AIR EMISSION TEST REPORT
FOR THE
VERIFICATION OF AIR POLLUTANT EMISSIONS
FROM A
LANDFILL GAS FUELED TURBINE

Prepared for:

ARBOR HILLS ENERGY, LLC
SRN N2688

ICT Project No.: 2200176
January 12, 2023

IMPACT
COMPLIANCE & TESTING

Report Certification

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Arbor Hills Energy, LLC
Northville, MI

The material and data in this document were prepared under the supervision and direction of the undersigned.

Report Prepared By:
[signature]
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1.0 Introduction

Arbor Hills Energy, LLC (Arbor Hills Energy) operates three (3) EGT Typhoon gas-fired turbines and one (1) Solar Taurus gas-fired turbine at its renewable energy facility located at the Arbor Hills Landfill in Northville, Washtenaw County, Michigan. The turbines are fueled by landfill gas (LFG) that is collected from the Arbor Hills Landfill.

The conditions of Renewable Operating (RO) Permit No. MI-ROP-N2688-2011a issued to the source specify that for EUTURBINE4-S3, verification of the emission rates for nitrogen oxides (NOx) and sulfur dioxide (SO_2) is required.

The compliance testing presented in this report was performed by Impact Compliance & Testing, Inc. (ICT), a Michigan-based environmental consulting and testing company. ICT representatives Andrew Eisenberg and Blake Beddow performed the field sampling and measurements on November 16, 2022.

The turbine emission performance tests consisted of triplicate, one-hour sampling periods for nitrogen oxides (NOx) and sulfur dioxide (SO_2). Exhaust gas velocity, moisture, oxygen (O_2) content, and carbon dioxide (CO_2) content were determined for each test period to calculate volumetric exhaust gas flowrate and pollutant mass emission rates.

The exhaust gas sampling and analysis was performed using procedures specified in the Test Plan dated August 23, 2022, that was reviewed and approved by the State of Michigan Department of Environment, Great Lakes, and Energy-Air Quality Division (EGLE-AQD). Ms. Regina Angelotti and Ms. Diane Kavanaugh Vetort of EGLE-AQD observed portions of the compliance testing.

Questions regarding this air emission test report should be directed to:

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Facility Compliance Manager	Suparna Chakladar Vice President – Fuel Supply & Environmental Services Opal Fuels 5087 Junction Road Lockport, NY 14094 (951) 833-4153 schakladar@opalfuels.com
Responsible Official	Anthony Falbo Chief Operating Officer Opal Fuels

2.0 Summary of Test Results and Operating Conditions

2.1 Purpose and Objective of the Tests

Stack testing was performed to measure NOx and SO_2 emissions for one (1) Solar Taurus turbine that is identified as EUTURBINE4-S3 to satisfy the annual testing requirement specified in Renewable Operating (RO) Permit No. MI-ROP-N2688-2011a.

The compliance test results presented in this report are for testing that was performed on November 16, 2022.

2.2 Operating Conditions During the Compliance Tests

Testing was performed while the unit operated at normal, maximum levels during the test periods. During the test event, the electricity generator connected to the Solar Taurus gas combustion turbine produced an average of 4.25 MW-hr.

Fuel flowrate (standard cubic feet per minute (scfm)), fuel methane content (%), power production (kW/MW), and fuel vacuum to plant (in. H2O) were recorded at 15-minute intervals for each test period.

Appendix 2 provides operating records provided by Arbor Hills Energy representatives for the test periods.

Table 2.1 presents a summary of the average turbine process operating conditions during the test periods.

2.3 Summary of Air Pollutant Sampling Results

The gas exhausted from the sampled LFG fueled turbine (EUTURBINE4-S3) were each sampled for three (3) one-hour test periods during the compliance testing performed November 16, 2022.

Table 2.2 presents the average measured NO_X and SO_2 emission rates for the turbine (average of the three test periods).

Test results for each one-hour sampling period and comparison to the permitted emission rates are presented in Section 6.0 of this report.

Table 2.1 Average turbine operating conditions during the test periods

Turbine Parameter	EUTURBINE4-S3 Solar Taurus
Turbine Output (MW)	4.25
Turbine Fuel Use (scfm)	2,056
LFG Methane Content (%)	47.7
Fuel Vacuum to Plant (in. H_2O)	76.9

Table 2.2 Measured emission rates for the turbine (three-test average)

	SO_2	NOx		
Emission Unit	(lb/MMBtu)	(lb/hr)	(ton/yr)	(lb/MWhr)
EUTURBINE4-S3	0.11	6.57	25.2	1.35
Permit Limit	***0.15***	***9.02***	***39.5***	***5.5***

3.0 Source and Sampling Location Description

3.1 General Process Description

Landfill gas (LFG) containing methane is generated in the Landfill from the anaerobic decomposition of disposed waste materials. The LFG is collected from both active and capped landfill cells using a system of wells (gas collection system). The collected LFG is transferred to the Arbor Hills Energy facility where it is treated and used as fuel to produce electricity, which is transferred to the local utility.

3.2 Rated Capacities and Air Emission Controls

EUTURBINE4-S3 is fueled exclusively with LFG recovered from the adjacent Landfill, transferred to Arbor Hills Energy, and treated (compressed, dewatered, and filtered) prior to its use as fuel. The fuel (treated LFG) consumption rate for EUTURBINE4-S3 is regulated automatically to maintain the required heat input rate to support the desired operating rate and is dependent on the fuel heat value (methane content).

EUTURBINE4-S3 typically produces up to 5.2 Megawatts (MW) of electricity. The combustion turbine is not equipped with add-on emission control equipment. NOX emissions are suppressed using dry low-NOX combustors.

3.3 Sampling Locations

The turbine exhaust gas is released to the atmosphere through a dedicated vertical exhaust stack with a vertical release point.

The sampling ports for EUTURBINE4-S3 are located in the exhaust stack, which has an inner diameter of 42 inches. Three (3) sampling ports are located 90° offset from one another and provide a sampling location 8.33 feet (2.38 duct diameters) upstream and 15.5 feet (4.43 duct diameters) downstream from any flow disturbance. These dimensions satisfy the USEPA Method 1 criteria for a representative sample location.
Individual traverse points were determined in accordance with USEPA Method 1.

All sample port locations satisfy the USEPA Method 1 criteria for a representative sample location.

Appendix 1 provides diagrams of the emission test sampling locations.

4.0 Sampling and Analytical Procedures

A Stack Test Protocol for the air emission testing was reviewed and approved by EGLE-AQD. This section provides a summary of the sampling and analytical procedures that were used during the testing periods.

4.1 Summary of Sampling Methods

USEPA Method 1	Exhaust gas velocity measurement locations were determined based on the physical stack arrangement and requirements in USEPA Method 1.
USEPA Method 2	Exhaust gas velocity pressure was determined using a Type-S Pitot tube connected to a red oil incline manometer; temperature was measured using a K-type thermocouple connected to the Pitot tube.
USEPA Method 3A	Exhaust gas O_2 and CO_2 content was determined using paramagnetic and infrared instrumental analyzers, respectively.
USEPA Method 4	Exhaust gas moisture was determined based on the water weight gain in chilled impingers.
USEPA Method 6C	Exhaust gas SO_2 concentration was determined using a pulsed ultraviolet florescence instrumental analyzer.
USEPA Method 7E	Exhaust gas NOx concentration was determined using chemiluminescence instrumental analyzers.
ASTM Method D-3588	Fuel gas methane and heat content analysis by gas chromatography.
ASTM Method D-5504	Fuel gas sulfur analysis by gas chromatography and chemiluminescence.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The turbine exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 during each test period. An S-type Pitot tube connected to a red-oil manometer was used to determine velocity pressure at each traverse point across the stack cross section. Gas temperature was measured using a K-type thermocouple mounted to the Pitot tube. The Pitot tube and connective tubing were leak-checked periodically throughout the test periods to verify the integrity of the measurement system.

The absence of significant cyclonic flow at the sampling location was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at each velocity traverse point with the planes of the face openings of the Pitot tube perpendicular to the stack cross-sectional plane. The Pitot tube was then rotated to determine the null angle (rotational angle as measured from the perpendicular, or reference, position at which the differential pressure is equal to zero).

Appendix 3 provides exhaust gas flowrate calculations and field data sheets.

4.3 Exhaust Gas Molecular Weight Determination (USEPA Method 3A)

CO_2 and O_2 content in the turbine exhaust gas stream was measured continuously throughout each test period in accordance with USEPA Method 3A. The CO_2 content of the exhaust was monitored using a Servomex 4900 infrared gas analyzer. The O_2 content of the exhaust was monitored using a Servomex 4900 gas analyzer that uses a paramagnetic sensor.

During each sampling period, a continuous sample of the turbine exhaust gas stream was extracted from the stack using a stainless-steel probe connected to a Teflon® heated sample line. The sampled gas was conditioned by removing moisture prior to being introduced to the analyzers; therefore, measurement of O_2 and CO_2 concentrations correspond to standard dry gas conditions. Instrument response data were recorded using an ESC Model 8816 data acquisition system that monitored the analog output of the instrumental analyzers continuously and logged data as one-minute averages.

Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document). Sampling times were recorded on field data sheets.

Appendix 4 provides O_2 and CO_2 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.4 Exhaust Gas Moisture Determination (USEPA Method 4)

Moisture content of the turbine exhaust gas was determined in accordance with USEPA Method 4 using a chilled impinger sampling train. Exhaust gas moisture content measurements were performed concurrently with the instrumental analyzer sampling periods. At the conclusion of each sampling period, the moisture gain in the impingers was determined gravimetrically by weighing each impinger to determine net weight gain.

Appendix 3 provides moisture calculations and data sheets.

4.5 SO_2 Concentration Measurements (USEPA Method 6C)

Turbine exhaust gas SO_2 concentration measurements was performed using a Thermo Environmental Instruments, Inc. (TEI) Model 43i that uses pulsed ultraviolet fluorescence technology in accordance with USEPA Method 6C for the measurement of SO2 concentration.

Appendix 4 provides SO_2 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.6 NO_x Concentration Measurements (USEPA Method 7E)

NO_X pollutant concentration in the turbine exhaust gas stream was determined using a TEI Model 42i High Level chemiluminescence NO_X analyzer.

Throughout each test period, a continuous sample of the turbine exhaust gas was extracted from the stack using the Teflon® heated sample line and gas conditioning system and delivered to the instrumental analyzers. Instrument response for each analyzer was recorded on an ESC Model 8816 data acquisition system that logged data as one-minute averages. Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias.

Appendix 4 provides NO_X calculation sheets. Raw instrument response data are provided in Appendix 5.

4.7 Fuel Gas Analysis (ASTM D-5504 and ASTM D-3588)

In addition to the exhaust gas SO_2 concentration measurements, two (2) samples of the treated LFG used as fuel were analyzed (one (1) for sulfur content and one (1) for methane content and heat content). The two (2) samples of the treated LFG were collected during the test event (November 16, 2022) using evacuated Silonite Suma canisters. The sample tubing was connected to the fuel header at a location after the treatment system and gas blower.

The gas samples were analyzed by ALS (Simi Valley, CA). Both gas samples were analyzed for sulfur bearing compounds by ASTM D-5504, and for methane content and heat content by ASTM D-3588.

In addition, the EGLE-AQD requested that inlet LFG be sampled for hydrogen sulfide (H_2S) concentration during each test period of the test event using Draeger® tubes.

Appendix 4 provides the SO_2 emission rates calculations based on analysis of the gas sample. Appendix 7 provides a copy of the laboratory analytical report for the treated LFG samples and a photo of the Draeger® tubes.

5.0 QA/QC Activities

5.1 Flow Measurement Equipment

Prior to arriving onsite, the instruments used during the source test to measure exhaust gas properties and velocity (pyrometer, Pitot tube, and scale) were calibrated to specifications in the sampling methods.

The absence of cyclonic flow for each sampling location was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at each of the velocity traverse points with the planes of the face openings of the Pitot tube perpendicular to the stack cross-sectional plane. The Pitot tube was then rotated to determine the null angle (rotational angle as measured from the perpendicular, or reference, position at which the differential pressure is equal to zero).

5.2 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the Model 42c analyzer was verified prior to the testing program. A USEPA Protocol 1 certified concentration of NO_2 was injected directly into the analyzer, following the initial three-point calibration, to verify the analyzer's conversion efficiency. The analyzer's NO_2 – NO converter uses a catalyst at high temperatures to convert the NO_2 to NO for measurement. The conversion efficiency of the analyzer is deemed acceptable if the measured NO_2 concentration is within 90% of the expected value.

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_2 concentration was 99.6% of the expected value).

Shortly after the test event Mrs. Regina Angellotti, EGLE-AQD, sent notice to ICT and Arbor Hills Energy personnel that NO_2 calibration gas balanced in nitrogen is no longer considered an USEPA Protocol 1 certified gas. This information is based on an USEPA memorandum dated February 25, 2022, titled *EPA Protocol Gas Long-Term Stability Requirements*. EGLE requested that the NO_x Converter Efficiency Test be repeated with an NO_2 calibration gas that is balanced in air, per the USEPA memorandum. ICT ordered an NO_2 calibration gas that is balanced in air, but it was not delivered before the due date of this report. Once the calibration gas is delivered, a NO_x Converter Efficiency Test will be performed with the calibration gas required by USEPA.

5.3 Gas Divider Certification (USEPA Method 205)

A STEC Model SGD-710C 10-step gas divider was used to obtain appropriate calibration span gases. The ten-step STEC gas divider was NIST certified (within the last 12 months) with a primary flow standard in accordance with Method 205. When cut with an appropriate zero gas, the ten-step STEC gas divider delivered calibration gas values ranging from 0% to 100% (in 10% step increments) of the USEPA Protocol 1 calibration gas that was introduced into the system. The field evaluation procedures presented in Section 3.2 of Method 205 were followed prior to use of gas divider. The field evaluation yielded no errors greater than 2% of the triplicate measured average and no errors greater than 2% from the expected values.

5.4 Instrumental Analyzer Interference Check

The instrumental analyzers used to measure NO_X, SO_2, O_2 and CO_2 have had an interference response test preformed prior to their use in the field, pursuant to the interference response test procedures specified in USEPA Method 7E. The appropriate interference test gases (i.e., gases that would be encountered in the exhaust gas stream) were introduced into each analyzer, separately and as a mixture with the analyte that each analyzer is designed to measure. All of analyzers exhibited a composite deviation of less than 2.5% of the span for all measured interferent gases. No major analytical components of the analyzers have been replaced since performing the original interference tests.

5.5 Instrument Calibration and System Bias Checks

At the beginning of each day of the testing program, initial three-point instrument calibrations were performed for the NO_x, SO_2, CO_2 and O_2 analyzers by injecting calibration gas directly into the inlet sample port for each instrument. System bias checks were performed prior to and at the conclusion of each sampling period by introducing the upscale calibration gas and zero gas into the sampling system (at the base of the stainless-steel sampling probe prior to the particulate filter and Teflon® heated sample line) and determining the instrument response against the initial instrument calibration readings.

The instruments were calibrated with USEPA Protocol 1 certified concentrations of CO_2, O_2, NO_x, and SO_2 in nitrogen and zeroed using hydrocarbon free nitrogen. A STEC Model SGD-710C ten-step gas divider was used to obtain intermediate calibration gas concentrations as needed.

5.6 Determination of Exhaust Gas Stratification

A stratification test was performed for the turbine exhaust stack. The stainless-steel sample probe was positioned at sample points according to USEPA Method 1. Pollutant concentration data were recorded at each sample point for a minimum of twice the maximum system response time.

The recorded concentration data for the turbine exhaust stack indicated that the measured SO_2, and NOx concentrations did vary by more than 10% of the mean across the stack diameter. Therefore, the turbine exhaust gas was considered to be stratified and the compliance test sampling was performed at 16 sampling points within the turbine exhaust stack.

5.7 System Response Time

The response time of the sampling system was determined prior to the compliance test program by introducing upscale gas and zero gas, in series, into the sampling system using a tee connection at the base of the sample probe. The elapsed time for the analyzer to display a reading of 95% of the expected concentration was determined using a stopwatch.

Sampling periods did not commence until the sampling probe had been in place for at least twice the greatest system response time.

5.8 Meter Box Calibrations

The dry gas meter sampling console used for moisture testing was calibrated prior to and after the testing program. This calibration uses the critical orifice calibration technique presented in USEPA Method 5. The metering console calibration exhibited no data outside the acceptable ranges presented in USEPA Method 5.

The digital pyrometer in the Nutech metering consoles were calibrated using a NIST traceable Omega® Model CL 23A temperature calibrator.

5.9 Cyclonic Flow Check

The absence of cyclonic flow for each sampling location was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at multiple velocity traverse points with the planes of the face openings of the Pitot tube perpendicular to the stack cross-sectional plane. The Pitot tube was then rotated to determine the null angle (rotational angle as measured from the perpendicular, or reference, position at which the differential pressure is equal to zero).

Appendix 6 presents test equipment quality assurance data (NO_2 – NO conversion efficiency test data, instrument calibration and system bias check records, calibration gas and gas divider certifications, interference test results, meter box calibration records, field equipment calibration records, and stratification checks).

6.0 Results

6.1 Test Results and Allowable Emission Limits

Turbine operating data and air pollutant concentration and emission measurement results for each one-hour test period are presented in Tables 6.1 and 6.2.

EUTURBINE4-S3 has the following allowable emission limits specified in MI-ROP-N2688-2011a:

- 0.15 lb/MMBtu or 0.9 lb/MWhr for SO_2.
- 9.02 lb/hr, 39.5 ton/yr, and 96 ppmvd @ 15% O_2 or 5.5 lb/MWhr for NOx.

The measured air pollutant concentrations and emission rates for EUTURBINE4-S3 are less than the allowable limits specified in MI-ROP-N2688-2011a.

6.2 Results of LFG Fuel Analyses

On the day of the test event (November 16, 2022), the treated LFG used as fuel for the Arbor Hills Energy facility was:

- Analyzed by Draeger® tubes during each test period (Draeger® tube samples are included in this test report for a total of six (6) samples).

- Sampled using an Evacuated Silonite Suma Canister and delivered to a third-party laboratory for analysis of sulfur-bearing compounds.

- Sampled using an Evacuated Silonite Suma Canister and delivered to a third-party laboratory for analysis of methane content and heat input.

The Draeger® tube results for the six (6) samples performed on 11/16/2022 ranged from approximately 400 to 490 ppm H_2S. The laboratory reported an H_2S content of 590 and 640 ppmv for the Suma canister samples with a calculated total reduced sulfur (TRS) content of 606 and 654 ppmv. The laboratory reported a methane content of 46% and a heat content of 468 Btu/scf. The measured turbine SO_2 emission rate (6.57 lb/hr) correlates to an inlet fuel sulfur (TRS) content of 320 ppmv in the fuel gas at the fuel consumption rate of 2,056 scfm, assuming complete conversion of TRS to SO_2. Based on the stain tube results and the measured SO_2 emissions at the turbine exhaust stack, the laboratory results of 606 and 654 ppmv TRS are greater than expected.

Arbor Hills Energy performed follow-up sampling on 1/10/2023 to verify H_2S recorded by Draeger® tubes versus laboratory analysis. The laboratory reported H_2S concentrations of 397 and 413 ppmv and calculated total reduced sulfur (TRS) concentrations of 405.7 and 421.4 ppmv for the follow-up sampling, which more closely matches the Draeger® tube and SO_2 emission rate measurements. Both laboratory analytical reports are presented in Table 6.2 and included in Appendix 7.

6.3 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with USEPA methods and the approved Stack Test Protocol dated August 23, 2022. The turbine operated at maximum achievable load conditions during the test periods.

Shortly after the test event Mrs. Regina Angellotti, EGLE-AQD, sent notice to ICT and Arbor Hills Energy personnel that NO_2 calibration gas balanced in nitrogen is no longer considered an USEPA Protocol 1 certified gas. This information is based on an USEPA memorandum dated February 25, 2022, titled *EPA Protocol Gas Long-Term Stability Requirements*. EGLE requested that the NO_x Converter Efficiency Test be repeated with an NO_2 calibration gas that is balanced in air, per the USEPA memorandum. ICT ordered an NO_2 calibration gas the is balanced in air, but it was not delivered before the due date of this report. Once the calibration gas is delivered a NO_x Converter Efficiency Test will be performed with the calibration gas required by USEPA.

Table 6.1 Measured exhaust gas conditions and air pollutant emission rates for Turbine No. 4 (EUTURBINE4-S3)

Test No. Test date Test period (24-hr clock)	1 11/16/2022 0800-0830, 0835-0905	2 11/16/2022 0935-1005, 1010-1040	3 11/16/2022 1145-1215, 1220-1250	Three Test Average
Fuel flowrate (scfm)	2,080	2,044	2,043	2,056
Turbine output (kW)	4,306	4,208	4,224	4,246
Turbine output (MW)	4.31	4.21	4.22	4.25
LFG methane content (%)	47.5	47.6	48.0	47.7
Fuel Vacuum to Plant (in. H_2O)	76.3	75.6	78.6	76.9
Exhaust Gas Composition				
CO_2 content (% vol)	4.49	4.39	4.41	4.43
O_2 content (% vol)	16.5	16.6	16.6	16.6
Moisture (% vol)	1.94	8.52	3.76	4.74
Exhaust gas flowrate (scfm)	41,422	41,074	41,079	41,192
Exhaust gas flowrate (dscfm)	40,619	37,573	39,536	39,243
Exhaust gas temperature (°F)	851	850	848	850
Nitrogen Oxides				
NO_X conc. (ppmvd)	20.6	20.6	20.2	20.5
NO_X emissions (lb/hr)	6.00	5.55	5.72	5.75
Permit Limit (lb/hr)	-	-	-	*9.02*
NO_X emissions (ton/yr)	26.3	24.3	25.0	25.2
Permit Limit (ton/yr)	-	-	-	*39.5*
NO_X emissions (lb/MWhr)	1.39	1.32	1.35	1.35
Permit Limit (lb/MWhr)	-	-	-	*5.5*
Sulfur Dioxide				
SO_2 conc. (ppmvd)	14.1	16.7	19.6	16.8
SO2 emissions (lb/hr)	5.70	6.25	7.74	6.57
SO_2 emissions (lb/MMBtu)	0.10	0.11	0.14	0.11
Permit Limit[1] (lb/MMBtu)	-	-	-	*0.15*
SO_2 emissions (lb/MWhr)	1.32	1.49	1.83	1.55

Notes:

1. The source has the option of complying with either the lb/MMBtu limit or the lb/MWhr limit.

Table 6.2 Summary of LFG fuel sulfur content analyses

Test Date	11/16/2022		11/16/2022		11/16/2022		1/10/2023	
Test No.	1		2		3		Resample	
Draeger® tube[1] (ppm H_2S)	450	450	400	420	480	490	400	420
Lab result (ppm H_2S)	--	--	590	640	--	--	397	413
Lab result[2] (ppm TRS)	--	--	606	654	--	--	406	421
Lab result (% CH_4)	--	--	45.9	46.0	--	--	--	--
Lab result (Btu/scf)	--	--	467	468	--	--	--	--

Notes:
1. Estimated from observation of Draeger® tubes. Photos are provided in Appendix 7.
2. TRS concentration based on the total of all sulfur-bearing compounds detected in the sample. See laboratory report in Appendix 7.
3. A resample was collected on 1/10/2023 after results from the original sulfur sampling event (11/16/2022) reported by the laboratory were greater than expected when compared to historic trends. Therefore, a new sample was shipped to a different lab. The resampled laboratory results closely align with historic trends, and with sulfur emissions data recorded during the emissions test.

APPENDIX 1

- Turbine Sample Port Diagram