Executive Summary

C & C ENERGY, LLC
LANDFILL GAS FUELED TURBINE
EMISSION TEST RESULTS

C & C Energy, LLC (C&C Energy) contracted Impact Compliance & Testing, Inc. (ICT) to conduct a performance demonstration for the determination of nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), sulfur dioxide (SO_2), and hydrogen chloride (HCl) concentrations and emission rates from a turbine (EU-TURBINE) used to drive an electrical generator at their facility located at the C & C Expanded Sanitary Landfill (C&C Landfill) in Marshall, Calhoun County, Michigan.

The Michigan Department of Environment, Great Lakes, and Energy-Air Quality Division (EGLE-AQD) renewable operating permit (ROP) MI-ROP-P0222-2018 requires that the permittee shall verify the emission rates of all the pollutants mentioned above at least 180 days before the ROP expires.

The following tables present the results from the performance demonstration.

	NO_x Emissions		CO Emissions		VOC Emissions		SO_2 Emissions		HCl Emissions	
Emission Unit	(lb/hr)	(lb/MWh)	(lb/hr)	(TPY)	(lb/hr)	(TPY)	(lb/hr)	(lb/MMBtu)	(lb/hr)	(TPY)
EU-TURBINE	4.61	1.9	3.34	15	0.01	<0.1	2.72	0.07	0.09	0.38
Permit Limits	-	***5.5***	-	***89***	-	***2.5***	-	***0.15***	-	***8.3***

Emission Unit	Turbine Output (MW)	Turbine Fuel Use (scfm)	Fuel CH_4 (%)
EU-TURBINE	2.39	1,221	52.5

The data presented above indicates that EU-TURBINE is in compliance with the lb/MWH, TPY, and lb/MMBTU emission standards specified in ROP No. MI-ROP-P0222-2018 for NOx, CO, VOC, SO_2, and HCl.

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1.0 Introduction

C&C Energy, LLC (C&C Energy) operates a Solar Centaur Model T-4500 landfill gas (LFG) fired turbine at the C&C Expanded Sanitary Landfill (C&C Landfill) in Marshall, Calhoun County, Michigan. The turbine is fueled by landfill gas that is collected from the C&C Landfill.

The conditions of Renewable Operating Permit (ROP) No. MI-ROP-P0222-2018 issued to the source specifies that for EU-TURBINE, verification of the emission rates of carbon monoxide (CO), sulfur dioxide (SO_2), volatile organic compounds (VOC), nitrogen oxides (NO_x), and hydrogen chloride (HCl) 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, Blake Beddow, and Max Fierro performed the field sampling and measurements August 23, 2022.

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

The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated June 17, 2022, that was reviewed and approved by the State of Michigan Department of Environment, Great Lakes, and Energy-Air quality Division (EGLE-AQD).

Questions regarding this emission test report should be directed to:

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2.0 Summary of Test Results and Operating Conditions

2.1 Purpose and Objective of the Tests

Stack testing was performed to measure CO, SO_2, VOC, NO_x, and HCl emissions for one Solar Centaur Turbine that is identified as EU-TURBINE to satisfy the testing requirement specified in ROP No. MI-ROP-P0222-2018.

The compliance test results presented in this report are for the testing that was performed on August 23, 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 combustion turbine produced an average of 2.39 MW-hr.

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

Appendix 2 provides operating records provided by C&C Energy representative 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 gases exhausted from the sampled LFG fueled turbine (EU-TURBINE) were sampled for three (3) one-hour test periods during the compliance testing performed August 23, 2022.

Table 2.2 presents the average measured CO, NO_X, VOC, SO_2, and HCl 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

Emission Unit	Turbine Output (MW)	Turbine Fuel Use (scfm)	Fuel CH_4 (%)
EU-TURBINE	2.39	1,221	52.5

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

	NO_x Emissions		CO Emissions		VOC Emissions		SO_2 Emissions		HCl Emissions	
Emission Unit	(lb/hr)	(lb/MWh)	(lb/hr)	(TPY)	(lb/hr)	(TPY)	(lb/hr)	(lb/MMBtu)	(lb/hr)	(TPY)
EU-TURBINE	4.61	1.9	3.34	15	0.01	<0.1	2.72	0.07	0.09	0.38
Permit Limits	-	***5.5***	-	***89***	-	***2.5***	-	***0.15***	-	***8.3***

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 treated and transferred to the C&C Energy facility where it is used as fuel to produce electricity, which is transferred to the local utility.

3.2 Rated Capacities and Air Emission Controls

The Solar Centaur Model T-4500 turbine is a simple cycle turbine that is connected to an electricity generator that is rated to produce 3,500 kW (3.5 MW) of electricity. The turbine is not equipped with add-on emission control equipment. NO_x emissions are suppressed using a dry low-NO_x combustor within the gas turbine.

Appendix 2 provides operating records provided by C&C Energy representatives for the test periods.

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 turbine exhaust stack sampling ports are located in a vertical portion of the stack with an inner diameter of 42 inches. The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location 41 inches (0.98 duct diameters) upstream and 168 inches (4.0 duct diameters) downstream from any flow disturbance.

All sample port locations 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 diagrams of the emission test sampling locations.

4.0 Sampling and Analytical Procedures

The 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 pulsed ultraviolet fluorescence.
USEPA Method 7E	Exhaust gas NOx concentration was determined using chemiluminescence instrumental analyzers.
USEPA Method 10	Exhaust gas CO concentration was measured using an infrared instrumental analyzer.
USEPA Method 25A / ALT-096	Exhaust gas VOC (as NMHC) concentration was determined using a flame ionization analyzer equipped with methane separation column.
USEPA Method 26	Exhaust gas HCl concentration was measured using single point (non-isokinetic) sampling and analysis by ion chromatography.
ASTM Method D-5504 / 3588	Fuel gas sulfur and heat content 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 1440 infrared gas analyzer. The O_2 content of the exhaust was monitored using a Servomex 1440 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 SO_2, NO_X, and CO Concentration Measurements (USEPA Methods 6C, 7E & 10)

SO2, NO_X, and CO pollutant concentrations in the turbine exhaust gas streams were determined using a Thermo Environmental Instruments, Inc. (TEI) Model 42i High-Level chemiluminescence NO_X analyzer, a TEI Model 43i pulsed ultraviolet fluorescence SO_2 analyzer, and a TEI 48i infrared CO 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, CO, and SO_2 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.5 Measurement of VOC (USEPA Method 25A / ALT-096)

The VOC emission rate was determined by measuring the nonmethane hydrocarbon (NMHC or NMOC) concentration in the engine exhaust gas. NMHC pollutant concentration was determined using a TEI Model 55i Methane / Nonmethane hydrocarbon analyzer. The TEI 55i analyzer contains an internal gas chromatograph column that separates methane from non-methane components. The concentration of NMHC in the sampled gas stream, after separation from methane, is determined relative to a propane standard using a flame ionization detector in accordance with USEPA Method 25A.

Samples of the exhaust gas were delivered directly to the instrumental analyzer using the Teflon® heated sample line to prevent condensation. The sample to the NHMC analyzer was not conditioned to remove moisture. Therefore, VOC measurements correspond to standard conditions with no moisture correction (wet basis).

Prior to, and at the conclusion of each test, the instrument was calibrated using mid-range calibration (propane) and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document).

Appendix 4 provides VOC calculation sheets. Raw instrument response data for the NMHC analyzer is provided in Appendix 5.

4.6 HCl by Sampling Train (USEPA Method 26)

HCl concentrations in the turbine exhaust gas were determined using a modified version of USEPA Method 26. A sample of the exhaust gas was withdrawn from the exhaust stack at a constant rate (i.e., non-isokinetic rate) using a glass lined probe and a quartz filter. The gas sample was bubbled through chilled impingers containing 0.1 normality sulfuric acid (0.1N H2SO4). The NaOH portion of the Method 26 sampling train was not used since halogen (Cl2) concentrations were not included in the analysis.

The wetted portions of the sampling train were constructed of glass. A silonite-coated stainless-steel probe union was used.

At the end of each one-hour test period, the impinger solutions and rinses were recovered and shipped to a third-party laboratory (Enthalpy Analytical in Durham, North Carolina) for HCl analysis by ion chromatography (IC) analysis in accordance with USEPA Method 26.

Appendix 4 provides HCl calculation sheets. Appendix 6 provides a copy of the HCl laboratory analytical report.

4.6 Fuel Gas Analysis (ASTM Method D5504/3588)

In addition to the exhaust gas SO_2 concentration measurements, two (2) samples of treated LFG used as fuel were analyzed for sulfur content and heat content. SO_2 emission calculations were performed based on the conversion of sulfur to SO_2. The two (2) samples of the treated LFG were collected during the test event (August 23, 2022) using evacuated, silonite-coated Summa Canisters. The sample tubing was connected to the fuel header at a location after the treatment system and gas blower. The 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 gross heating value by ASTM D3588 and sulfur bearing compounds by ASTM D-5504.

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.

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 (barometer and Pitot tube) 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 42i 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 within 10% of the expected value.

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_X concentration was 102.1% of the expected value).

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, CO, 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, CO, 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 CO in nitrogen and zeroed using hydrocarbon free nitrogen. The SO_2 instrument was calibrated with USEPA Protocol 1 certified concentrations of SO_2 in air and zeroed using hydrocarbon-free air. The NMHC (VOC) instrument was calibrated with USEPA Protocol 1 certified concentrations of propane in air and zeroed using hydrocarbon-free 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 turbine exhaust stack. The stainless-steel sample probe was positioned at 16 sample points across the stack diameter. 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 O_2 concentrations did not vary by more than 5% of the mean across the stack diameter. Therefore, the turbine exhaust gas was considered to be unstratified and the compliance test sampling was performed at a single sampling location within the turbine exhaust stack.

6.0 Results

6.1 Test Results and Allowable Emission Limits

Turbine operating data and air pollutant emission measurement results for each one-hour test period are presented in Table No. 6.1.

EU-TURBINE has the following allowable emission limits specified in MI-ROP-P0222-2018:

- 89 TPY for CO;
- 5.5 lb/MWh for NO_x;
- 2.5 TPY for VOC;
- 0.15 lb/MMBtu for SO_2; and
- 8.3 TPY for HCl.

The measured air pollutant concentrations and emission rates for EU-TURBINE are less than the allowable limits specified in MI-ROP-P0222-2018.

6.2 Results of LFG Fuel Analysis

On the day of the test event (August 23, 2022), the treated LFG used as fuel for the C&C Energy facility was:

- Sampled using an evacuated, silonite-coated Summa Canister and shipped to a third-party laboratory for analysis of sulfur-bearing compounds.

- Sampled using an evacuated, silonite-coated Summa Canister and shipped to a third-party laboratory for analysis of heat input.

The laboratory reported an H_2S content of 240 ppmv for the Summa Canister samples with a calculated total reduced sulfur (TRS) content of 251.9 ppmv. The laboratory reported a heat content of 503.5 Btu/scf.

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 June 17, 2022. The turbine operated at maximum achievable load conditions during the test periods.

Table 6.1 Measured exhaust gas conditions and air pollutant emission rates for the turbine (EU-TURBINE)

Test No. Test date Test period (24-hr clock)	1 8/23/2022 0945-1045	2 8/23/2022 1135-1235	3 8/23/2022 1310-1410	Three Test Average
Fuel flowrate (scfm)	1,219	1,221	1,223	1,221
Turbine output (kW)	2,389	2,361	2,412	2,387
Turbine output (MW)	2.39	2.36	2.41	2.39
LFG methane content (%)	52.2	52.5	52.8	52.5
Exhaust Gas Composition				
CO_2 content (%)	4.14	3.97	4.05	4.05
O_2 content (%)	8.31	8.29	8.27	8.29
Moisture (%)	6.0	6.2	5.8	6.0
Exhaust gas flowrate (dscfm)	29,995	29,621	29,689	29,768
Exhaust gas flowrate (scfm)	31,908	31,566	31,530	31,668
Exhaust gas temperature (°F)	778.0	798.0	799.0	791.7
Nitrogen Oxides				
NO_X conc. (ppmvd)	20.9	21.6	22.3	21.6
NO_X emissions (lb/hr)	4.49	4.59	4.75	4.61
NO_X emissions (lb/MWh)	1.88	1.95	1.97	1.93
Permit Limit (lb/MWh)	-	-	-	*5.5*
Carbon Monoxide				
CO conc. (ppmvd)	27.6	24.7	24.8	25.7
CO emissions (lb/hr)	3.61	3.19	3.21	3.34
CO emissions (TPY)	15.8	14.0	14.1	14.6
Permit Limit (TPY)	-	-	-	*89*
Sulfur Dioxide				
SO_2 conc. (ppmvd)	9.1	9.3	9.1	9.2
SO_2 emissions (lb/hr)	2.74	2.74	2.69	2.72
SO_2 emissions (lb/MMBtu)	0.07	0.07	0.07	0.07
Permit Limit (lb/MMBtu)	-	-	-	*0.15*
Volatile Organic Compounds				
VOC conc. (ppmvd)	0.1	0	0	0
VOC emissions (lb/hr)	0.02	0	0	0.01
VOC emissions (TPY)	0.1	0	0	0
Permit Limit (TPY)	-	-	-	*2.5*

Table 6.1 Measured exhaust gas conditions and air pollutant emission rates for the turbine (EU-TURBINE) [Continued]

Test No. Test date Test period (24-hr clock)	1 8/23/2022 0945-1045	2 8/23/2022 1135-1235	3 8/23/2022 1310-1410	Three Test Average
Hydrogen Chloride				
HCl catch weight (µg)	1,079	1,022	971	1,024
HCl conc. (ppmvd)	0.54	0.51	0.49	0.51
HCl emissions (lb/hr)	0.09	0.09	0.08	0.09
HCl emissions (TPY)	0.40	0.38	0.36	0.38
Permit Limit (TPY)	-	-	-	*8.3*

Table 6.2 Summary of LFG fuel sulfur content analyses

Canister No.	1	2	Average
ASTM-D5504			
Lab result (ppm H_2S)	220	260	240
Lab result[1] (ppm TRS)	231	272	252
ASTM-D3588			
Lab result (Btu/scf)	502	505	504

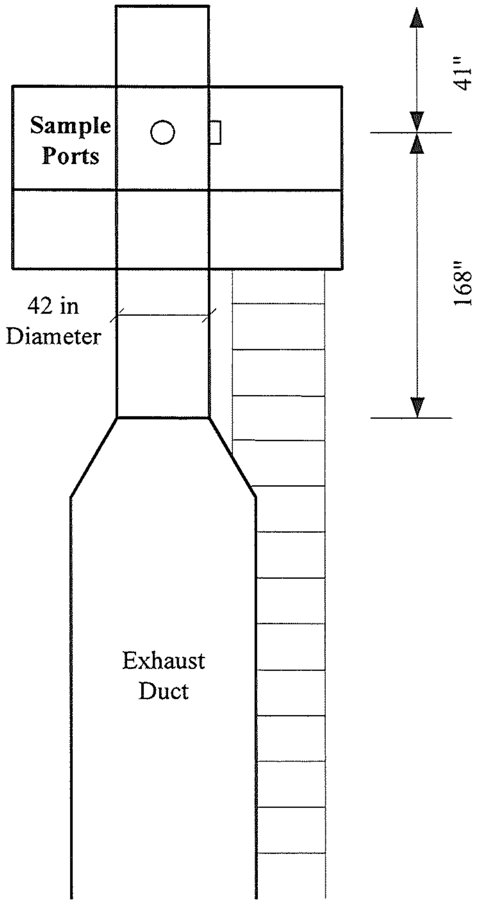
Table 6.2 Notes

1. TRS concentration based on the total of all sulfur-bearing compounds detected in the sample. See laboratory report in Appendix 6.

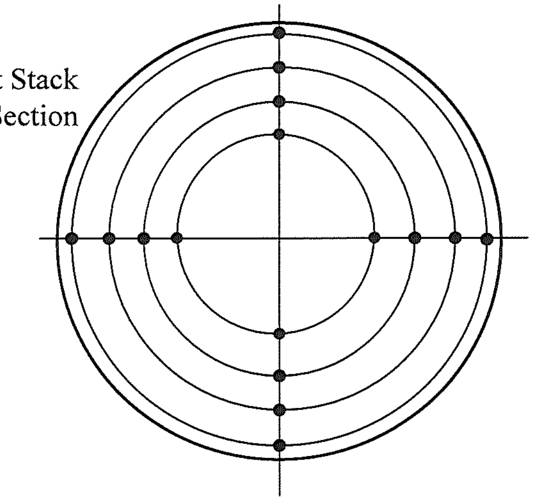
APPENDIX 1

- EU-TURBINE Sample Port Diagram

EU-TURBINE



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

8/2/18	**C & C Energy, LLC** **Exhaust Sampling Location – EU-TURBINE**		
	Scale None	Sheet 1 of 1	IMPACT COMPLIANCE & TESTING