AIR EMISSION TEST REPORT

Title:	AIR EMISSION TEST REPORT FOR THE VERIFICATION OF AIR POLLUTANT EMISSIONS FROM A LANDFILL GAS FUELED TURBINE
Report Date:	February 18, 2020
Test Date:	December 20, 2019

Facility Information	
Name:	Arbor Hills Energy, LLC
Street Address:	1611 W. Five Mile Road
City, County:	Northville, Washtenaw
SRN:	N2688

Facility Permit Information	
Permit No.:	MI-ROP-N2688-2011
Emission Unit:	EUTURBINE4-S3 (Solar Taurus)

Testing Contractor	
Company:	Impact Compliance & Testing, Inc.
Mailing Address:	37660 Hills Tech Drive Farmington Hills, MI 48331
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Project No.:	1900234

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

ARBOR HILLS ENERGY, LLC

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 with landfill gas (LFG) that is collected from the Arbor Hills Landfill.

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

The compliance test results presented in this report are for testing that was performed on December 20, 2019 for EUTURBINE4-S3. The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated October 2, 2019.

Questions regarding this emission test report should be directed to:

Test Methods and Procedures	Tyler J. Wilson Senior Project Manager Impact Compliance and Testing, Inc. 37660 Hills Tech Drive Farmington Hills, MI 48331 (734) 464-3880 / Tyler.Wilson@ImpactCandT.com
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Responsible Official	Anthony Falbo Vice President, Operations

Report Certification

This test report was prepared by Impact Compliance & Testing, Inc. (ICT) based on field sampling data collected by ICT personnel Tyler Wilson and Tom Andrews. Facility process data were collected and provided by Arbor Hills Energy employees or representatives.

A ROP Report Certification Form signed by the facility's Responsible Official accompanies this report.

I certify that the testing was conducted in accordance with the specified test methods and submitted test plan unless otherwise specified in this report. I believe the information provided in this report and its attachments are true, accurate, and complete.

Report Prepared By:

Tyler J. Wilson
Senior Project Manager
Impact Compliance & Testing, Inc.

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 Solar Taurus turbine that is identified as EUTURBINE4-S3 to satisfy the annual testing requirement specified in RO Permit No. MI-ROP-N2688-2011.

The compliance test results presented in this report are for testing that was performed on December 20, 2019.

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 4.80 MW.

Fuel flowrate (standard cubic feet per minute), fuel methane content (%), power production (MW), and fuel vacuum to plant (in. H_2O) 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 process operating conditions during the test periods.

Table 2.1 Average turbine operating conditions during the test periods

Device	Power Production (MW)	Fuel Flowrate (scfm)	Methane Content (%)	Fuel Vacuum to Plant (in. H_2O)
#4 / Taurus	4.80	2,221	44.9	80.5

2.3 Summary of Air Pollutant Sampling Results

The gas exhausted from EUTURBINE4-S3 was sampled for three (3) one-hour test periods during the compliance testing performed December 20, 2019.

Table 2.2 presents a summary of results for EUTURBINE4-S3.

Test data presented in Table 2.2 is the three-test average for EUTURBINE4-S3. Annual ton per year (ton/yr) values are based on continuous operation (8,760 hr/yr) at the measured lb/hr emission rate. Actual ton/yr values will be reported by facility based on actual operating time.

The test results demonstrate compliance with the emission rates specified in MI-ROP-N2688-2011 for NO_X. Measured SO_2 emission rates exceeded the pounds per hour (lb/hr) rate specified in MI-ROP-N2688-2011 for EUTURBINE4-S3.

Test results for each one-hour sampling period are presented in Section 6.0 of this report.

Table 2.2 Summary of EUTURBINE4-S3 emission rates compared to allowable emission rates

Emission Parameter		Turbine No. 4 Emissions	Permit Limit
NOx	NO_X emissions (lb/hr)	6.68	9.02
	NO_X emissions (ton/yr)	29.3	39.5
SO_2	SO_2 emissions (lb/MWhr)	2.16	0.9

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. NO_X emissions are suppressed by the use of dry low-NO_X 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.

Appendix 1 provides a diagram 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 the Michigan Department of Environment, Great Lakes, and Energy (EGLE) Air Quality Division (AQD). This section provides a summary of the sampling and analytical procedures that were used during the Arbor Hills Energy 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 zirconia ion/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	SO_2 by pulsed ultraviolet florescence instrument analyzer.
USEPA Method 7E	Exhaust gas NOx concentration was determined using chemiluminescence instrumental analyzers.
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.

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 single beam single wavelength (SBSW) infrared gas analyzer. The O_2 content of the exhaust was monitored using a 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 Content (USEPA Method 4)

Moisture content of the turbine exhaust gas was determined in accordance with USEPA Method 4 using a chilled impinger sampling train. During each sampling period, a gas sample was extracted from the source where moisture was removed from the sampled gas stream using impingers that were submersed in an ice bath. 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.

4.5 Sulfur Dioxide by Instrumental Analyzer (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 SO_2 concentration.

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

4.6 NO_x Concentration Measurements (USEPA Methods 7E)

NO_X pollutant concentrations in the turbine exhaust gas stream were determined using a 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 analyzer. Instrument response for the 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 instrument was calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias.

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

4.7 Fuel Gas Analysis for Sulfur (ASTM Method D-5504)

In addition to the exhaust gas SO_2 concentration measurements, a sample of the treated LFG used as fuel was analyzed for sulfur content and SO_2 emission calculations were performed based on the conversion of sulfur to SO_2. A representative sample of the treated LFG was collected during the test event (December 20, 2019) using an evacuated, inert (silonite-coated) stainless steel canister. The sample Teflon tubing was connected to the fuel header at a location after the treatment system and gas blower. Sample canister vacuum was recorded before and after sampling and verified by the laboratory upon receipt.

The gas samples were analyzed by ALS Analytical (Simi Valley, CA) for sulfur bearing compounds by ASTM D-5504.

In addition, the EGLE-AQD requested that inlet LFG be sampled for hydrogen sulfide (H_2S) concentration once per 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 canister sample and a photo of the three (3) Draeger® tubes.

5.0 QA/QC ACTIVITIES

5.1 Exhaust Gas Flow

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

The Pitot tube and connective tubing were leak-checked onsite, prior to the test event, to verify the integrity of the measurement system.

The absence of significant cyclonic flow for the exhaust configurations were 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).

5.2 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the chemiluminescence NOx 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_x concentration is at least 90% of the expected value.
The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NOx concentration was greater than 90% of the expected value as required by Method 7E).

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 NOx, 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 NOx, 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, NOx, and SO_2 in nitrogen and zeroed using hydrocarbon free nitrogen (or air). 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 exhaust stack. The stainless steel sample probe was positioned at sample points correlating to 16.7, 50.0 (centroid) and 83.3% of the stack diameter. Pollutant concentration data were recorded at each sample point for a minimum of twice the maximum system response time. For the turbine exhaust stack, each sample point had less than 5% variation from the mean, therefore, the turbine exhaust stack was determined to be unstratified. A single point was used for instrument sampling.

5.7 Meter Box Calibrations

The dry gas meter sampling console, which was used for exhaust gas moisture content sampling, 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 metering console was calibrated using a NIST traceable Omega® Model CL 23A temperature calibrator.

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, Pitot tube, scale, pyrometer, and barometer calibration records).

6.0 RESULTS

6.1 Turbine Exhaust Test Results and Allowable Emission Limits

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

Hourly (lb/hr) emission rates are compared to the allowable lb/hr (pph) limit specified in the RO Permit. Maximum annual (ton/yr) emissions presented in Tables 6.1 and 6.2 are calculated based on continuous operation (8,760 hours/yr) at the measured lb/hr emission rate. However, it should be noted that actual annual emissions will be calculated by the facility based on actual process operating hours.

The measured air pollutant emission rates for EUTURBINE4-S3, are less than the allowable limits specified in Section 3 of RO Permit No. MI-ROP-N2688-2011 for NOx (9.02 pph and 39.5 tpy NOx); and exceed the allowable rates specified for SO_2 (0.9 pounds per megawatt-hour, lb/MWhr, or 0.15 pounds per million British Thermal Unit, lb/MMBtu)

6.2 Results of LFG Fuel Sulfur Content Analyses

On the day of the test event (December 20, 2019), the treated LFG used as fuel for the Arbor Hills Energy facility was:

- Analyzed by Draeger® tubes for sulfur during each test period.
- Sampled using a vacuum canister and sent to a third-party laboratory for analysis of sulfur-bearing compounds.

The Draeger® tube results for the three (3) samples ranged from approximately 420 to 460 ppm H_2S. The laboratory reported an H_2S content of 920 ppmv for the canister sample with a calculated total reduced sulfur (TRS) content of 949 ppmv. The canister sample data has been determined to be erroneous as discussed below in section 6.3. Subsequent inlet fuel sample results reported by a different laboratory yielded an H2S content of 451 ppmv and a calculated total reduced sulfur (TRS) content of 471 ppmv.

6.3 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with USEPA methods and the Stack Test Protocol dated October 2, 2019 (the test date was moved to December 20, 2019 as opposed to December 17 as specified in the test plan). The turbine operated at maximum achievable load during the test periods.

There is a significant discrepancy between the fuel sulfur content measured on-site with the Draeger® tubes and the value reported by the laboratory. The fuel sulfur content measured using Draeger® tubes during the test periods is consistent with historical data maintained by Arbor Hills Energy and correlates to the SO_2 stack concentration measured by the test crew. The measured SO_2 emission rate (10.4 lb/hr) correlates to a sulfur input of 5.2 lb/hr in the fuel gas. At a fuel consumption rate of 2,221 scfm, this is equivalent to a sulfur content of 469 ppmv in the fuel gas.

Therefore, there is independent verification (stack SO_2 measurements and Draeger® tubes measurements) that the fuel sulfur content is in the range of 450-460 ppmv and that the laboratory analysis is not correct.

We are confident that the laboratory results from the inlet fuel gas canister samples collected on 12/20/2019 are erroneous, as the results are not consistent with other data (Draeger® tubes and SO_2 emission rates) collected during testing or with historical trends at the facility. In order to verify that the 12/20/19 Method ASTM D5504 lab data was inaccurate, the inlet fuel gas was resampled on 2/12/2020 and sent to a different laboratory for analysis by Method ASTM D5504 as requested in the 11/1/2019 Test Protocol Approval Letter. See Table 6.3 and laboratory report in Appendix 7 for accurate sulfur data. In addition, three (3) H_2S Draeger® tube samples were collected on 2/12/2020 (in approximately 15-minute intervals) and results are presented in Table 6.3 and Appendix 7. The results of resampling further demonstrate the 12/20/19 Method ASTM D5504 lab data was inaccurate (for the reasons discussed above) and that the Draeger® tube test results from 12/20/19 provide the only accurate measurement of H_2S concentrations.

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

Test No. Test date Test period (24-hr clock)	1 12/20/19 0745-0845	2 12/20/19 0911-1011	3 12/20/19 1039-1139	Three Test Average
Fuel flowrate (scfm)	2,219	2,221	2,222	2,221
Generator output (MW)	4.80	4.80	4.80	4.80
LFG methane content (%)	44.7	44.9	45.1	44.9
Exhaust O_2 Content (%)	15.7	15.7	15.7	15.7
Exhaust CO_2 Content (%)	4.89	4.92	4.95	4.92
Exhaust Moisture Content (%)	5.23	5.31	5.12	5.22
Exhaust Temperature (°F)	834	846	850	843
Exhaust Flowrate (scfm)	41,871	41,303	41,288	41,487
Exhaust Flowrate (dscfm)	39,682	39,108	39,175	39,322
NOx Concentration (ppmvd)	23.5	23.5	24.1	23.7
NOx Emission Rate (lb/hr)	6.69	6.58	6.76	6.68
NOx Permit Limit (lb/hr)	-	-	-	*9.02*
NOx Emission Rate (ton/yr)	29.3	28.8	29.6	29.3
NOx Permit Limit (ton/yr)	-	-	-	*39.5*
SO_2 Concentration (ppmvd)	26.0	26.3	26.8	26.4
SO_2 Emission Rate (lb/hr)	10.3	10.3	10.5	10.4
SO_2 Emission Rate (lb/MWhr)	2.15	2.14	2.18	2.16
SO_2 Permit Limit (lb/MWhr)	-	-	-	*0.9*

Table 6.2 Summary of LFG fuel sulfur content analyses

Test No.	1	2	3
Draeger® tube[1] (ppm H_2S)	460	420	430
Lab result (ppm H_2S)	--	--	920
Lab result[2] (ppm TRS)	--	--	949

Table 6.2 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.

Table 6.3 Summary of additional LFG fuel sulfur content analyses

Test No.	1	2	3
Draeger® tube[1] (ppm H_2S)	400	390	410
Lab result (ppm H_2S)	--	--	451
Lab result[2] (ppm TRS)	--	--	471

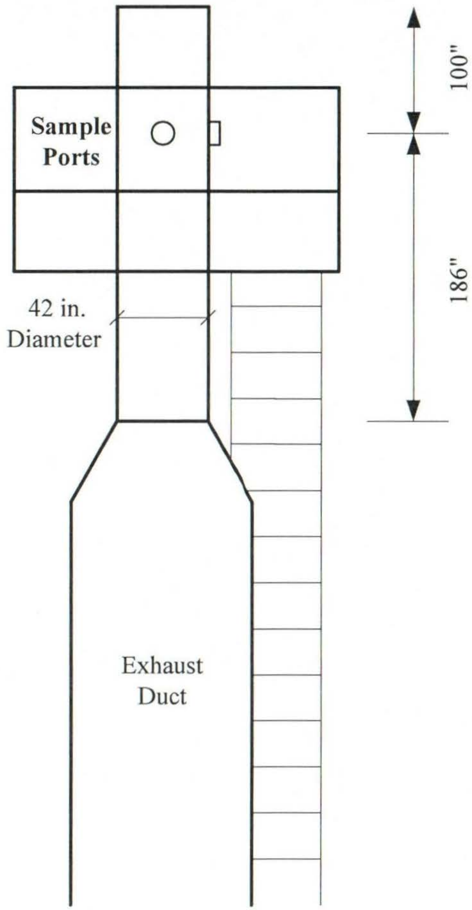
Table 6.3 Notes

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.

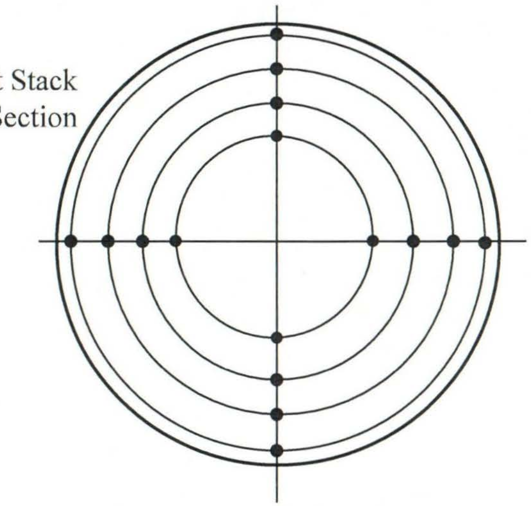
APPENDIX 1

- Sample Port Diagram

Turbine 4
(EUTURBINE4-S3)



Exhaust Stack Cross-Section



Velocity sample locations as measured from stack wall (not including 6" sampling port nipple)

Pt. #	in.
1	1.34
2	4.41
3	8.15
4	13.52
5	28.43
6	33.85
7	37.59
8	40.66

7/20/18

Arbor Hills Energy
Exhaust Sampling Location – Turbine #4

Scale	Sheet
None	1 of 1

IMPACT COMPLIANCE & TESTING