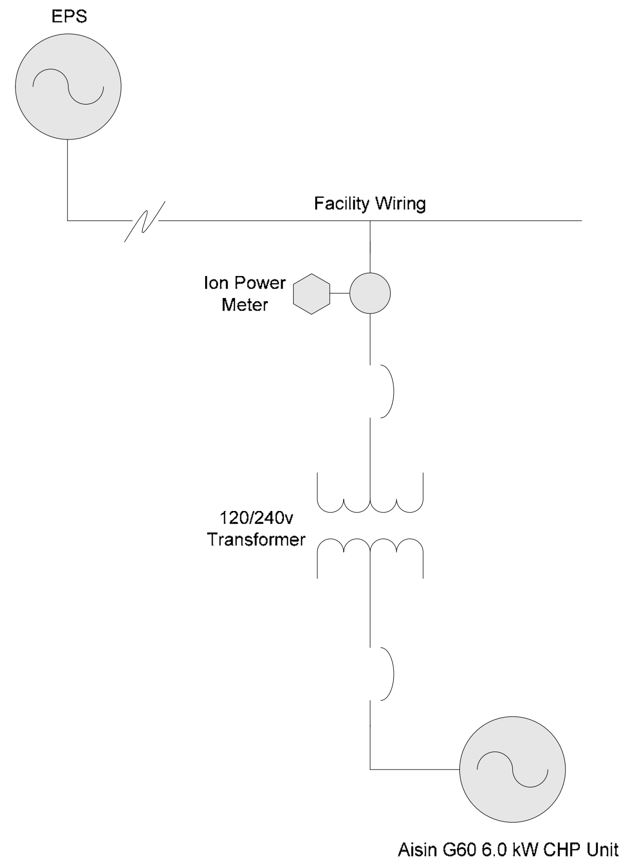

Figure 2-2. Position of Test Instrumentation for SUT Electrical System

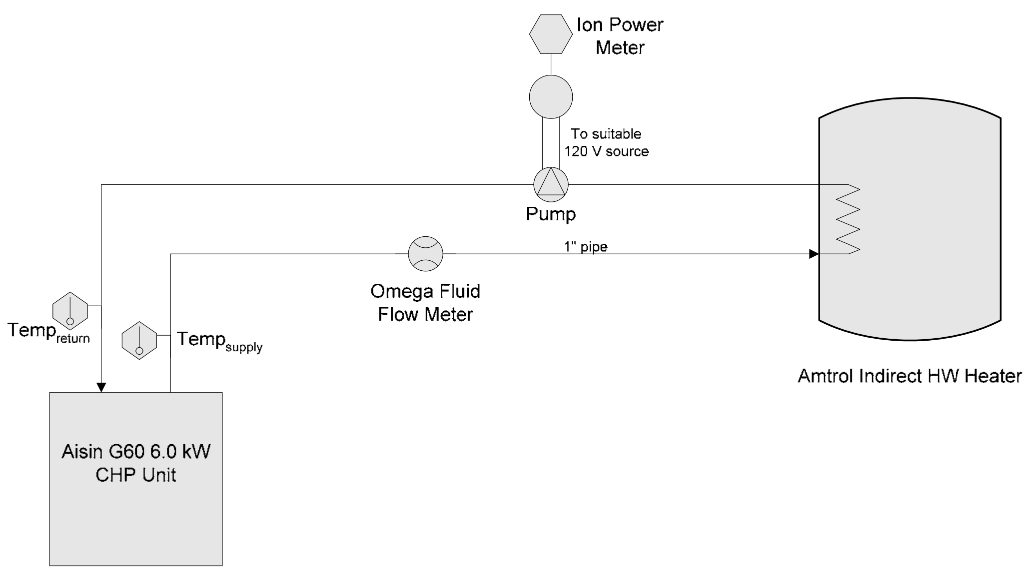

Figure 2-3. Location of Test Instrumentation for SUT Thermal System

2.2.6 Estimated NO_X and CO_2 Emission Offsets

This verification parameter is not included in the GVP, so the approach and procedures to be used in this verification are described here. Use of the Aisin cogeneration system at this facility will change the NO_X and CO_2 emission rates associated with the operation of the Hooligans facility. Annual emission offsets for these pollutants will be estimated and reported by subtracting emissions of the on-site CHP unit from emissions associated with baseline electrical power generation technology and baseline hot water heating equipment.

Appendix A provides the procedure for estimating emission reductions resulting from electrical generation. The procedure correlates the estimated annual electricity savings in MWh with New York and nationwide electric power system emission rates in lb/MWh. For this verification, analysts will assume that the Aisin system generates power at a rate similar to that recorded during the 1 week verification monitoring period throughout the entire year.

Appendix B provides the procedure for estimating emission reductions resulting from heat recovered by the Aisin system. The amount of heat recovered and used for water heating offsets an equivalent amount of energy that would otherwise be consumed by the facility's baseline heating system (the gas-fired water heater). Therefore, emissions from the baseline water heater's burners associated with the equivalent amount of heat produced by the Aisin cogeneration unit are eliminated. The procedure estimates the amount of gas that would be consumed by the water heater based on the amount of heat recovered by the cogen unit, and applies NO_X and CO_2 emission factors to that estimate. As with the offsets attributable to power generation, analysts will assume that the Aisin system provides heat to the facility throughout the entire year at a rate similar to that recorded during the 1 week verification monitoring period.

3.0 DATA QUALITY OBJECTIVES

Under the ETV program, the GHG Center specifies data quality objectives (DQOs) for each verification parameter before testing commences as a statement of data quality. The DQOs for this verification were developed based on past DG/CHP verifications conducted by the GHG Center, input from EPA's ETV QA reviewers, and input from both the GHG Centers' executive stakeholders groups and industry advisory committees. As such, test results meeting the DQOs will provide an acceptable level of data quality for technology users and decision makers. The DQOs for electrical and CHP performance are quantitative, as determined using a series of measurement quality objectives (MQOs) for each of the measurements that contribute to the parameter determination:

Verification Parameter	DQO (relative uncertainty)
Electrical Performance	±2.0 %
Electrical Efficiency	±2.5 %
CHP Thermal Efficiency	±3.5 %

Each test measurement that contributes to the determination of a verification parameter has stated MQOs, which, if met, ensure achievement of that parameter's DQO. This verification is based on the GVP which contains MQOs including instrument calibrations, QA/QC specifications, and QC checks for each measurement used to support the verification parameters being evaluated. Details regarding the measurement MQOs are provided in the following sections of the GVP:

§ 8.1 Electrical Performance Data Validation
§ 8.2 Electrical Efficiency Data Validation
§ 8.3 CHP Performance Data Validation

The DQO for emissions is qualitative in that the verification will produce emission rate data that satisfies the QC requirements contained in the EPA Reference Methods specified for each pollutant. The verification report will provide sufficient documentation of the QA/QC checks to evaluate whether the qualitative DQO was met. Details regarding the measurement MQOs for emissions are provided in the following section of the GVP:

§ 8.4 Emissions Data Validation

Completeness goals for this verification is to obtain valid data for 90 percent of the test periods (controlled test period and extended monitoring).

4.0 DATA ACQUISITION, VALIDATION, AND REPORTING

4.1 DATA ACQUISITION AND DOCUMENTATION

Test personnel will acquire the following electronic data and generate the following documentation during the verification:

Electronic Data

Electronic data will be monitored for the following measurements:

- power output and power quality parameters
- parasitic load of the circulation pump
- fuel flow, pressure, and temperature
- transfer fluid flow, supply temperature, and return temperature
- ambient temperature and barometric pressure

The two ION power meters will poll their sensors once per second. They will then calculate and record one-minute averages throughout all tests. The field team leader will download the one-minute data directly to a laptop computer during the short-term tests. GHG Center personnel will download the data by telephone during the long term monitoring period.

An Agilent / HP Model 34970A datalogger will record all of the temperature, pressure, and flow meter data once every 5 seconds. The field team leader will download the data directly during short-term tests while GHG Center will download the data by telephone during the long term monitoring period. Analysts will use Excel spreadsheet routines to calculate one-minute averages from the 5-second snapshots.

The electronically-recorded one-minute averages (except for the manually-logged water system pressure data) will be the source data for all calculated results.

Documentation

Printed or written documentation will be recorded on the log forms provided in Appendix B of the GVP and will include:

- Daily test log, including water system pressure data, starting and ending times for test runs, notes, etc.
- Appendix A forms which show the results of QA / QC checks
- Copies of calibrations and manufacturers' certificates

The GHG Center will archive all electronic data, paper files, analyses, and reports at their Research Triangle Park, NC office in accordance with their quality management plan.

4.1.1 Corrective Action and Assessment Reports

A corrective action will occur if audits or QA / QC checks produce unsatisfactory results or upon major deviations from this test plan. Immediate corrective action will enable quick response to improper procedures, malfunctioning equipment, or suspicious data. The corrective action process involves the field team leader, project manager, and QA Manager. The GHG Center QMP requires that test personnel submit a written corrective action request to document each corrective action.

The field team leader will most frequently identify the need for corrective actions. In such cases, he or she will immediately notify the project manager. The field team leader, project manager, QA Manager and other project personnel, will collaborate to take and document the appropriate actions.

Note that the project manager is responsible for project activities. He is authorized to halt work upon determining that a serious problem exists. The field team leader is responsible for implementing corrective actions identified by the project manager and is authorized to implement any procedures to prevent a problem's recurrence.

4.2 DATA REVIEW, VALIDATION, AND VERIFICATION

The project manager will initiate the data review, validation, and analysis process. At this stage, analysts will classify all collected data as valid, suspect, or invalid. The GHG Center will employ the QA/QC criteria specified in Section 3.0 and the associated tables. Source materials for data classification include factory and on-site calibrations, maximum calibration and other errors, subcontractor deliverables, etc.

In general, valid data results from measurements which:

- meet the specified QA/QC checks, including subcontractor requirements,
- were collected when an instrument was verified as being properly calibrated, and
- are consistent with reasonable expectations (e.g., manufacturers' specifications, professional judgment).

The report will incorporate all valid data. Analysts may or may not consider suspect data, or it may receive special treatment as will be specifically indicated. If the DQO cannot be met, the project manager will decide to continue the test, collect additional data, or terminate the test and report the data obtained.

Data review and validation will primarily occur at the following stages:

- on site -- by the field team leader,
- upon receiving subcontractor deliverables,
- before writing the draft report -- by the project manager, and
- during draft report QA review and audits -- by the GHG Center QA Manager.

The field team leader's primary on-site functions will be to install and operate the test equipment. He will review, verify, and validate certain data (QA / QC check results, etc.) during testing. The log forms in Appendix B of the GVP provide the detailed information he will gather.

The QA Manager will use this test plan and documented test methods as references with which to review and validate the data and the draft report. He will review and audit the data in accordance with the GHG Center's quality management plan. For example, the QA Manager will randomly select raw data, including data generated and submitted by subcontractors, and independently calculate the verification parameters. The comparison of these calculations with the results presented in the draft report will yield an assessment of the GHG Center's QA/QC procedures.

4.3 INSPECTION/ACCEPTANCE OF SUPPLIES, CONSUMABLES, AND SERVICES

The procurement of purchased items and services that directly affect the quality of environmental programs defined by this TQAP will be planned and controlled to ensure that the quality of the items and services is known, documented, and meets the technical requirements and acceptance criteria herein. For this verification, this includes services provided by Empact Analytical for fuel analyses and O'Brien & Gere, Inc. for emissions testing services.

Procurement documents shall contain information clearly describing the item or service needed and the associated technical and quality requirements. The procurement documents will specify the quality system elements of the GVP for which the supplier is responsible and how the supplier's conformity to the customer's requirements will be verified.

Procurement documents shall be reviewed for accuracy and completeness by the project manager and QA manager as noted in Sections 1.4 and 4.2. Changes to procurement documents will receive the same level of review and approval as the original documents. Appropriate measures will be established to ensure that the procured items and services satisfy all stated requirements and specifications.

4.4 DATA QUALITY OBJECTIVES RECONCILIATION

A fundamental component of all verifications is the reconciliation of the collected data with its DQO. In this case, the DQO assessment consists of evaluation of whether the stated methods were followed, MQOs achieved, and overall accuracy is as specified in the GVP. The field team leader and project manager will initially review the collected data to ensure that they are valid and are consistent with expectations. They will assess the data's accuracy and completeness as they relate to the stated QA / QC goals. If this review of the test data show that QA / QC goals were not met, then immediate corrective action may be feasible, and will be considered by the project manager. DQOs will be reconciled after completion of corrective actions. As part of the internal audit of data quality, the GHG Center QA Manager will include an assessment of DQO attainment.

4.5 ASSESSMENTS AND RESPONSE ACTIONS

The field team leader, project manager, QA Manager, GHG Center Director, and technical peer-reviewers will assess the project and the data's quality as the test campaign proceeds. The project manager and QA Manager will independently oversee the project and assess its quality through project reviews, inspections if needed, and an audit of data quality.

4.5.1 Project Reviews

The project manager will be responsible for conducting the first complete project review and assessment. Although all project personnel are involved with ongoing data review, the project manager must ensure that project activities meet measurement and DQO requirements. The project manager is also responsible for maintaining document versions, managing the review process, and ensuring that updated versions are provided to reviewers and tracked.

The GHG Center Director will perform the second project review. The director is responsible for ensuring that the project's activities adhere to the ETV program requirements and stakeholder expectations. The GHG Center Director will also ensure that the field team leader has the equipment, personnel, and resources to complete the project and to deliver data of known and defensible quality.

The QA Manager will perform the third review. He is responsible for ensuring that the project's management systems function as required by the quality management plan. The QA Manager is the GHG Center's final reviewer, and he is responsible for ensuring the achievement of all QA requirements.

ECOTS and NYSERDA personnel will then review the report. ECOTS will also have the opportunity to insert supplemental unverified information or comments into a dedicated report section.

The GHG Center will submit the draft report to EPA QA personnel, and the project manager will address their comments as needed. Following this review, the report will undergo EPA management reviews, including the GHG Center Director, EPA ORD Laboratory Director, and EPA Technical Editor.

4.5.2 Test/QA Plan Implementation Assessment

The GHG Center has previously conducted numerous internal technical systems audits (TSAs) of the methods and procedures proposed for this verification and will therefore not repeat a TSA for this test. However, the GHG Center QA Manager or designee will conduct a readiness review and observe and document a pre-test assessment and bench test of the measurements system including the following systems:

- flow meters, transmitter, and datalogger
- temperature and pressure sensors and datalogger
- power consumption meters

During the assessment, the QA Manager will verify that the equipment, procedures, and calibrations are as specified in this test plan. Should the QA Manager note any deficiencies in the implementation of the test plan, corrective actions will be immediately implemented by the project manager. The QA Manager will document this assessment in a separate report to the GHG Center Director.

EPA QA management is planning to conduct an external TSA on this verification which will include on-site assessment of the equipment, procedures, and calibrations.

4.5.3 Audit of Data Quality

The audit of data quality is an evaluation of the measurement, processing, and data analysis steps to determine if systematic errors are present. The QA Manager, or designee, will randomly select approximately 10 percent of the data. He will follow the selected data through analysis and data processing. This audit is intended to verify that the data-handling system functions correctly and to assess analysis quality. The QA Manager will also include an assessment of DQO attainment.

The QA Manager will route audit results to the project manager for review, comments, and possible corrective actions. The ADQ will result in a memorandum summarizing the results of custody tracing, a study of data transfer and intermediate calculations, and review of the QA/QC data. The ADQ report will include conclusions about the quality of the data from the project and their fitness for the intended use. The project manager will take any necessary corrective action needed and will respond by addressing the QA Manager's comments in the verification report.

4.6 VERIFICATION REPORT AND STATEMENT

The report will summarize each verification parameter's results as discussed in Section 2.0 and will contain sufficient raw data to support findings and allow others to assess data trends, completeness, and quality. The report will clearly characterize the verification parameters, their results, and supporting measurements as determined during the test campaign. It will present raw data and/or analyses as tables, charts, or text as is best suited to the data type. The report will also contain a Verification Statement, which is a 3 to 5 page document summarizing the technology, the test strategy used, and the verification results obtained.

The project manager will submit the draft report and Verification Statement to the QA Manager and GHG Center Director for review. A preliminary outline of the report is as follows:

Preliminary Outline
Aisin Seiki 6.0 kW Natural Gas Fired Cogeneration Unit Verification Report

Verification Statement

Section 1.0: *Verification Test Design and Description*
Description of the ETV program
Aisin Seiki System and Host Facility Description
Overview of the Verification Parameters and Evaluation Strategies

Section 2.0: *Results*
electrical performance
electrical efficiency
CHP performance
atmospheric emissions
NO_X and CO_2 emission offsets

Section 3.0: *Data Quality*

Section 4.0: *Additional Technical and Performance Data Supplied by ECOTS (optional)*

Section 5.0: *References*

Appendices: *Raw Verification or Other Data*

4.7 TRAINING AND QUALIFICATIONS

This test does not require specific training or certification beyond that required internally by the test participants for their own activities. The GHG Center's project manager has approximately 20 years experience in field testing of air emissions from many types of sources and will directly oversee field activities. He is familiar with the test methods and standard requirements that will be used in the verification test.

The field team leader has performed numerous field verifications under the ETV program, and is familiar with EPA and GHG Center quality management plan requirements. The QA Manager is an independently appointed individual whose responsibility is to ensure the GHG Center's conformance with the EPA approved QMP.

4.8 HEALTH AND SAFETY REQUIREMENTS

This section applies to GHG Center personnel only. Other organizations involved in the project have their own health and safety plans which are specific to their roles in the project.

GHG Center staff will comply with all known host, state/local and Federal regulations relating to safety at the test facility. This includes use of personal protective gear (such as safety glasses, hard hats, hearing protection, safety toe shoes) as required by the host and completion of site safety orientation.

5.0 REFERENCES

[1] *Distributed Generation and Combined Heat and Power Field Testing Protocol, DG/CHP Version,* Association of State Energy Research and Technology Transfer Institutions, Madison, WI, October 2004.

[2] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1999, Annex A: Methodology for Estimating Emissions of CO2 from Fossil Fuel Combustion,* U.S. Environmental Protection Agency, EPA 236-R-01-001, Washington, DC, 2001.

[3] *DAP-42, Compilation of Air Pollutant Emission Factors – Volume 1, Stationary Point and Area Sources, Fifth Edition,* U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Washington, DC, 1995.

Appendix A
Electric Power System Emissions Reduction Estimates

The verification report will provide estimated emissions reductions (or increases) as compared to aggregated electric power system (EPS) emission rates for the state in which the apparatus is located (New York for this verification). The report will also include estimated reductions based on aggregated nationwide emission rates. Analysts will employ the methods described in this Appendix.

A DG asset or power-saving device, when connected to the EPS, will change the overall EPS emissions signature. As an example, a zero-emission generator, such as a hydroelectric power plant, will decrease EPS CO_2 emissions on a lb/MWh basis. The potential emissions reduction (or increase) for DG is the difference between the EPS and DG emission rates, multiplied by the expected power generation or savings rate:

$$Reduction_i = (ER_{EPS,i} - ER_{DG,i}) * MWh_{DG,Ann} \qquad \text{Eqn. A1}$$

Where:

$Reduction_i$ = annual reduction for pollutant i, pounds per year (lb/y)
$ER_{EPS,i}$ = EPS emission rate for pollutant i (see below), pounds per megawatt-hour (lb/MWh)
$ER_{DG,i}$ = DG emissions rate for pollutant i, lb/MWh
$MWh_{DG,Ann}$ = annual estimated DG power production or device-based power savings, megawatt-hours per year (MWh/y)

The potential emissions reduction for a power savings device is simply:

$$Reduction_i = ER_{EPS,i} * MWh_{Device,Ann} \qquad \text{Eqn. A2}$$

Values for $ER_{DG,i}$ are available from the performance verification results. Estimated $MWh_{DG,Ann}$ or $MWh_{Device,Ann}$ should also be available from the verification results. This estimate depends on the specific verification strategy and its derivation should be clearly described in the test plan and verification results. A simple example is the power production or power savings multiplied by the annual availability or capacity factor. For example, a 200 kW fuel cell which operates at full capacity 75 percent of the time can be expected to generate 1314 MWh annually.

$ER_{EPS,i}$ for specific pollutants can vary widely because the EPS may obtain its power from many different generators. The generation mix can change dramatically from hour to hour, depending on market forces, system operations, wheeling practices, emergencies, maintenance, and other factors. Many different approaches have been suggested for estimating $ER_{EPS,i}$, but no consensus has been achieved.

The following estimation methodology is simple, it uses peer-reviewed carbon dioxide (CO_2), nitrogen oxide (NO_X), mercury (Hg), and sulfur dioxide (SO_2) data available from the US Environmental Protection Agency's "EGRID" database, and it provides some analysis flexibility.

EGRID is available from www.epa.gov/cleanenergy/egrid/download.htm. At this writing, data is available through 2000. The example presented here is for a generator located in Florida, but this procedure can be used for any state. Data through 2003 will likely be available in late 2005. Figure A-1 shows the introductory screen prompts which provide year 2000 emission rates for Florida.

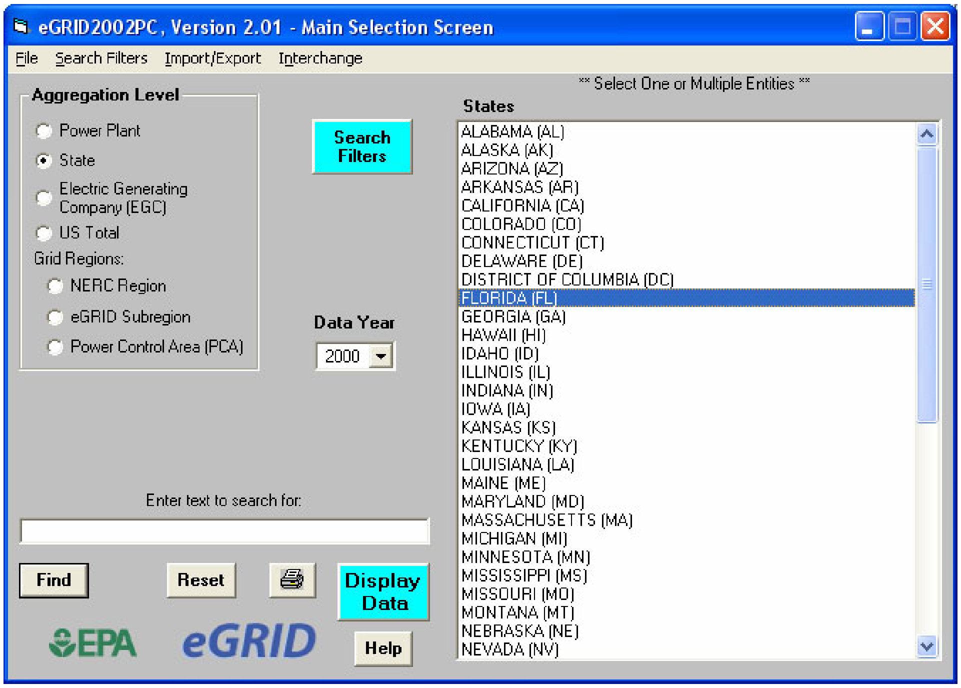

Figure A-1. Example Aggregated Emissions Introductory Screen

Double-clicking the state of interest brings up the emissions data, as shown in Figure A-2.

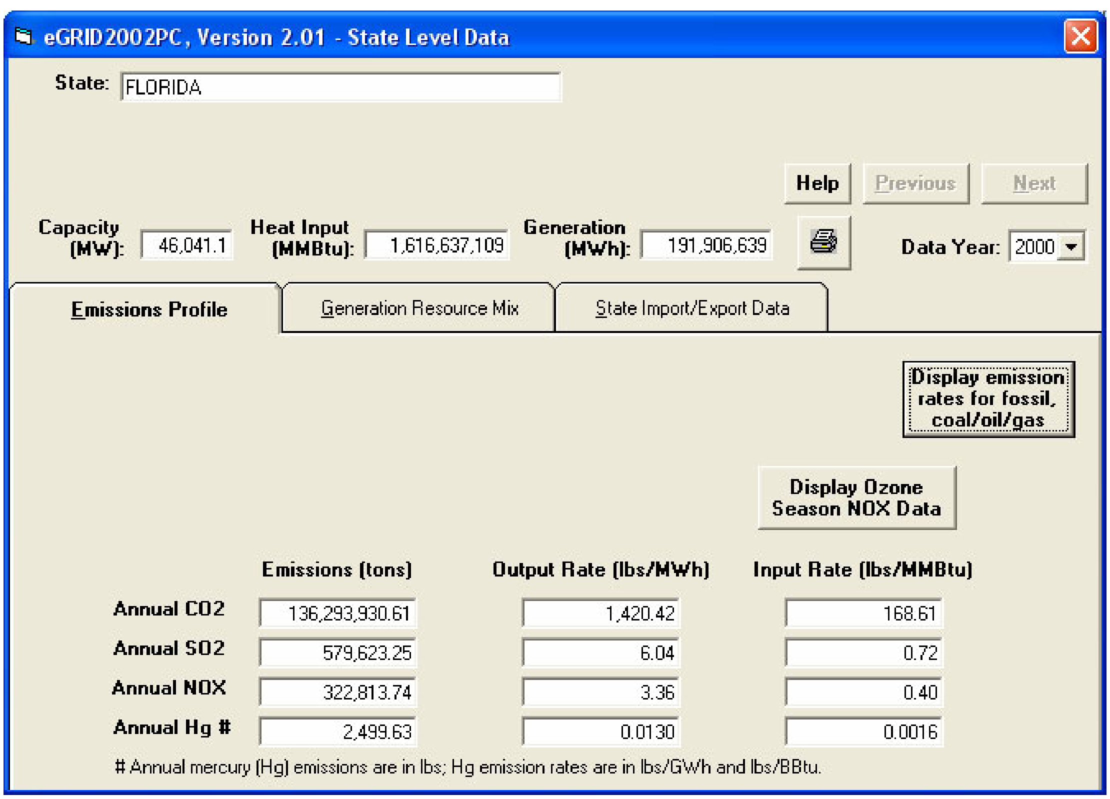

Figure A-2. Example EPS Emission Rates for 2000

Figure A-3 provides the nationwide emission rates for 2000.

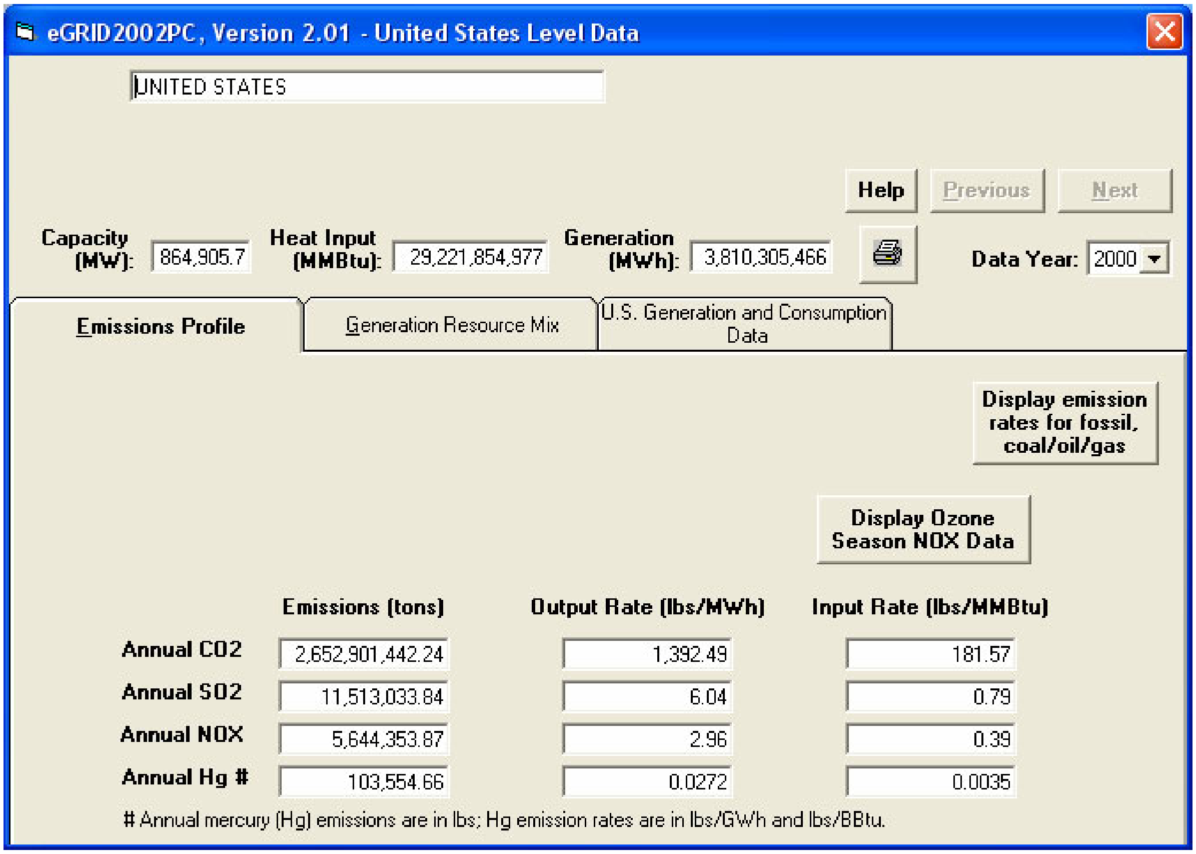

Figure A-3. Nationwide Emission Rates

These results form the basis for comparison. Table A-1 provides emissions offsets estimates for a hypothetical 200 kW fuel cell located in Florida.

Table A-1. Example Fuel Cell Emissions Offsets Estimates

	Florida		Nationwide	
Pollutant	CO_2	NO_X	CO_2	NO_X
ER_{EPS} (from EGRID), lb/MWh	1420	3.36	1392	2.96
ER_{DG} (from verification tests), lb/MWh	1437	0.13	1437	0.13
ER_{EPS} - ER_{DG}, lb/MWh	-17[a]	3.23	-45[a]	2.83
DG capacity, kW	200		200	
Estimated availability or capacity factor	75 %		75 %	
$MWh_{DG, Ann}$	1314		1314	
Emission offset, lb/y	-22400	4250	-59130	3720

[a]Negative numbers represent an increase over the EPS emission rate

Note that this fuel cell increases the overall EPS CO_2 emission rate if electricity generation alone is considered. The increased CO_2 emissions in this example would be balanced by the fuel cell's heat or chilling power production if it is in combined chilling / heat and power (CHP) service. Each verification test plan must provide a specific accounting methodology for electricity production and CHP utilization because it is impossible to consider all the permutations here. The simplest case, that the unit really operates at a constant power output, predictable availability (or capacity factor), and that all the heat produced is actually used, is not necessarily true for every installation. Also, the CHP application may displace units fired by various fuels (electricity, heating oil, natural gas, etc.) with their own efficiencies and emission factors. Each verification strategy should explicitly discuss these considerations as part of the specific emissions offset calculation.

It is useful, however, to continue this example. Assume that the fuel cell provides a constant 800,000 British thermal units per hour (Btu/h) to a domestic hot water system, thus displacing an electric-powered boiler. This heat production is equivalent to 234 kW, which would require approximately 239 kW of electricity from the EPS at 0.98 water heating efficiency (source: ASHRAE Standard 118.1-2003, § 9.1). The fuel cell would therefore save approximately 15700 MWh annually at 75 percent capacity factor. Table A-2 shows the resulting emissions offsets estimates.

Table A-2. Example CHP Emissions Offsets Estimates

	Florida		Nationwide	
Pollutant	CO_2	NO_X	CO_2	NO_X
ER_{EPS} (from EGRID), lb/MWh	1420	3.36	1392	2.96
ER_{DG} (from verification tests), lb/MWh	0[a]	0[a]	0[a]	0[a]
ER_{EPS} - ER_{DG}, lb/MWh	1420	3.36	1392	2.96
DG capacity, kW	239[b]		239[b]	
Estimated availability or capacity factor	75 %		75 %	
$MWh_{DG, Ann}$	15700		15700	
Emission offset, lb/y	2.23×10^7 (11100 tons)	52800 (26.4 tons)	2.19×10^7 (10900 tons)	46500 (23.2 tons)

[a]Emissions are zero here because the electricity production offset estimate included them.
[b]Based on the power required to run an electric-fired boiler at 98 % water heating efficiency.

In this CHP application, the fuel cell represents a considerable net annual CO_2 emissions reduction for New York of 2.23×10^7 lb/y.

This approach is generally conservative because it does not include transmission and distribution (T&D) losses. T&D losses vary between approximately 3 to 8 percent depending on dispatch practices, the unit's location with respect to the EPS generator actually being displaced, and other factors. This means that 100 kW of energy at the DG unit's terminals will actually displace between 103 and 109 kW (and the associated emissions) at the EPS generator.

EGRID provides numerous other aggregation options, and the reader may wish to conduct other comparisons, such as for a particular utility, North American Electric Reliability Council (NERC) region, or control area.

Appendix B
Heat Recovery System Emissions Reduction Estimates

For each Btu of thermal energy recovered by the CHP system (and used by the host facility), an equivalent amount of energy is no longer needed from the baseline gas-fired burners in the existing water heater. At many CHP applications, estimation of emission reductions resulting from CHP systems is fairly straightforward provided all of the recovered heat can be utilized throughout the year. When this is the case, the first step then in estimating the burners' avoided emissions is to measure the maximum CHP heat recovery rate at full load. These heat rates (MMBtu/hr) combined with the projected annual operating hours at this load factor allows the estimation of annual heat recovered. This heat recovery from the unit (assuming constant full heat demand) will be calculated as shown in B1 and reported as a reference value.

$$Q_{CHP,Ann} = Q_{CHP} * h * 60 \qquad \text{(Eqn. B1)}$$

Where:

$Q_{CHP,Ann}$ = maximum total CHP heat recovered (MMBtu/yr)
Q_{CHP} = CHP heat recovery rate at 100 percent load factor (MMBtu/min)
h = projected (or proven) operating hours at 100 percent

For this verification, CHP emissions offsets associated with use of CHP thermal energy will be estimated based on the heat delivered to the Amtrol water heater through the fluid recirculation loop. As shown in Equation B2 and described below, projected heat use at the Hooligans site will be used to estimate emissions reductions specific to the installed application. The CO_2 and NO_X emission rates, combined with the avoided heat input to the primary water heater burners yields the potential burner emissions eliminated by use of the CHP system:

$$E_{BURNERS} = Q_{BURNERS} * ER_{Burners} \qquad \text{(Eqn. B2)}$$

Where:

$E_{BURNERS}$ = potential annual burner emissions offset, lb/yr
$Q_{BURNERS}$ = avoided heat input to the burners, MMBtu/yr
$ER_{Burners}$ = estimated gas burner emission rates; lb/MMBtu CO_2 and lb/MMBtu NO_X

Analysts will use the $E_{BURNERS}$ estimate, along with emission offsets from the electrical grid (Appendix A), to calculate the overall potential annual GHG emission reductions. Using the projected annual heat input offset ($Q_{BURNERS}$ above), calculation of emission offsets due to heat use is as follows. The carbon in the natural gas, when combusted, forms CO_2. The resulting CO_2 emission rate is:

$$ER_{BurnersCO2} = [\frac{44}{12} * (CC) * (FO) / E] \qquad \text{(Eqn. B3)}$$

Where:

$ER_{BurnersCO2}$ = burners CO_2 emission rate, (lb/MMBtu)
44 = molecular weight of CO_2 (lb/lb.mol)
12 = molecular weight of carbon (lb/lb.mol)
CC = measured fuel carbon content (approx. 31.9 lb/MMBtu) [2]
FO = 0.995; Fraction of fuel carbon oxidized during combustion [2]
E = burner efficiency

The EPA has compiled emission factors for natural gas burners in AP-42 [3]. Burners such as those used in the water heater are categorized as similar to commercial boilers under 100 MMBtu/hr heat input. The NO_X emission factor for such units is listed as 100 lb/10^6 scf of natural gas. The LHV for the natural gas used at the host facility is expected to be approximately 950 Btu/scf. This means that 10^6 scf of natural gas will supply approximately 950 MMBtu of heat to the burners. The resulting NO_X emission rate is expected to be approximately 100/950 or 0.1053 lb/MMBtu.