SRI/USEPA-GHG-VR-37
September 2005

Environmental Technology Verification Report

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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THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Gas-Fired Internal Combustion Engine Combined With Heat Recovery System
APPLICATION:	Distributed Electrical Power and Heat Generation Using Aisin Seiki Cogeneration Unit
TECHNOLOGY NAME:	Aisin Seiki 6.0 kW Natural Gas-Fired Cogeneration Unit
COMPANY:	Aisin Seiki Co., LTD.
ADDRESS:	Aichi, Japan
WEB ADDRESS:	www.aisin.com

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Greenhouse Gas Technology Center (GHG Center), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. A technology of interest to GHG Center stakeholders is distributed generation (DG) sources, especially when they include combined heat and power (CHP) capabilities. The

improved efficiency of DG/CHP systems make them a viable complement to traditional power generation technologies.

The GHG Center collaborated with the New York State Energy Research and Development Authority (NYSERDA) to evaluate the performance of an Aisin Seiki G60 6.0 kilowatt (kW) natural gas fired engine cogeneration unit manufactured by Aisin Seiki Co., LTD in Aichi, Japan. The Aisin Seiki G60 is an internal combustion engine generator set capable of producing nominal 6 kW of electrical power with the potential to produce an additional 13 kW of heat. The G60 selected for this verification is owned by the manufacturer and operated at Hooligans Bar and Grille in Liverpool, New York. 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.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by Aisin and ECOTS and does not represent verified information. 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 thousand Btu per hour (MBtu/h)] is recovered from engine coolant and 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. Heat transfer fluid is circulated through the Aisin heat recovery system by an external circulation pump to provide heat for use in the facility. Table S-1 summarizes the physical and electrical specifications for the unit.

Table S-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 AC/DC conversion + inverter
	Electrical Output at Hooligans	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
	Rated Power Generating Efficiency	26.5%
	Rated Waste Heat Recovery Efficiency	59.5%

At Hooligans, the Aisin G60 is integrated into the facility's existing domestic hot water and electrical distribution systems. The output of the cogeneration unit is 120/240v, 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 120/240 to 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/h. 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 (in this case water) 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.

VERIFICATION DESCRIPTION

Field testing was conducted from July 10 through July 21, 2005. The defined system under test (SUT) was tested to determine performance for the following verification parameters:

- Electrical performance
- Electrical efficiency
- CHP thermal performance
- Atmospheric emissions performance
- Nitrogen oxides (NO_X)and carbon dioxide (CO_2) emission offsets

The verification included a series of controlled test periods on July 20 and 21 in which the GHG Center maintained steady system operations for 3 one-hour test periods to evaluate electrical and CHP efficiency and emissions performance. The controlled tests were preceded by a 10-day period of continuous monitoring to examine heat and power output, power quality, efficiency, and emission reductions. Annual NO_X and CO_2 emissions reductions resulting from the use of the Aisin Seiki system were estimated by comparing measured emission rates with corresponding emission rates for the baseline scenario at Hooligans.

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in the draft ETV Generic Verification Protocol (GVP) for DG/CHP verifications developed by the GHG Center. Site specific information and details regarding instrumentation, procedures, and measurements specific to this verification were detailed in the Test and Quality Assurance Plan titled *Test and Quality Assurance Plan – Aisin Seiki 6.0 kW Natural Gas-Fired Engine Cogeneration Unit.*

VERIFICATION OF PERFORMANCE

Results of the verification are representative of the Aisin Seiki system's performance as installed at Hooligans. Quality Assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). The GHG Center's QA manager conducted an audit of data quality on at least 10 percent of the data generated during this verification and a review of this report. Data review and validation was conducted at three levels including the field team leader (for data generated by subcontractors), the project manager, and the QA manager. Through these activities, the QA manager has concluded that the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan.

Also in support of this verification, QA staff from EPA-ORD's Technical Services Branch conducted an on-site technical systems audit (TSA) of the GHG Center's testing activities and procedures. Based on the verification approaches and testing procedures specified in the test plan, the overall conclusion of the audit was that the GHG Center performed well during this verification and there were no significant deviations from the planned activities, measurements, or data quality objectives.

Electrical and Thermal Performance

Table S-2. Aisin Seiki G60 Electrical and Thermal Performance

Test ID	Fuel Input (MBtu/h)	Electrical Power Generation Performance			Heat Recovery Performance		Total CHP System Efficiency (%)
		Power Delivered (kW)	Parasitic Load (kW)	Efficiency [a] (%)	Heat Recovered (MBtu/h)	Thermal Efficiency (%)	
Run 1	76.0	5.32	0.17	23.1	43.3	57.1	80.2
Run 2	75.9	5.30	0.17	23.1	44.6	58.8	81.9
Run 3	76.0	5.31	0.18	23.1	43.0	56.8	79.9
Avg.	**76.0**	**5.31**	**0.17**	**23.1**	**43.6**	**57.5**	**80.6**

[a] Based on actual power available for consumption at the test site (power generated less transformer and circulation pump losses) and the fuel lower heating value (LHV).

- After transformer and parasitic losses, electrical efficiency averaged approximately 23 percent at this site.
- The amount of heat recovered and used for water heating at Hooligans averaged 43.6 MBtu/hr. Corresponding thermal efficiency was 57.5 percent and combined heat and power efficiency averaged 80.6 percent.
- During the 10-day monitoring period, the Aisin unit cycled on and off according to facility hot water demand and operated for a total of total of approximately 61 hours, or 26 percent of the time. During this time, a total of 261.6 kWh electricity was generated and 2,213 MBtu (649 kWh) of heat was recovered and used for water heating. There were no recorded startup failures or periods of unavailability when the unit was commanded to start by hot water demand.

Emissions Performance

Table S-3. Aisin Seiki Emissions During Controlled Test Periods

Run ID	NO_x Emissions		CO Emissions		THC Emissions		CO_2 Emissions	
	ppmv at 15% O_2	lb/MWh	ppmv at 15% O_2	lb/MWh	ppmv at 15% O_2	lb/MWh	%	lb/MWh
Run 1	58	3.1	240	8.1	900	17	7.5	1750
Run 2	61	3.3	250	8.4	920	17	7.5	1720
Run 3	55	3.0	250	8.3	930	18	7.8	1740
Avg.	**58**	**3.2**	**250**	**8.3**	**920**	**17**	**7.7**	**1730**

- NO_X and carbon monoxide (CO) emissions were consistent throughout the testing and averaged 3.1 lb/MWh and 8.3 lb/MWh, respectively. CO_2 emissions averaged 1,730 lb/MWh.
- Concentrations of total hydrocarbons (THC) averaged 2,000 ppm at stack conditions, or 920 ppm at 15% O_2. Results of the methane (CH_4) analyses conducted on composite bag samples averaged 2,340

ppm at stack conditions, or 1,020 ppm at 15% O_2. The THC measurement is considered more reliable since it is an on-site analysis with real time results and all QA/QC criteria were met. The CH_4 results and QA/QC checks indicate that they are suspect and therefore not reported (see Section 2.4.1 of the verification report for details). In any event, it is evident that all or nearly all of the hydrocarbons measured by the THC analyzer are CH_4. THC emission rates averaged 17 lb/MWh.

- Compared to the baseline emissions scenarios for the New York State Independent System Operator (NY ISO) and national grid regions, estimated annual NO_X emissions for the Aisin unit are about 0.003 tons higher than the NY ISO and 0.003 tons (18 %) lower than the national scenario. For CO_2, estimated annual Aisin system emissions are lower than both the NY ISO and national grid regions by 2.2 tons (22 %) and 4.1 tons (34 %), respectively.

Power Quality Performance

- Average electrical frequency was 60.00 Hz and average power factor was 98.0 percent.
- The average current total harmonic distortion (THD) was 2.53 percent and the average voltage THD was 1.76 percent, both well within the IEEE recommended threshold of 5 percent.

Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the Test Plan titled *Test and Quality Assurance Plan – Aisin Seiki 6.0 kW Natural Gas-Fired Engine Cogeneration Unit* (SRI 2005). Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report for Aisin Seiki 6.0 kW Natural Gas-Fired Engine Cogeneration Unit* (SRI 2005). Both can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

Signed by Sally Gutierrez (9/30/2005)	**Signed by Tim Hansen (9/30/2005)**
Sally Gutierrez Director National Risk Management Research Laboratory Office of Research and Development	Tim A. Hansen Director Greenhouse Gas Technology Center Southern Research Institute

Notice: GHG Center verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The EPA and Southern Research Institute make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and Local requirements. Mention of commercial product names does not imply endorsement or recommendation.

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Greenhouse Gas Technology Center

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

Environmental Technology Verification Report

Aisin Seiki 6.0 kW Natural Gas-Fired Cogeneration Unit

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ACKNOWLEDGMENTS

The Greenhouse Gas Technology Center wishes to thank NYSERDA, especially Richard Drake and Nag Patibandla, for supporting this verification and reviewing and providing input on the testing strategy and this Verification Report. Thanks are also extended to ECOTS personnel, especially Kamyar Zadeh and Anthony Baleno, for their input supporting the verification and assistance with coordinating field activities. Finally, thanks go out to the ownership, management, and staff of Hooligans for hosting the test and accommodating field testing activities.

ACRONYMS AND ABBREVIATIONS

ADQ	Audit of Data Quality
Btu	British thermal units
Btu/scf	British thermal units per standard cubic feet
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CT	current transformer
DG	distributed generation
DQO	data quality objective
DUT	device under test
ECOTS	ECO Technology Solutions, LLC
EGRID	Emissions and generation resource integrated database
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
GHG Center	Greenhouse Gas Technology Center
GVP	generic verification protocol
gpm	gallons per minute
Hz	hertz
IC	internal combustion
IEEE	Institute of Electrical and Electronics Engineers
kVA	kilovolt-amperes
kVAr	kilovolt-amperes reactive
kW	kilowatts
kWh	kilowatt hours
lb/hr	pounds per hour
lb/kWh	pounds per kilowatt-hour
LHV	lower heating value
MBtu/h	thousand British thermal units per hour
MMBtu/hr	million British thermal units per hour
MQO	Measurement quality objective
NIST	National Institute of Standards and Technology
NO_X	nitrogen oxides
NYSERDA	New York State Energy Research and Development Authority
NY ISO	New York State Independent System Operator
O_2	oxygen
ORD	Office of Research and Development
ppm	parts per million volume, dry
psia	pounds per square inch, absolute
QA/QC	Quality Assurance/Quality Control
QMP	Quality Management Plan
RTD	resistance temperature detector
scf	standard cubic feet
scfh	standard cubic feet per hour
SUT	system under test
TQAP	Test and Quality Assurance Plan
THC	total hydrocarbons
THD	total harmonic distortion
TSA	technical systems audit

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 ETV is to further environmental protection by 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 greenhouse gas 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 stakeholder input, and reporting findings. Performance evaluations are conducted according to externally reviewed verification Test and Quality Assurance Plans and established protocols for quality assurance.

The GHG Center is guided by volunteer groups of stakeholders, who direct the GHG Center regarding which technologies are most appropriate for testing, help disseminate results, and review Test Plans and Technology Verification Reports. A technology area of interest to some GHG Center stakeholders is distributed electrical power generation (DG), particularly with combined heat and power (CHP) capability. DG refers to electricity generation equipment, typically under 1,000 kilowatts (kW), that provides electric power at a customer's site (as opposed to central station generation). A DG unit can be connected directly to the customer or to a utility's transmission and distribution (T&D) system. Examples of technologies available for DG include gas turbine generators, internal combustion engine generators (gas, diesel, other), photovoltaics, wind turbines, fuel cells, and microturbines. DG technologies provide customers one or more of the following main services: standby generation (i.e., emergency backup power), peak shaving generation (during high-demand periods), base-load generation (constant generation), and CHP generation. An added environmental benefit of some DG technologies is the ability to fuel these systems with renewable energy sources such as anaerobic digester gas (ADG) or landfill gas. These gases, when released to atmosphere, contribute millions of tons of methane emissions annually in the U.S. Cost- effective technologies are available that significantly reduce these emissions by recovering methane and using it as an energy source.

The GHG Center and the New York State Energy Research and Development Authority (NYSERDA) have agreed to collaborate and share the cost of verifying several new DG technologies located throughout the State of New York. The verification described in this document evaluated the performance of one such DG system: the 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 evaluated the performance of the Aisin G60 system by conducting field tests over an 11-day verification period (July 10 – 21, 2005). These tests were planned and executed by the GHG Center to independently verify the electricity generation rate, thermal energy recovery rate, electrical power quality, energy efficiency, emissions, and greenhouse gas emission reductions for the unit as operated at Hooligans. Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures are contained in two related documents:

Technology and site specific information can be found in the document titled *Test and Quality Assurance Plan – Aisin Seiki 6.0 kW Natural Gas-Fired Engine Cogeneration Unit* [1]. It can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv). This Test and Quality Assurance Plan (TQAP) describes the system under test (SUT), project participants, site specific instrumentation and measurements, and verification specific QA/QC goals. The TQAP was reviewed and revised based on comments received from NYSRDA, ECOTS, and the EPA Quality Assurance Team. The TQAP meets the requirements of the GHG Center's Quality Management Plan (QMP) and satisfies the ETV QMP requirements.

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) DG/CHP Distributed Generation and Combined Heat and Power Performance Protocol for Field Testing [2].]. It can be downloaded from the web location www.dgdata.org/pdfs/field_protocol.pdf. The ETV GHG Center has adopted portions of this protocol as a draft generic verification protocol (GVP) for DG/CHP verifications [3]. This ETV performance verification of the Aisin system was based on the GVP.

The remainder of Section 1.0 describes the Aisin Seiki G60 system technology and test facility and outlines the performance verification procedures that were followed. Section 2.0 presents test results, and Section 3.0 assesses the quality of the data obtained. Section 4.0, submitted by ECOTS and Aisin, presents additional information regarding the CHP system. Information provided in Section 4.0 has not been independently verified by the GHG Center.

1.2. AISIN SEIKI G60 ENGINE COGENERATION UNIT 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 permanent magnet generator with inverter. Some of the waste heat produced by the engine (approximately 46 thousand Btu per hour (MBtu/h)) is recovered from the engine coolant and 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. Water was used as the transfer fluid and 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.

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	Engine Type	Water-cooled vertical 4-cycle 3-cylinder OHV
	Generator Type	Permanent magnet rotating-field type
	Rated Power Generating Efficiency	26.5%
	Rated Waste Heat Recovery Efficiency	59.5%

1.3. HOOLIGANS FACILITY AND SYSTEM INTEGRATION

The performance verification of the Aisin Seiki G60 was conducted 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 to 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/h. 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 heat 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 Seiki 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. PERFORMANCE VERIFICATION OVERVIEW

Following the GVP, the verification included evaluation of the Aisin system performance over a series of controlled test periods. Because this unit is designed to operate at full load only, tests were only conducted while the unit operated at nominal 6 kW. In addition to the controlled test periods, the GHG Center collected 10 days of continuous fuel consumption, power generation, power quality, and heat recovery rate data to characterize the Aisin system's performance over normal facility operations.

The Aisin Seiki verification was limited to the performance of the system under test (SUT) within a defined system boundary. Figure 1-2 illustrates the SUT boundary for this verification. The figure indicates two distinct boundaries. The device under test (DUT) or product boundary includes the Aisin Seiki G60 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 and the isolation transformer. Following the GVP, this verification incorporated the system boundary into the performance evaluation. Although the Amtrol water heater installed with the Aisin system will have thermal losses, it is expected that the thermal losses are less than the baseline Hooligans system (the existing A.O. Smith gas fired unit). Therefore, this verification did not include evaluation of hot water tank thermal losses.

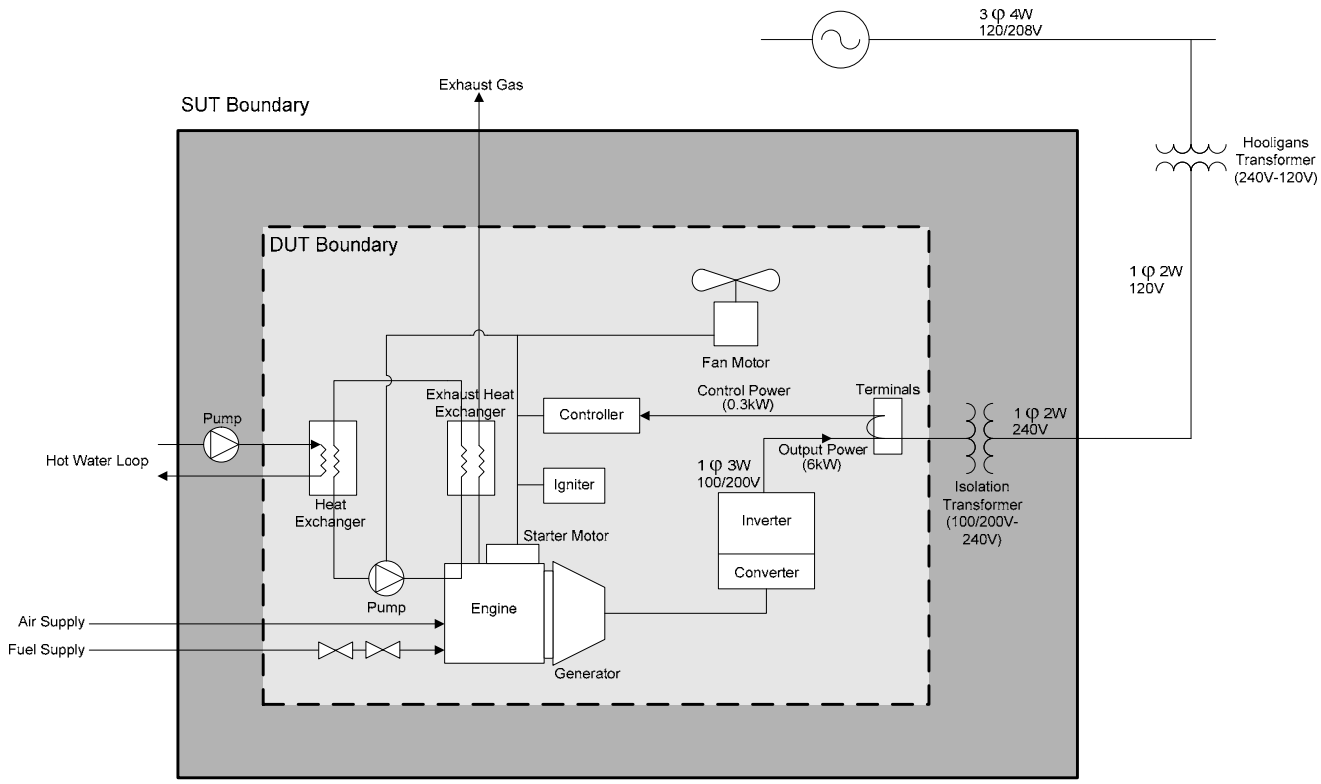

Figure 1-2. Aisin Seiki G60 Cogeneration System Boundary Diagram

The defined SUT was 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

Each of the verification parameters listed were evaluated during the controlled or extended monitoring periods as summarized in Table 1-2. This table also specifies the dates and time periods during which the testing was conducted. Simultaneous monitoring for power output, heat recovery rate, heat input, ambient meteorological conditions, and exhaust emissions was performed during each of the controlled test periods. Fuel gas samples were collected to determine fuel lower heating value and other gas properties. Average electrical power output, heat recovery rate, energy conversion efficiency (electrical, thermal, and total), and exhaust stack emission rates are reported for each test period.

Results from the extended test are used to report total electrical energy generated and used on site, total thermal energy produced, greenhouse gas emission reductions, and electrical power quality.

Table 1-2. Controlled and Extended Test Periods

Controlled Test Periods			
Start Date, Time	**End Date, Time**	**Test Condition**	**Verification Parameters Evaluated**
07/20/05, 11:15	07/21/05, 10:45	Power command 6 kW, three 60-minute test runs	NO_X, CO, CH_4, CO_2 emissions, and electrical, thermal, and CHP efficiency

Extended Test Period			
Start Date, Time	**End Date, Time**	**Test Condition**	**Verification Parameters Evaluated**
07/10/05, 10:30	07/20/05, 11:00	Unit operated according to hot water demand	Daily and total electricity generated and heat recovered; power quality; and emission offsets

The following sections identify the sections of the GVP that were followed during this verification, identify site specific instrumentation for each, and specify any exceptions or deviations.

1.4.1. Electrical Performance (GVP §2.0)

Determination of electrical performance was conducted following §2.0 and Appendix D1.0 of the GVP. The following parameters were 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 were measured with a digital power meter manufactured by Power Measurements Ltd. (Model 7600 ION). The meter operated continuously, unattended, scanning all power parameters once per second and computing and recording one-minute averages. 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 was ± 1.0 percent.

1.4.2. Electrical Efficiency (GVP §3.0)

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

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

Real power production net of transformer losses was measured by the Power Measurements Ltd. Digital power meter, as described in §1.4.1 above. Ambient temperature was recorded on the datalogger from a single Class A 4-wire RTD. The specified accuracy of the RTD was ± 0.6 °F. Ambient barometric pressure was 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 was measured by a Model 8C175 Series B3 Roots Meter manufactured by Dresser Measurement with a specified accuracy of ± 1%. Gas temperature was measured by a Class A 4-wire platinum resistance temperature detector (RTD). The specified accuracy of the RTD is ± 0.6 °F. Gas pressure was 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. Three gas samples were collected and shipped to Empact Analytical of Brighton, Colorado for LHV analysis. Results of the gas samples collected during the controlled tests were invalidated due to the indication of a small amount of air in the sample canisters. Three additional samples were collected on July 29 and submitted to Empact. Results of these samples show that air was not present in the canisters and results of these samples were therefore used for the efficiency calculations.

The external parasitic load introduced by the heat transfer fluid circulation pump was monitored using a second digital power meter manufactured by Power Measurements Ltd. (Model 7500 ION). Meter specifications and accuracy was the same as those for the power meter described in §1.4.1 above.

1.4.3. CHP Thermal Performance (GVP §4.0)

Determination of CHP thermal performance was conducted following §4.0 and Appendix D3.0 of the GVP. The following parameters were 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 was measured throughout the verification. This verification used an Omega Model FTB-905 flow meter with a nominal linear range of 2.5 – 29 gpm. An Omega Model FSLC-64 transmitter amplified the flow meter's pulse output. An Agilent / HP Model 34970A totalized and logged the pulse output. Accuracy of this system was ± 1.0% of reading. Class A 4-wire platinum resistance temperature detectors (RTD) were 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 °F. Pretest calibrations documented the RTD performance. The density and specific heat of the fluid (water) was obtained from standard tables [4].

1.4.4. Emissions Performance (GVP §5.0)

Determination of emissions performance was conducted following §5.0 and Appendix D4.0 of the GVP and included emissions of NO_X, CO, CO_2, CH_4, and THC. Emissions testing was performed by O'Brien & Gere, Inc. of Syracuse, New York. A fully equipped mobile emissions testing laboratory was transported to the facility to conduct the EPA Reference Methods emission testing. Results for each pollutant are reported in units of ppm corrected to 15% O_2, lb/h, and lb/kWh.

1.4.5. Field Test Procedures and Site Specific Instrumentation

Field test procedures followed 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

Controlled tests were conducted as three one-hour test replicates at a cogeneration power command of approximately 6.0 kW. Hot water was 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 was monitored continuously for a period of 10 days while the unit operated under normal Hooligans facility operations. The Aisin unit was allowed to cycle on and off during this period depending on facility hot water demand. Continuous measurements were 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 evaluated Aisin system performance and usage rates for Hooligans under typical facility operations.

Site specific measurement instrumentation is summarized in Table 1-3. The location of the instrumentation relative to the SUT is illustrated in Figures 1-3 and 1-4. All measurement instrumentation met the GVP specifications.

Table 1-3. Site Specific Instrumentation for Aisin Seiki G60 Cogeneration System Verification

Verification Parameter	Supporting Measurement	Instrument	Instrument Range	Range of Measurements	Instrument Rated Accuracy
Electrical Performance	Real power	Power Measurements Ltd. ION power meter (Model)	0 – 260 kW	0.0 – 5.2 kW	± 1% of reading
	Apparent power		0 – 260 kVA	0.0 – 5.3 kVA	± 1% of reading
	Reactive power		0 – 260 kVAR	0.0 – 1.0 kVAR	± 1% of reading
	Power factor		0 – 100%	39.7 – 98.7%	± 0.5% of reading
	Voltage THD		0 – 100%	1.3 – 2.2%	± 1% FS
	Current THD		0 – 100%	1.6 – 17.1%	± 1% FS
	Frequency		57 – 63 Hz	59.9 – 60.1 Hz	± 0.01% of reading
	Voltage		0 – 600 V	119.5 – 123.1 V	± 1% of reading
	Current		0 – 400 A	5 – 45.4 A	± 1% of reading
	Ambient temperature	Omega Class A 4-wire RTD	0 – 250 °F	64 – 113 °F	± 0.6 °F
	Barometric pressure	Setra Model 280E	0 – 25 psia	10.8 – 14.5 psia	± 0.1% FS
	Parasitic load	ION power meter (Model 7600 or 7500)	0 – 260 kW	0 – 0.181 kW	± 1% of reading
Electrical Efficiency	Gas flow	Model 8C175 Roots Meter	0 – 800 cfh	0 – 193 cfh	± 1% of reading
	Gas pressure	Omega PX205 Pressure Transducer	0-30 psia	11.1 – 14.9 psia	± 0.25% of reading
	Gas temperature	Omega Class A 4-wire RTD	0 – 250 °F	64 – 100 °F	± 0.6 °F
CHP Thermal Performance	Transfer fluid flow	Omega Model FTB-905 turbine meter	2.5 – 29 gpm	0 – 9 gpm	± 1.0% of reading
	Transfer fluid supply temp.	Omega Class A 4-wire RTD	0 – 250 °F	68 – 164 °F	± 0.6 °F
	Transfer fluid return temp.	Omega Class A 4-wire RTD	0 – 250 °F	69 – 157 °F	± 0.6 °F
Emissions Performance	NO_X concentration	TEI Model 42C Chemiluminescence	0 – 400 ppmv	113 – 1500 ppmv	± 2% FS
	CO concentration	TEI Model 48C (NDIR)-gas filter correlation	0 – 1000 ppmv	526 – 589 ppmv	± 2% FS
	CO_2 concentration	Servomex 1415C NDIR	0 – 20%	7.2 – 8.9%	± 2% FS
	O_2 concentration	Servomex 1420C Paramagnetic	0 – 25%	6.9 – 8.4%	± 2% FS
	THC concentration	TEI Model 51C Flame ionization detector (FID)	0 – 1000 ppmv (as propane)	563 – 648 ppmv	± 2% FS
	CH_4 concentration	Gas chromatograph with FID	0 – 10000 ppmv	2100 – 2500 ppmv	± 2% FS

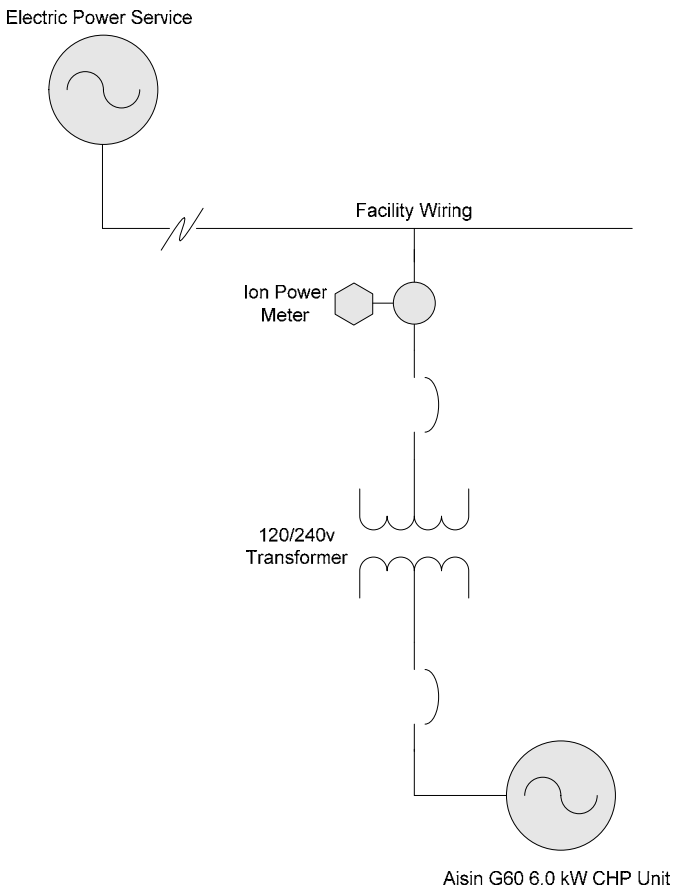

Figure 1-3. Location of Test Instrumentation for SUT Electrical System

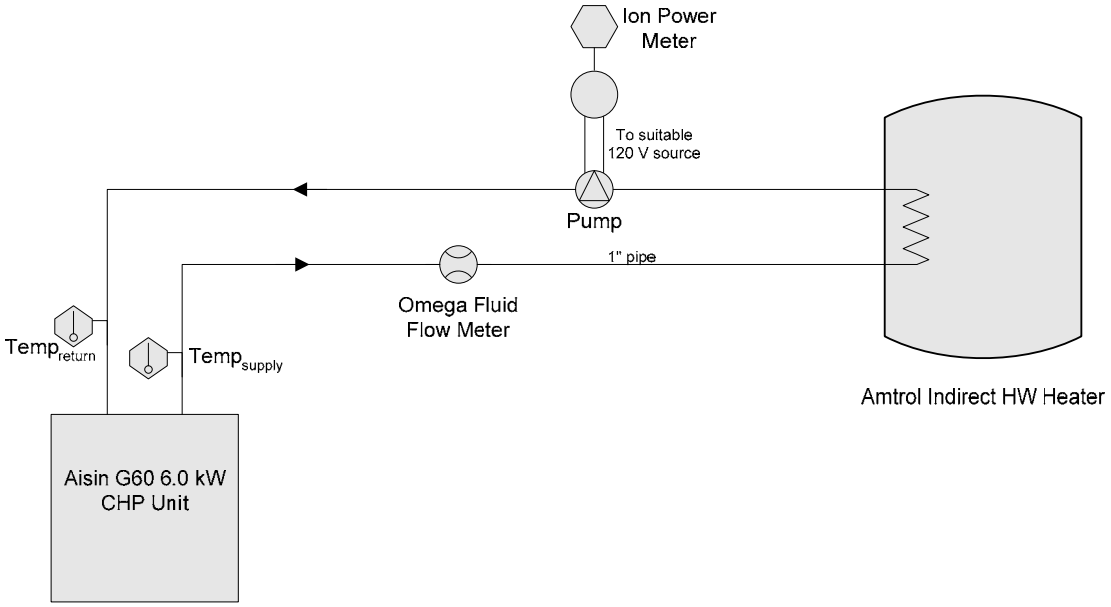

Figure 1-4. Location of Test Instrumentation for SUT Thermal System

1.4.6. Estimated NO_X and CO_2 Emission Offsets

Use of the Aisin cogeneration system changes the NO_X and CO_2 emission rates associated with the operation of the Hooligans facility. Annual emission offsets for these pollutants were 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.

The TQAP provided the detailed 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 assumed that the Aisin system generates power at a rate similar to that recorded during the 10-day verification monitoring period throughout the entire year.

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 assumed that the Aisin system provides heat to the facility throughout the entire year at a rate similar to that recorded during the 10-day verification monitoring period.

2.0 VERIFICATION RESULTS

2.1. OVERVIEW

The verification period started on July 10, 2005, and continued through July 21, 2005. The controlled tests were conducted on July 20 and 21, and were preceded by the 10-day period of continuous monitoring to examine heat and power output, power quality, efficiency, and emission reductions. The 10-day period included a storm related power outage on July 14 when data was not collected for a period of 164 minutes between 4:56 and 7:40 PM.

The GHG Center acquired several types of data that represent the basis of verification results presented here. The following types of data were collected and analyzed during the verification:

- Continuous measurements (fuel gas pressure, temperature, and flow rate, power output and quality, heat recovery rate, parasitic load, and ambient conditions)
- Fuel gas heating value data
- Emissions testing data

The field team leader reviewed, verified, and validated some data, such as DAS file data and reasonableness checks while on site. The team leader reviewed collected data for reasonableness and completeness in the field. The data from each of the controlled test periods was reviewed on site to verify that variability criteria specified below in Section 2.2 were met. The emissions testing data was validated by reviewing instrument and system calibration data and ensuring that those and other reference method criteria were met. Calibrations for fuel flow, pressure, temperature, electrical and thermal power output, and ambient monitoring instrumentation were reviewed on site to validate instrument functionality. Other data such as fuel LHV analysis results were reviewed, verified, and validated after testing had ended. All collected data was classified as either valid, suspect, or invalid upon review, using the QA/QC criteria specified in the TQAP. Review criteria are in the form of factory and on-site calibrations, maximum calibration and other errors, audit gas analyses, and lab repeatability. Results presented here are based on measurements which met the specified Data Quality Objectives (DQOs) and QC checks and were validated by the GHG Center.

The GHG Center attempted to obtain a reasonable set of short-term data to examine daily trends in electricity and heat production, and power quality. It should be noted that these results may not represent performance over longer operating periods or at significantly different operating conditions.

Test results are presented in the following subsections:

Section 2.1 – Electrical and Thermal Performance and Efficiency
Section 2.2 – Power Quality Performance
Section 2.3 – Emissions Performance and Reductions

The results show that the Aisin Seiki unit produces high quality power and is capable of operating in parallel with the utility grid. At the Hooligans installation, the unit can produce a steady 5.14 kW of net electrical power after transformer and associated parasitic losses, and net electrical efficiency at full load averaged 23.1 percent. The average heat recovery rate measured during the controlled test periods was 43.7 MBtu/h and thermal efficiency averaged 57.5 percent.

NO_X emissions averaged 3.1 lb/MWh, and emissions of CO and THC averaged 8.3 and 17 lb/MWh, respectively. CO_2 emission reductions for Hooligans through use of the Aisin Seiki G60 are estimated at approximately 35 percent. Detailed analyses are presented in the following sections.

In support of the data analyses, the GHG Center conducted an audit of data quality (ADQ) following procedures specified in the QMP, and the EPA QA manager conducted a technical systems audit (TSA). A full assessment of the quality of data collected throughout the verification period is provided in Section 3.0.

2.2. ELECTRICAL AND THERMAL PERFORMANCE AND EFFICIENCY

The heat and power production performance evaluation included electrical power output, heat recovery, and CHP efficiency determinations during controlled test periods. After each test run, analysts reviewed the data and determined that all test runs were valid by meeting the following criteria:

- at least 90 percent of the one-minute average power meter data were logged
- data and log forms that show SUT operations conformed to the permissible variations throughout the run (Table 2-1)
- ambient temperature and pressure readings were recorded at the beginning and end of the run
- at least 3 complete kW or kVA readings from the external parasitic load were recorded
- field data log forms were completed and signed
- records demonstrate that all equipment met the allowable QA/QC criteria

Based on American Society of Mechanical Engineers (ASME), Performance Test Code 17 (PTC-17), the GVP specified guidelines state that efficiency determinations were to be performed within 60 minute test periods in which maximum variability in key operational parameters did not exceed specified levels. Table 2-1 summarizes the maximum permissible variations observed in power output, ambient temperature, ambient pressure, gas pressure, and gas temperature at the meter for each test run. The table shows that the PTC-17 requirements for all parameters were met for all test runs.

Table 2-1. Variability in Operating Conditions

	Maximum Observed Variation in Measured Parameters				
	Power Output[a]	**Ambient Temp. (°F)**	**Ambient Pressure[a]**	**Gas Pressure[a]**	**Gas Temperature (°F)**
Maximum Allowable Variation	**± 5 %**	**± 5 °F**	**± 1 %**	**± 2 %**	**± 5 °F**
Run 1	0.56	2.7	0.07	0.13	1.9
Run 2	0.57	2.6	0.07	0.07	0.9
Run 3	0.38	3.5	0.07	0.13	3.6

[a] Maximum (Average of Test Run – Observed Value) / Average of Test Run · 100

2.2.1. Electrical Power Output, Heat Production, and Efficiency During Controlled Tests

Table 2-2 summarizes the power output, heat production, and efficiency performance of the SUT. The heat recovery and fuel input determinations corresponding to the test results are summarized in Tables 2-3 and 2-4. A total of 3 fuel samples were collected for compositional analysis and calculation of LHV for heat input determinations. There was very little variability in any of the measurements associated with the efficiency determinations.

As mentioned in Section 1.4.2, the original three gas samples collected during the controlled tests were invalidated due to the indication of a small amount of air in the sample canisters. Oxygen levels in the first set of samples ranged from 0.4 to 0.9 percent, indicating air contamination. Three additional samples were collected with a longer canister purge time (1 full minute) on July 29 and the oxygen content was 0.02 percent or lower for each. Results of these samples show that air was not present in the canisters and results of these samples were therefore used for the efficiency calculations.

The average net electrical power delivered to the facility was 5.14 kW during operation. The average electrical efficiency at this power output was 23.1 percent. Electric power generation heat rate, which is an industry-accepted term to characterize the ratio of heat input to electrical power output, averaged 14,800 Btu/kWh.

Heat recovery and use during the controlled test periods averaged 43.6 MBtu/h, or 12.8 kW_e. Thermal efficiency at this site averaged 57.5 percent and total CHP efficiency (electrical and thermal combined) averaged 80.6 percent under these conditions.

Table 2-2. Aisin Seiki G60 Electrical and Thermal Performance

Test ID	Fuel Input (MBtu/h)	Electrical Power Generation Performance			Heat Recovery Performance		Total CHP System Efficiency (%)	Ambient Conditions	
		Power Delivered at Transformer (kW)	Parasitic Load (kW)	Efficiency [a] (%)	Heat Recovered (MBtu/h)	Thermal Efficiency (%)		Temp (^oF)	Pbar (psia)
Run 1	76.0	5.32	0.17	23.1	43.3	57.1	80.2	83.3	14.48
Run 2	75.9	5.30	0.17	23.1	44.6	58.8	81.9	89.4	14.47
Run 3	76.0	5.31	0.18	23.1	43.0	56.8	79.9	82.0	14.44
Avg.	**76.0**	**5.31**	**0.17**	**23.1**	**43.6**	**57.5**	**80.6**	**84.9**	**14.46**

[a] Based on actual power available for consumption at the test site (power generated less transformer and circulation pump losses).

Table 2-3. Aisin Seiki G60 Heat Recovery Conditions

Test ID	Hot Water Header Heating Loop			
	Fluid Flow Rate (gpm)	Supply Temperature (°F)	Return Temperature (°F)	Heat Recovery Rate (MBtu/h)
Run 1	7.99	143.1	132.1	43.3
Run 2	7.98	137.2	125.9	44.6
Run 3	8.02	120.5	109.6	43.0
Avg.	**8.00**	**133.6**	**122.5**	**43.6**

Table 2-4. Aisin Seiki G60 Heat Input Determinations

Test ID	Fuel Input				
	Heat Input (MBtu/h)	Gas Flow Rate (scfh)	LHV (Btu/scf)	Gas Pressure (psia)	Gas Temp (°F)
Run 1	76.0	83.3	910.9[a]	14.88	82.5
Run 2	75.9	83.2		14.87	89.2
Run 3	76.0	83.4		14.85	77.9
Avg.	**76.0**	**83.3**	**910.9**	**14.87**	**83.2**

[a] Reported LHV is the average of three fuel gas samples collected on July 29, 2005

2.2.2. Electrical and Thermal Energy Production and Efficiency During the Extended Test Period

Power production on each of the 10 days monitored was very consistent. Each day the system cycled on and off numerous times (according to hot water demand) between the noon and midnight hours when Hooligans was in full operation. During the 10-day period the system operated for a total of approximately 61 hours, or approximately 25.7 percent of the time. Figure 2-1 presents a time series plot of 1-minute average real power generated and the voltage and current for one randomly selected day (July 12). The data shown for this day are consistent with each of the other days.

The net real power delivered is shown less transformer losses and power consumed by the circulation pump. The SUT produced 29.4 kWh net on the day shown. Over the entire 10-day period, 261.6 kWh net power was produced at the site for a daily average of 26.2 kWh. It should be noted that the system's transformer draws approximately 200 watts of power from the grid during idle periods, which reduces the net power production rate by about 3.6 kWh per day.

Figure 2-2 shows corresponding heat recovery rates for July 12. Similar to power production, each of the remaining days monitored were very similar in heat production as the plot shown for the 12th. A total of 280.9 MBtu were recovered for hot water heating on the 12th. Over the entire 10-day period, a total of 2,213.3 MBtu were recovered and used for an average of 221.3 MBtu per day.

Figure 2-3 shows the electrical, thermal, and total CHP efficiencies for July 12, which is typical for each of the days. CHP efficiencies were consistent with those verified during the control test periods with net electrical efficiency approximately 23 percent, thermal efficiency in the range of 55 to 62 percent, and CHP efficiency in the range of 78 to 84 percent.

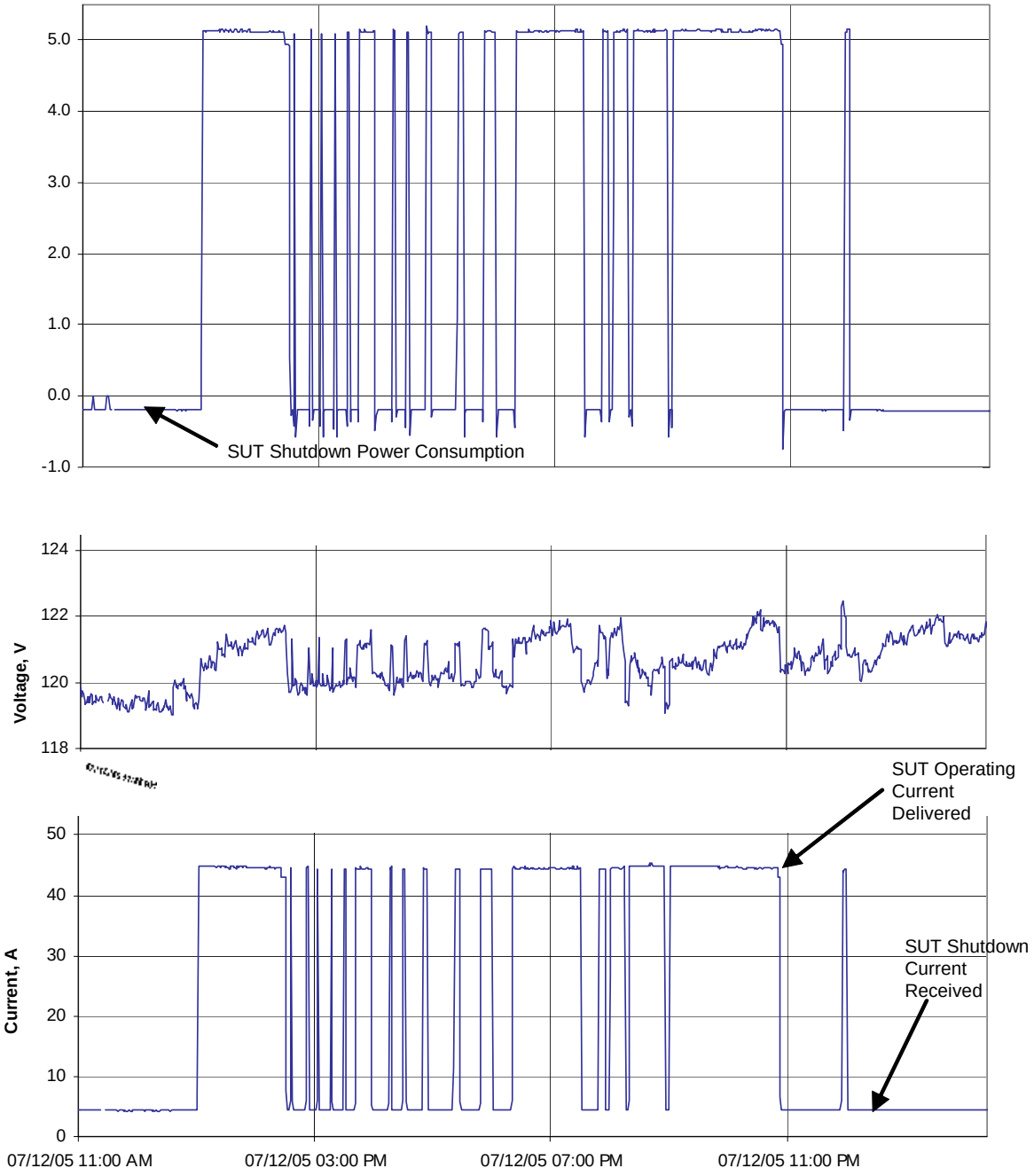

Figure 2-1. Aisin Seiki G60 Power Generation for Typical Day at Hooligans

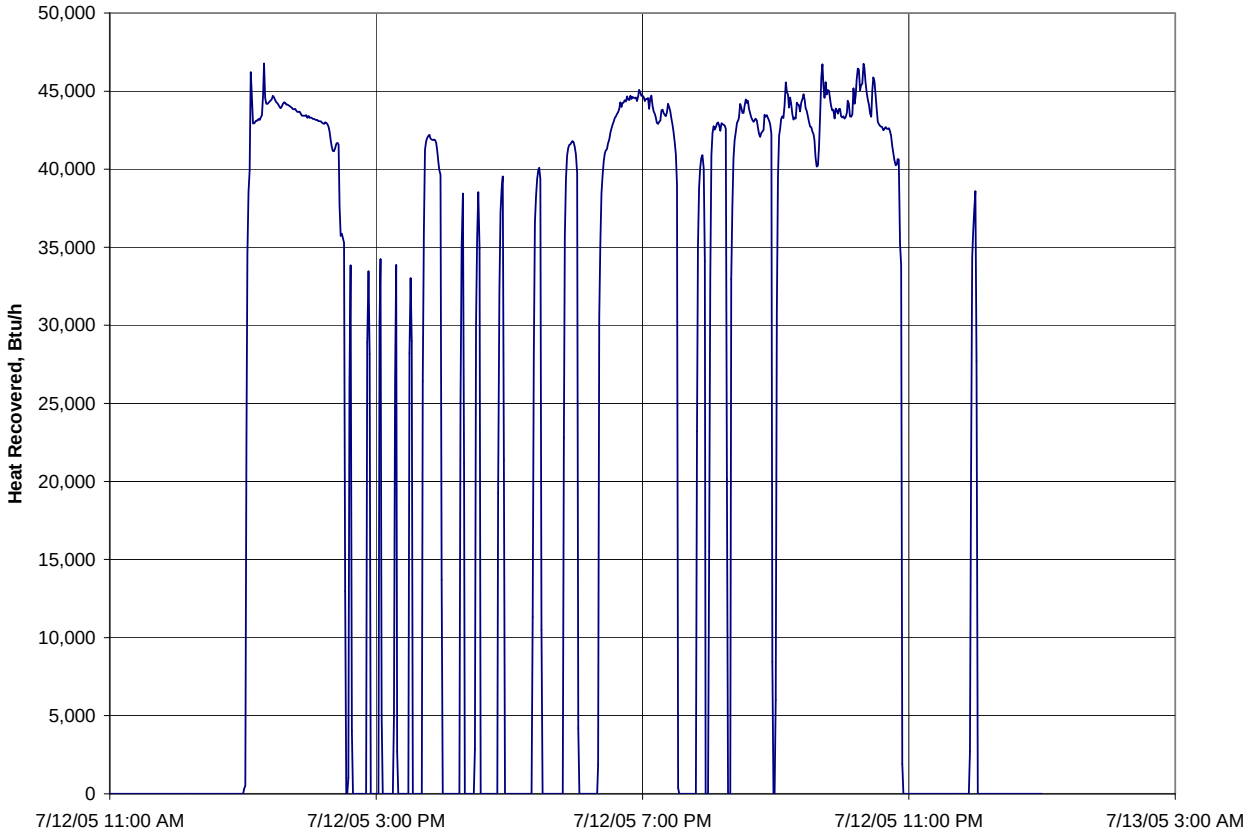

Figure 2-2. Aisin Seiki G60 Heat Recovery for Typical Day at Hooligans

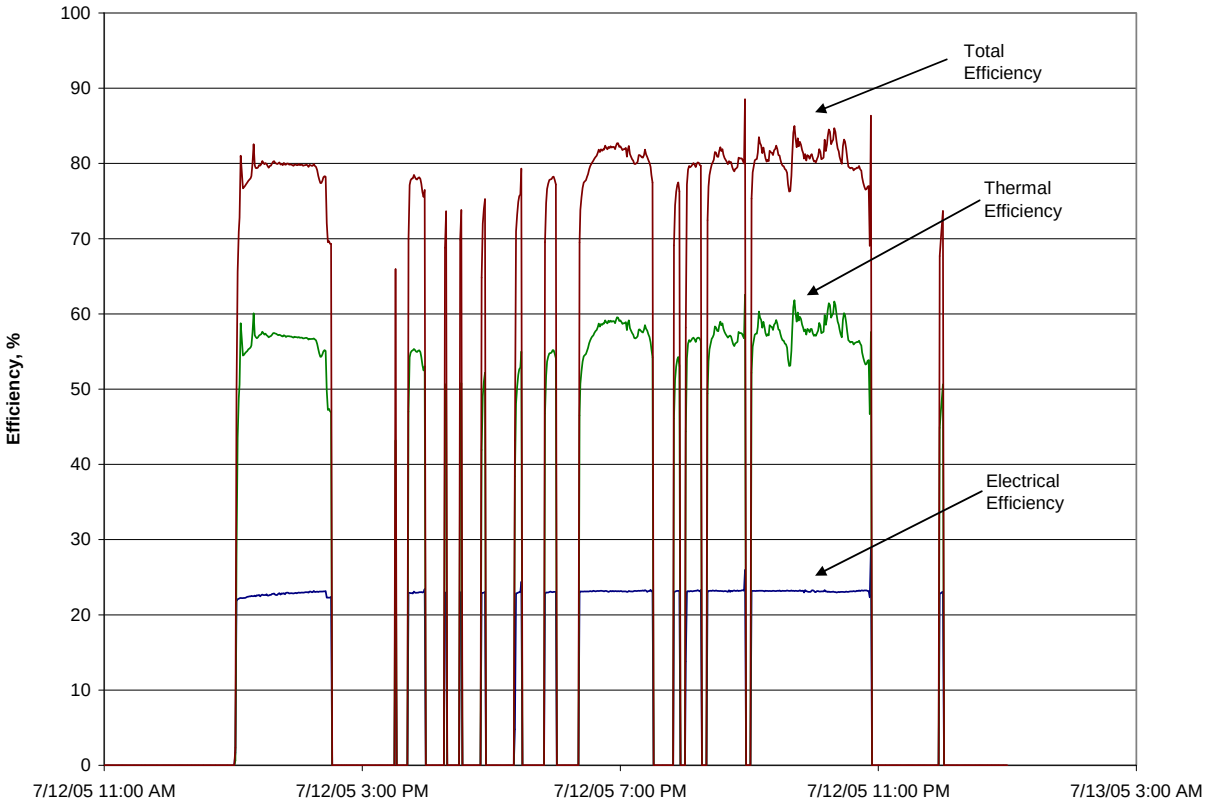

Figure 2-3. Aisin Seiki G60 Efficiency for Typical Day at Hooligans

2.3. POWER QUALITY PERFORMANCE

Figure 2-4 plots the power quality for the period including frequency, power factor, and voltage and current THD. Table 2-5 summarizes the power quality statistics. The data show that the unit had little or no impact on grid voltage, frequency, or voltage THD. Given the types of electrical appliances that operate at the restaurant, their random operations and the fact that the area has numerous businesses that may create other harmonics, it is difficult to determine the true source of harmonics that were measured. No-load current THD is an artifact of the transformer magnetic core presenting a non-linear load. It is unlikely that this parameter reflects on the performance of the Aisin equipment. Although some high current THD occurred during operation, this may have been primarily during start up, or during periods of low power production. The average voltage and current THD were both well within the IEEE recommendation of 5 percent.

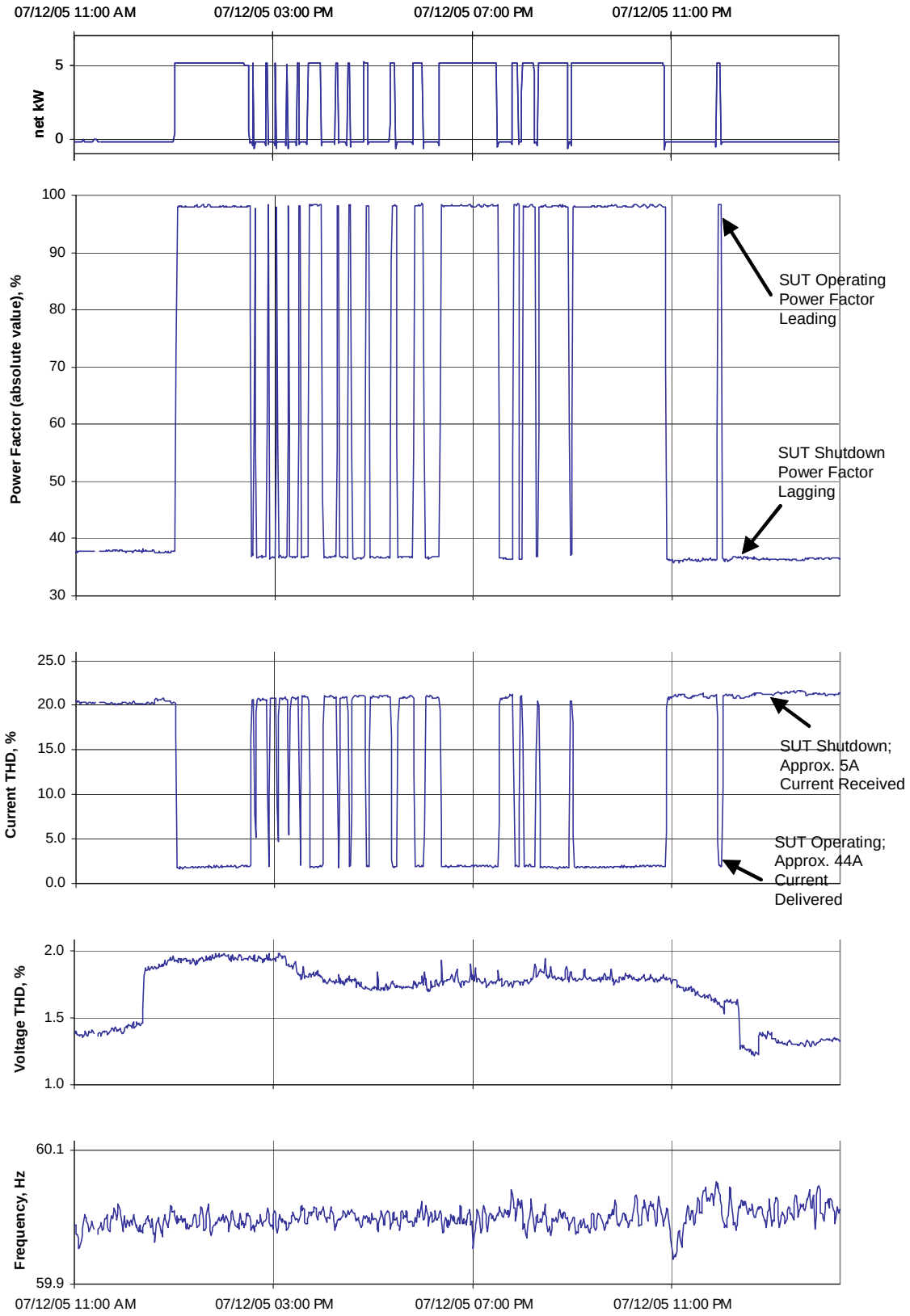

Figure 2-4. Aisin Seiki G60 Power Quality on Typical Day at Hooligans

Table 2-5. Summary of Aisin Seiki G60 Power Quality

Parameter		Average	Maximum Recorded	Minimum Recorded	Standard Deviation
Frequency (Hz)	Idle[a]	60.00	60.06	59.93	0.016
	Operating	60.00	60.06	59.95	0.015
Voltage THD (%)	Idle[a]	1.54	2.40	1.03	0.243
	Operating	1.76	2.20	1.30	0.192
Power Factor (%)	Operating	97.98	98.68	39.70	1.76
Current THD (%)	Operating	2.53	17.1	1.59	2.14

[a] Idle frequency and voltage THD values are summarized to demonstrate the power quality of the local grid.

2.4. EMISSIONS PERFORMANCE

2.4.1. Aisin Seiki Exhaust Emissions

Stack emission measurements were conducted during each of the controlled test periods in accordance with the EPA reference methods listed in the GVP. Following the GVP, the SUT was maintained in a stable mode of operation during each test run based on PTC-17 variability criteria. Results are summarized in Table 2-6.

Table 2-6. Aisin Seiki G60 Emissions During Controlled Test Periods

Run ID	Net Power (kW)	Exhaust O_2 (%)	CO Emissions			NO_x Emissions			THC and CH_4 Emissions[a,b]				CO_2 Emissions		
			ppm at 15% O_2	lb/hr	lb/MWh	ppm at 15% O_2	lb/hr	lb/MWh	THC ppm at 15% O_2	CH_4 ppm at 15% O_2	lb/hr	lb/MWh	%	lb/hr	lb/MWh
Run 1	5.15	7.7	240	0.041	8.1	58	0.016	3.1	900	1050	0.088	17	7.5	9.0	1750
Run 2	5.13	7.4	250	0.043	8.4	61	0.017	3.3	920	940	0.089	17	7.5	8.8	1720
Run 3	5.13	7.1	250	0.043	8.3	55	0.015	3.0	930	1080	0.090	18	7.8	8.9	1740
AVG	**5.13**	**7.4**	**250**	**0.043**	**8.3**	**58**	**0.016**	**3.1**	**920**	**1020**	**0.090**	**17**	**7.6**	**8.8**	**1730**

[a] Laboratory results from the CH_4 bag samples returned CH_4 concentrations approximately 16 percent higher than the real time THC concentrations, so reported CH_4 concentrations are considered suspect.

[b] THC emission rates are quantified as CH_4.

Emissions results are reported in units of parts per million volume dry, corrected to 15-percent O_2 (ppm at 15% O_2) for NO_X, CO, and THC. Concentrations of CO_2 are reported in units of volume percent. Measured pollutant concentration data were converted to mass emission rates using EPA Method 19 and are reported in units of pounds per hour (lb/hr). The emission rates are also reported in units of pounds per megawatt hour electrical output (lb/kMWh). They were computed by dividing the mass emission rate by the net electrical power generated during each test run.

NO_X concentrations in the exhaust stack were consistent throughout the testing averaging 58 ppm at 15% O_2. The average NO_X emission rate normalized to power output was 3.1 lb/MWh. Exhaust gas CO concentrations averaged 250 ppm at 15% O_2 and corresponding CO emission rates averaged 8.3 lb/MWh.

Concentrations of THC averaged 2,000 ppm at stack conditions, or 920 ppm at 15% O_2. Results of the CH_4 analyses conducted on the bag samples averaged 2,340 ppm at stack conditions, or 1,010 ppm at 15% O_2. The THC measurement is considered more reliable since it is an on-site analysis with real time results and on-site measurement system calibrations using EPA Protocol 1 gases. All of the daily linearity checks and pre- and post-test system calibration checks on the THC measurement system were well within the reference method criteria, validating the accuracy of the THC measurements. The QA/QC procedures for the CH_4 analyses however indicate a spike blank recovery of 114%. While this recovery is within the method criteria of 80 to 120%, it does indicate a possible high bias. In addition, the duplicate analyses QC check showed a precision error of 9%. These issues, coupled with the fact that the CH_4 analyses were conducted off-site and two days after sampling, were cause to consider the CH_4 results suspect and rely on the THC measurements. In any event, it is evident that all or nearly all of the hydrocarbons measured by the THC analyzer are CH_4. Fuel analyses show that methane constitutes approximately 95% of the natural gas and ethane is the only other hydrocarbon found in significant amounts of about 2%t. As such, the reported average THC emission rate of 17 lb/MWh is representative of both THC and CH_4 emissions.

Concentrations of CO_2 in the exhaust gas averaged 7.6% with a corresponding average CO_2 emission rate of 1,730 lb/MWh.

2.4.2. Estimation of Annual NO_X and CO_2 Emission Reductions

Section 1.4.6 outlined the approach for estimating the annual emission reductions that may result from use of the Aisin Seiki unit at this facility. The Aisin Seiki emissions were compared to both the NY ISO and national power system average emissions as published in EPA's Emissions and Generation Resource Integrated Database (EGRID). The detailed approach was provided in the TQAP.

<u>Step 1 – Estimated Annual SUT Emissions</u>

The first step is to estimate annual NO_X and CO_2 emissions from the SUT based on data generated during this verification. The average NO_X and CO_2 emission rates during the verification were 3.1 and 1,730 lb/MWh, respectively. The power delivered by the SUT during the verification period averaged 26.2 kWh per day. Assuming a system availability of 95%, this results in an estimated annual generating rate of 9.08 MWh. These values result in estimated annual NO_X and CO_2 emissions of 0.014 and 7.83 tons per year (ton/yr) of NO_X and CO_2, respectively.

Step 2 – Utility Grid Emissions

The average NY ISO NO_X and CO_2 emission rates published by EGRID for the year 2000 are used here and are 1.46 and 979.7 lb/MWh, respectively. Based on the measured Aisin generating rate described above, the annual estimated NO_X and CO_2 emissions for an equivalent amount of power from the grid are 0.007 and 4.45 ton/yr, respectively.

The average national NO_X and CO_2 emission rates published by EGRID and used here are 2.96 and 1,393 lb/MWh, respectively. Based on the measured Aisin generating rate described above, the annual estimated NO_X and CO_2 emissions for an equivalent amount of power from the grid are 0.013 and 6.32 ton/yr, respectively.

Step 3 – Hot Water Heater Emissions

Use of recovered heat from the SUT offsets an equivalent amount of heat that would otherwise be produced by Hooligans' gas-fired hot water heater. The SUTs' emission rates for heat production are assigned as zero because emissions are accounted for in electricity generation. The existing water heater is an A.O. Smith Master Fit Model BTR 365104 with a rated heat input of 365 MBtu/hr and rated efficiency of 80 percent. The rated efficiency was used to calculate the CO_2 emission factor for the water heater and provides a very conservative estimate of emissions. Following the procedures provided in Appendix B of the TQAP, NO_X and CO_2 emission factors for the water heater were determined to be 0.375 and 496 lb/MWh, respectively. The heat recovered and used by the SUT during the verification period (average 221.3 MBtu/day, or 0.065 MWh per day), results in an estimated annual heat recovery and use rate of 22.5 MWh at 95 percent availability. These values result in estimated elimination of annual NO_X and CO_2 emissions from the water heater of 0.0042 and 5.59 ton/yr of NO_X and CO_2, respectively.

Step 4 – Determination of Estimated Emission Reductions

Estimated annual NO_X and CO_2 emissions for the two regional scenarios described are summarized in Table 2-7. For the NY ISO region, the SUT introduces a small increase in NO_X emissions (0.003 tons) and CO_2 emission reductions are estimated at 22 percent. For the national grid, NO_X and CO_2 reductions are estimated to be approximately 18 and 34 percent, respectively.

Table 2-7. Estimation of Aisin Seiki G60 Emission Reductions at Hooligans

Regional Power System Scenarios	Annual SUT Emissions[a] (tons)		Baseline Case (Hooligans without Aisin Seiki) Annual Emissions (tons)						Estimated Annual Emission Reductions (tons (%))	
			Grid Emissions		Water Heater Emissions[b]		Total Emissions			
	NO_X	CO_2	NO_X	CO_2	NO_X	CO_2	NO_X	CO_2	NO_X	CO_2
NY ISO	0.014	7.83	0.007	4.45	0.0042	5.59	0.011	10.0	-0.003 (-27)	2.2 (22)
National	0.014	7.83	0.013	6.32	0.0042	5.59	0.017	11.9	0.003 (18)	4.1 (34)

[a] Based on the SUT's operating schedule during the verification period, an expected availability of 95 percent, and the average measured power output.
[b] Based on the SUT's operating schedule during the verification period, an expected availability of 95 percent,, and the average measured heat recovery and use rate.

3.0 DATA QUALITY ASSESSMENT

3.1. 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 performances 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, demonstrate 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. 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 were to obtain valid data for 90 percent of the test periods (controlled test period and extended monitoring). These goals were met as all of the planned controlled tests were conducted and validated, and 99 percent of valid one-minute average data were collected during the 10-day monitoring period.

The following sections document the MQOs for this verification, followed by a reconciliation of the DQOs stated above based on the MQO findings.

3.2. DOCUMENTATION OF MEASUREMENT QUALITY OBJECTIVES

3.2.1. Electrical Generation Performance

Table 3-1 summarizes the MQOs for electrical generation performance.

Table 3-1. Electrical Generation Performance MQOs

Measurement	QA/QC Check	When Performed	Allowable Result	Result Achieved
kW, kVA, kVAR, PF, I, V, f(Hz), THD	Power meter NIST-traceable calibration	18-month period	± 2.0%	ION 7600: calibration is within spec. ION 7500: calibration is within spec., but was 27 months old (meter was used only for parasitic load).
	CT documentation	At purchase	ANSI Metering Class 0.3%; ± 1.0% to 360 Hz (6th harmonic)	Meets spec.
V, I	Sensor function checks	Beginning of load tests	V: ± 2.01% I: ± 3.01%	V (7500, 7600): 0.5%, 1.02% I (7500, 7600): 2.06%, 0.5%
	Power meter crosschecks	Before field testing	± 0.1% differential between meters	V: 0.07% I: 0.03%
Ambient temperature	NIST-traceable calibration	18-month period	± 1 °F	Meets spec.
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Before (ice, hot): 0.01 °F, 0.1 °F After (ice, hot): 0.1 °F, 0 °F
Barometric pressure	NIST-traceable calibration	18-month period	± 0.1 "Hg or ± 0.05 psia	Meets spec.
	Crosscheck with gas pressure sensor	Before and after field testing	± 0.08 psia differential between sensors	Before: 0.3 psia After: 0.19 psia

All of the MQOs met the performance criteria with the exception of the ION 7500 power meter calibration interval and the pressure sensor cross checks. The expired power meter calibration (the ION 7500 was used to measure power consumed by the circulation pump) is not expected to impact results and the meter passed the other MQO criteria. Based on manufacturer recommendations, the GHG Center's SOP for power meter calibration has since been revised to 6 year intervals. The differential between the two pressure sensors (the Omega gas pressure sensor and the Setra barometric pressure sensor) was traced to the Setra. Calibration curves developed for both sensors indicated excessive noise in the linearity of the Setra sensor, while the Omega calibration curve is much more linear. The barometric pressure readings are not used in any of the determinations so the error in the sensor cross checks does not impact results.

Following the GVP, the MQO criteria demonstrate that the DQO of ±2 % relative uncertainty for electrical performance was met.

3.2.2. Electrical Efficiency Performance

Table 3-2 summarizes the MQOs for electrical efficiency performance.

Table 3-2. Electrical Efficiency MQOs

Measurement	QA/QC Check	When Performed	Allowable Result	Result Achieved
Gas meter	NIST-traceable calibration	18-month period	± 1.0% of reading	Meets spec.
	Differential pressure check	At installation	< 0.1 in.	0.025 in.
Gas pressure	NIST-traceable calibration	18-month period	± 0.5% of FS	Meets spec.
	Crosscheck with ambient pressure sensor	Before and after field testing	± 0.08 psia differential between sensors	Before: 0.3 psia After: 0.19 psia
Gas temperature	NIST-traceable calibration	18-month period	± 1.0% of FS	Meets spec.
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 ^{o}F Hot water: ± 1.2 ^{o}F	Before (ice, hot): 0.01 °F, 0.1 °F After (ice, hot): 0.1 °F, 0 °F
Fuel Gas LHV	NIST-traceable standard gas calibration	Weekly	± 1.0% of reading	Meets spec.
	ASTM D1945 duplicate sample analysis and repeatability	Each sample	Within D1945 repeatability limits for each gas component	Meets spec.

All of the MQOs met the performance criteria with the exception of the pressure sensor cross checks. Error in the barometric pressure sensor was discussed in the Section 3.2.1. Following the GVP, the MQO criteria in Tables 3-1 and 3-2 demonstrate that the DQO of ± 2.5% relative uncertainty for electrical efficiency was met.

3.2.3. CHP Thermal Efficiency Performance

Table 3-3 summarizes the MQOs for CHP thermal efficiency performance.

Table 3-3. CHP Thermal Efficiency Performance MQOs

Description	QA/QC Check	When Performed	Allowable Result	Result Achieved
Heat transfer fluid flow meter	NIST-traceable calibration	18-month period	± 1.0% of reading	Meets spec.
	Sensor function checks	At installation	See Appendix B8 of TQAP	Zero flow: 0 gpm Normal flow: 8 gpm
	Zero flow response check	At installation; Immediately prior to first test run	Less than 0.3 gpm	Installation: 0 gpm Prior to testing: 0 gpm
T_{supply} and T_{return} sensors	NIST-traceable calibration	18-month period	± 0.6 ^{o}F between 100 and 210 ^{o}F	Meets spec.
	Sensor function checks	At installation	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Ice water: 0.2 °F Hot water: 0.1 °F
	Ice and hot water bath crosschecks	Before and after field testing	Ice water: ± 0.6 °F Hot water: ± 1.2 °F	Before (ice, hot): 0.08 ^{o}F, 0.13 ^{o}F After (ice, hot): 0 °F, 0 °F

All of the MQOs met the performance criteria. Following the GVP, the MQO criteria in Tables 3-1, 3-2, and 3-3 demonstrate that the DQO of ± 3.5% relative uncertainty for CHP thermal efficiency was met.

3.2.4. Emissions Measurement MQOs

Sampling system QA/QC checks were conducted in accordance with GVP and TQAP specifications to ensure the collection of adequate and accurate emissions data. The reference methods specify detailed sampling methods, apparatus, calibrations, and data quality checks. The procedures ensure the quantification of run-specific instrument and sampling errors and that runs are repeated if the specific performance goals are not met. Table 3-4 summarizes relevant QA/QC procedures.

Table 3-4. Summary of Emissions Testing Calibrations and QA/QC Checks

Description	QA/QC Check	When Performed	Allowable Result	Result Achieved
CO, CO_2, O_2	Analyzer calibration error test	Daily before testing	± 2% of analyzer span	All calibrations, system bias checks, and drift tests were within the allowable criteria.
	System bias checks	Before each test run	± 5% of analyzer span	
	System calibration drift test	After each test run	± 3% of analyzer span	
NO_x	Analyzer interference check	Once before testing begins	± 2% of analyzer span	All criteria were met for the NO_X measurement system.
	Sampling system calibration error and drift checks	Before and after each test run	± 2% of analyzer span	
THC	System calibration error test	Daily before testing	± 5% of analyzer span	All criteria were met for the THC measurement system.
	System calibration drift test	After each test run	± 3% of analyzer span	
CH_4	Duplicate analysis	One sample	± 5% difference	9% difference
	Calibration of GC with gas standards by certified laboratory	Immediately prior to sample analyses and/or at least once per day	± 5%	Calibration criteria were met.

Satisfaction and documentation of each of the calibrations and QC checks verified the accuracy and integrity of the measurements and that reference method criteria were met for each of the parameters with the exception of CH_4. Reported CH_4 concentrations are considered suspect because they were higher than the measured THC values. In addition, the duplicate analysis conducted on the sample from run 3 exceeded the ± 5% MQO.

3.3. AUDITS

This verification was supported by ADQ conducted by the GHG Center QA manaager. During the ADQ, the QA manager randomly selected data supporting each of the primary verification parameters and followed the data through the analysis and data processing system. The ADQ confirmed that no systematic errors were introduced during data handling and processing.

Also in support of this verification, QA staff from EPA-ORD's Technical Services Branch conducted an on-site TSA of the GHG Center's testing activities and procedures. Based on the verification approaches

and testing procedures specified in the test plan, the overall conclusion of the audit was that the GHG Center performed well during this verification and there were no significant deviations from the planned activities, measurement, or data quality objectives.

Finally, a readiness/planning review was conducted by the QA manager. During the readiness/planning review, the QA Manager confirmed that the field measurements and activities conformed to the approved TQAP.

4.0 TECHNICAL AND PERFORMANCE DATA SUPPLIED BY AISIN

Note: This section provides an opportunity for ECOTS and Aisin Seiki to provide additional comments concerning the G60 System and its features not addressed elsewhere in the Report. The GHG Center has not independently verified the statements made in this section.

The Aisin G-60 Micro CHP system, which is the target of this study, is currently installed in over 400 applications in Japan. The unit is scheduled for commercial sales in the United States Starting in 2007.

The product is manufactured by Aisin Seiki Co., Ltd. (AISIN), a major manufacturer of automotive and energy products in Japan with reported annual consolidated sales of $16.6 billion (USD). AISIN currently manufactures several commercial products in vacuum, cooling and energy fields that provide resource conservation and energy efficiency.

The system was introduced into the U.S. market by ECO Technology Solutions beginning in Fall 2003. In the first phase of the project, an Aisin G-60 was installed Hooligans Restaurant in Liverpool, New York. This installation utilized the 2002 model of Aisin G-60, as it was being used then in Japan, with minimal modifications. This unit was modified for US operation by the internal installation if 100/200 X 120/240 transformers to correspond to US single phase distribution standards. Additionally, a separate external 240 X 120 volt external transformer was installed to allow input to a single phase of the site's 120/208 volt 3-phase electyrical system. These additional transformers lead to considerable losses and reduce the net efficiency by several percentage points.

The system was installed commissioned in January 2003 and has accumulated over 3,500 hours of operation to-date. The Hooligans demonstration has shown that the Aisin unit operates flawlessly and requires no intervention during operation. Start/stop and grid interconnection has occurred many times during the timer-driven operation of the unit with no problems encountered. Due to the patterns of hot water use at the restaurant, the timer- driven operation was changed in October 2004 to a thermal control mode and once again, the unit has shown an excellent performance record. The Hooligans unit is the unit under Testing by ETV.

During the second Phase of commercial introduction, five Aisin G-60 units were installed at various customer locations in U.S. The demonstrations, which were hosted by the electric cooperatives in Michigan, Iowa and Oklahoma, show economic applications of Aisin G-60 at a dairy farm, hydronic floor heating in commercial office buildings, a small candy-production factory and heat source for utility's standby generation units. These installations demonstrated the application of Aisin G-60 in different control modes including: multi-unit installation, temperature control, time-of-use, load-following, manual, and a combination of the above. In each of these installations, the Aisin unit has met or exceeded its performance expectations.

Based on the results of these demonstration projects, and in cooperation with the ECO Technology Solutions, Aisin is making further improvements to make the U.S. commercial product even more fitting with the customer expectation in U.S. The 2007 model is expected to feature the following attributes:

- On-Site Power: 6.0 kW of continuous, single phase 120/240V, 60 Hz electric power output,
  - Grid-Parallel Operation: The Aisin G-60 will operate in parallel with the host's electrical distribution system when grid conditions are within the range allowed by the local utility.

- Utility Compliant Grid-Protection System: The Aisin G-60 grid-protection system will meet or exceed IEEE-1547 and UL 1741 standards for grid-parallel operation, protect the utility and the host from any disturbances, provide grid-safety in the event of line outage or voltage and frequency events, and prevent flow of electricity back to the grid, and provides grid-safety in the event of line outage or line disturbance.

- On-Site Heat: Provide a 40,000 Btu/hour heating source with doublewall stainless steel heat exchanger that provides a heat source at temperatures less than 158º F.
- Energy Efficiency: An improved lean-burn low-emission internal combustion engine fueled by natural gas or propane, provides the customers with an 85% combined heating and power efficiency, which is substantially higher than conventional methods.
- Backup Generation: For the purpose of the U.S. market, Aisin is modifying the internal controls that will make the system capable of operation during a utility grid-outage event. This will provide customers with imporved power reliability and productivity in addition to the energy cost savings resulting from the operation of the unit.
- Quiet Operation: During operation, the unit operates quietly producing 56dbA of operating noise.
- Flexible controls that allow operation under different control modes: pre-programmed time-of-use, hot water demand, load following, or external dispatch control signal.
- Low Maintenance: The engine is specially designed for base-load stationary power generation applications. It is intended for long duration continuous operation and requires minor maintenance every 10,000 hours.

The table below summarizes the general specifications of Aisin G-60 (2007 Commercial Model).

Electric Output	6.0kW	1-Ø 120/240V 3W
Fuel Use	22.64 kW	81.4 CF/h of Natural Gas
Thermal Output	11.7kW	30.2 l/min at 65ºC-70ºC
Efficiency (LHV)	85.0% Total	electric 28.8% Thermal 56.2%
Noise	56 dBA	
Weight	1,023 lbs	(465Kg)
Operating Modes	- Time-Of –Use - Thermal Demand - Load Follow - Remote Dispatch - Manual - Stand-Alone	
Grid Protection	Meets UL 1741	Programmable
Certifications	- UL 2200 - UL 1741	

5.0 REFERENCES

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