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AIR QUALITY DIVISION

**AIR EMISSION TEST REPORT
FOR THE
VERIFICATION OF AIR POLLUTANT EMISSIONS
FROM A
NATURAL GAS FIRED ENGINE**

Prepared for:
**CORE ENERGY, LLC
CHESTER 10 CO₂ INJECTION FACILITY
SRN N5798**

**ICT Project No.: 2200057
March 9, 2022**



N5798-test-20220216

Report Certification

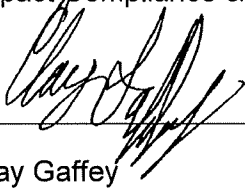
AIR EMISSION TEST REPORT FOR THE VERIFICATION OF AIR POLLUTANT EMISSIONS FROM A NATURAL GAS FIRED ENGINE

Core Energy, LLC
Chester Twp., Michigan

This report has been reviewed by Core Energy representatives and approved for submittal to the Michigan Department of Environment, Great Lakes, and Energy (EGLE) Air Quality Division (AQD).

I certify that the testing was conducted in accordance with the reference 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.

Impact Compliance & Testing, Inc.



Clay Gaffey
Environmental Consultant

I certify that the facility and emission unit was operated at maximum routine operating conditions for the test event. Based on information and belief formed after reasonable inquiry, the statements and information in this report are true, accurate and complete.

Responsible Official Certification:



Brian Dorr
Chief Operating Officer
Core Energy, LLC

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1.0 Introduction

Core Energy, LLC (Core Energy) operates natural gas-fired reciprocating internal combustion engines (RICE) at the Chester 10 CPF Facility in Chester Township, Otsego County, Michigan. The RICE are fueled by natural gas and are used to provide mechanical power to operate gas compressors. The facility compresses carbon dioxide gas prior to injecting it into oil wells.

The State of Michigan Department of Environment, Great Lakes, and Energy-Air Quality Division (EGLE-AQD) has issued Permit to Install (PTI) No. 579-95F to the Core Energy Chester 10 CPF Facility, which generally consists of:

- Two (2) Caterpillar (CAT®) Model No. G3608 RICE identified as emission units EUENGINE1 and EUENGINE2 (Flexible group ID FGENGINES).
- One (1) CAT® Model No. G3612 RICE identified as emission unit EUENGINE3 (Flexible Group ID FGENGINES).

EUENGINE3 is subject to periodic emission testing pursuant to the federal Standards of Performance for Stationary Spark Ignition Internal Combustion Engines (the SI-RICE NSPS; 40 CFR Part 60 Subpart JJJJ). The conditions of PTI No. 579-95F specify that:

Unless EUENGINE3 is a certified engine according to procedures specified in 40 CFR Part 60 Subpart JJJJ, and is maintained and operated as such, the permittee shall conduct performance testing every 8,760 hours of operation or three years from the previous performance test, whichever comes first, for EUENGINE3 to verify compliance with the emission limits in SC I.4, SC I.8, and SC I.9.

The compliance testing was performed by Impact Compliance & Testing, Inc. (ICT), a Michigan-based environmental consulting and testing company. ICT representatives Clay Gaffey and Max Fierro performed the field sampling February 16, 2022.

The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated January 4, 2022 that was reviewed and approved by EGLE-AQD. EGLE-AQD representative Mr. Robert Dickman observed portions of the testing project.

Questions regarding this air 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

The conditions for FGENGINES in PTI No. 579-95F state:

Unless EUENGINE3 is a certified engine according to procedures specified in 40 CFR Part 60 Subpart JJJJ, and is maintained and operated as such, the permittee shall conduct performance testing every 8,760 hours of operation or three years from the previous performance test, whichever comes first, for EUENGINE3 to verify compliance with the emission limits in SC 1.4, SC 1.8, and SC 1.9.

Testing was performed to demonstrate compliance with the air pollutant emission limits specified in PTI No. 579-95F (and Subpart JJJJ) for EUENGINE3.

2.2 Operating Conditions During the Compliance Tests

The testing was performed while EUENGINE3 operated at maximum routine operating conditions.

Fuel flowrate (scfm), engine shaft rotation (rpm), catalyst inlet temperature (°F), and engine load (%) were recorded by Core Energy representatives at 15-minute intervals for each test period.

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

Engine output (bhp) cannot be measured directly and was calculated based on the recorded engine shaft rotation (rpm). Core Energy provided engine spec sheets that list the horsepower produced and engine shaft rotation (rpm) at maximum load. To determine the horsepower output at a lower load the following equation was used:

Engine Output (bhp-hr) = Max Output (bhp-hr) * Measured rotation (rpm) / Max rotation (rpm)

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

2.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the RICE (EUENGINE3) for three (3) one-hour test periods during the compliance testing performed February 16, 2022.

Table 2.2 presents the average measured emission rates for EUENGINE3 (average of the three test periods).

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

Table 2.1 Average engine operating conditions during the test periods

Engine Parameter	EUENGINE3 CAT® G3612
Engine rotation (RPM)	812
Calculated engine output (bhp)	2,883
Engine load (%)	87
Engine fuel use (scfm)	289
Catalyst inlet temperature (°F)	738

Table 2.2 Average measured emission rates for Engine 3 (three-test average)

Emission Unit	CO		NOx		VOC
	(tpy)	(g/bhp-hr)	(tpy)	(g/bhp-hr)	(g/bhp-hr)
EUENGINE3	14.4	0.52	5.46	0.20	0.56
Permit Limit	17.13	2.0	18.11	1.0	0.7

Tons per year is based on 8,760 hour per year operation

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3.0 Source and Sampling Location Description

3.1 General Process Description

Core Energy operates a gas compressor station at the Chester Township facility. Natural gas, which has been recovered from nearby wells, has the carbon dioxide removed at an adjacent facility. The carbon dioxide gas stream is routed to the Core Energy Chester 10 CPF Facility containing three (3) natural gas fired RICE that power gas compressors. The compressed carbon dioxide gas stream is injected into an oil reservoir.

3.2 Rated Capacities and Air Emission Controls

The Core Energy CAT® Model No. G3612 RICE (EUENGINE3) has a rated output of 3,071 bhp at 865 rpm (3,550 bhp at 1,000 rpm).

The RICE and connected gas compressor is a continuous-type process. The engine is operated at the load (percent output) needed to drive the gas compressor to provide the desired volumetric flow and compression ratio for the transport and injection of carbon dioxide. The engine is equipped with an air-to-fuel ratio controller (AFRC) that manages the fuel flow and combustion air flowrates based on the engine load.

The RICE is equipped with an oxidation catalyst.

3.3 Sampling Locations

After the oxidation catalyst, the RICE exhaust gas is directed through a muffler and is released to the atmosphere through a dedicated vertical exhaust stack.

The engine exhaust sampling ports for EUENGINE3 are located in the exhaust stack that has an inner diameter of 26.0 inches. The stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location 180 inches (6.9 duct diameters) upstream and 63.0 inches (2.4 duct diameters) downstream from any flow disturbance and satisfies the USEPA Method 1 criteria for a representative sample location.

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 a diagram of the emission test sampling locations with actual stack dimension measurements.

4.0 Sampling and Analytical Procedures

A Stack Test Protocol for the air emission testing was reviewed and approved by the 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 7E	Exhaust gas NO _x 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.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The RICE exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once 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)

CO₂ and O₂ content in the RICE exhaust gas stream was measured continuously throughout each test period in accordance with USEPA Method 3A. The CO₂ content of the exhaust was monitored using a Servomex infrared gas analyzer. The O₂ content of the exhaust was monitored using a Servomex gas analyzer that uses a paramagnetic sensor.

During each sampling period, a continuous sample of the RICE 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 O₂ and CO₂ 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 O₂ and CO₂ calculation sheets. Raw instrument response data are provided in Appendix 5.

4.4 Exhaust Gas Moisture Determination (USEPA Method 4)

Moisture content of the RICE 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 NO_x and CO Concentration Measurements (USEPA Methods 7E and 10)

NO_x and CO pollutant concentrations in the RICE exhaust gas streams were determined using a Thermo Environmental Instruments, Inc. (TEI) Model 42i High Level chemiluminescence NO_x analyzer and a California Analytics / Fuji ZRF infrared CO analyzer.

Throughout each test period, a continuous sample of the engine 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 CO and NO_x calculation sheets. Raw instrument response data are provided in Appendix 5.

4.6 Measurement of Volatile Organic Compounds (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.

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The USEPA Office of Air Quality Planning and Standards (OAQPS) has issued an alternate test method approving the use of the TEI 55i-series analyzer as an effective instrument for measuring NMOC from gas-fueled RICE (ALT-096).

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.

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 (Pitot tube and scale) were calibrated to specifications in the sampling methods.

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 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 NO₂ – NO conversion efficiency of the Model 42i analyzer was verified prior to the testing program. A USEPA Protocol 1 certified concentration of NO₂ was injected directly into the analyzer, following the initial three-point calibration, to verify the analyzer's conversion efficiency. The analyzer's NO₂ – NO converter uses a catalyst at high temperatures to convert the NO₂ to NO for measurement. The conversion efficiency of the analyzer is deemed acceptable if the measured NO_x concentration is within 10% (i.e., at least 90%) of the expected value.

The NO₂ – NO conversion efficiency test satisfied the USEPA Method 7E criteria.

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, O₂, and CO₂ have had an interference response test performed 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, CO₂, and O₂ 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.

At the beginning of each test day, appropriate high-range, mid-range, and low-range span gases followed by a zero gas were introduced to the NMHC analyzer, in series at a tee connection, which is installed between the sample probe and the particulate filter, through a poppet check valve. After each one-hour test period, mid-range and zero gases were re-introduced in series at the tee connection in the sampling system to check against the method's performance specifications for calibration drift and zero drift error.

The instruments were calibrated with USEPA Protocol 1 certified concentrations of CO₂, O₂, NO_x, and CO in nitrogen and zeroed using hydrocarbon free nitrogen. 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 each RICE 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.

The recorded concentration data for the RICE exhaust stacks indicated that the measured O₂, CO₂, and NO_x concentrations did not vary by more than 5% of the mean across the stack diameter. Therefore, the RICE exhaust gas was considered to be unstratified and the compliance test sampling was performed at a single sampling location within each RICE 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 metering console was calibrated using a NIST traceable Omega® Model CL 23A temperature calibrator.

Appendix 6 presents test equipment quality assurance data (NO₂ – NO conversion efficiency test data, instrument calibration and system bias check records, calibration gas certifications, interference test results, meter box calibration records, and field equipment calibration records).

6.0 Results

6.1 Test Results and Allowable Emission Limits

Engine operating data and air pollutant emission measurement results for each one-hour test period are presented in Table 6.1.

EUENGINE3 has the following allowable emission limits specified in PTI No. 579-95F:

- 2.0 g/bhp-hr and 17.13 tons/year for CO;
- 1.0 g/bhp-hr and 11.88 tons/year for NO_x;
- 0.7 g/bhp-hr for VOC.

The measured air pollutant concentrations and emission rates for EUENGINE3 are less than (in compliance with) the allowable limits specified in PTI No. 579-95F.

6.2 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. The RICE was operated at maximum routine operating conditions throughout the test program.

There were times where the exhaust gas oxygen content measured by the analyzer was greater than the original instrument calibration span. After discussion with Robert Dickman of EGLE it was decided to challenge the instrument with a calibration gas at the end of the test periods (during the post-test calibration check) that was higher than the highest recorded oxygen content. This verified instrument accuracy and linearity throughout the actual measurement range of the instrument.

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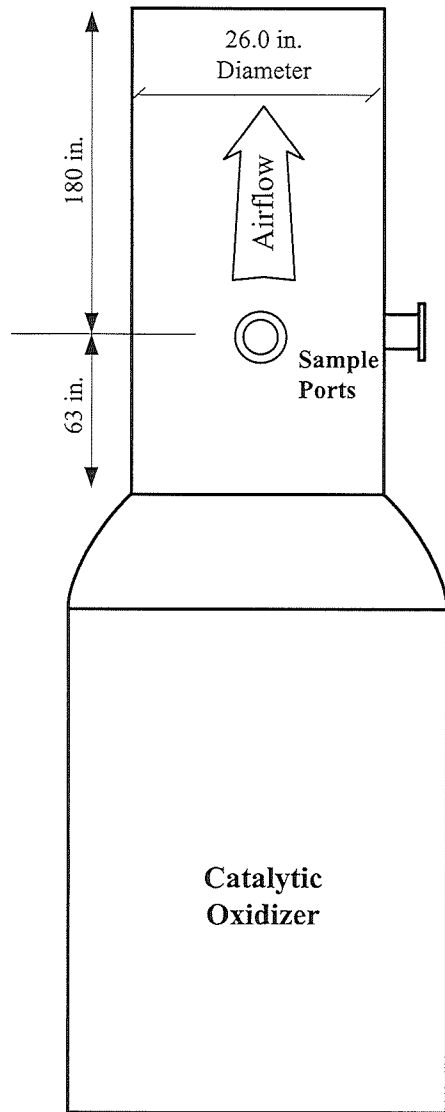
Table 6.1 Measured exhaust gas conditions and air pollutant emission rates for Engine No. 3 (EUENGINE3)

Test No.	1	2	3	
Test date	02/16/2022	02/16/2022	02/16/2022	Three Test
Test period (24-hr clock) ¹	0816-0931	1005-1105	1138-1238	Average
Engine rotation (RPM)	812	811	813	812
Calculated engine output (bhp)	2,884	2,878	2,885	2,883
Engine load (%)	87	87	86	87
Engine fuel use (scfm)	290	289	289	289
Catalyst inlet temperature (°F)	739	738	739	738
<u>Exhaust Gas Composition</u>				
CO ₂ content (% vol)	5.3	5.2	5.3	5.3
O ₂ content (% vol)	12.2	13.3	12.5	12.7
Moisture (% vol)	9.7	8.6	9.9	9.4
Exhaust gas temperature (°F)	638	639	636	638
Exhaust gas flowrate (dscfm)	6,291	6,361	6,328	6,326
Exhaust gas flowrate (scfm)	6,969	6,961	7,025	6,985
<u>Nitrogen Oxides</u>				
NO _x conc. (ppmvd)	27.3	27.4	27.6	27.5
NO _x emissions (lb/hr)	1.23	1.25	1.25	1.25
NO _x emissions (tpy)	5.40	5.48	5.49	5.46
Permit Limit (tpy)	-	-	-	18.11
NO _x emissions (g/bhp-hr)	0.19	0.20	0.20	0.20
Permit Limit (g/bhp-hr)	-	-	-	1.0
<u>Carbon Monoxide</u>				
CO conc. (ppmvd)	118	118	119	119
CO emissions (lb/hr)	3.25	3.29	3.30	3.28
CO emissions (tpy)	14.2	14.4	14.4	14.4
Permit Limit (tpy)	-	-	-	17.13
CO emissions (g/bhp-hr)	0.51	0.52	0.52	0.52
Permit Limit (g/bhp-hr)	-	-	-	2.0
<u>Volatile Organic Compounds</u>				
VOC conc. (ppmv as C ₃)	73.4	73.4	74.0	73.6
VOC emissions (lb/hr)	3.52	3.51	3.57	3.53
VOC emissions (g/bhp-hr)	0.55	0.55	0.56	0.56
Permit Limit (g/bhp-hr)	-	-	-	0.7

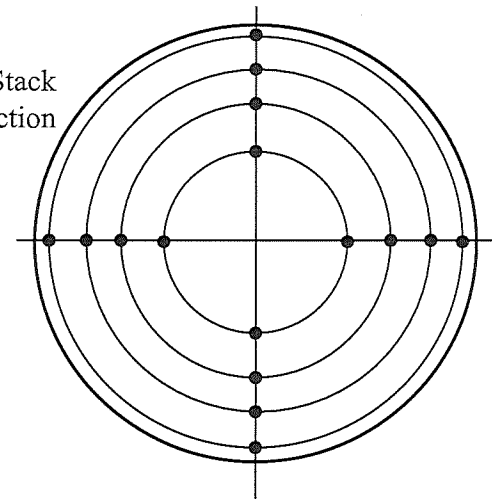
1. Each test period is one hour in duration, except that Test 1 was extended to complete the moisture sampling, which started late due to equipment issues.

APPENDIX 1

- RICE Engine Sample Port Diagram



Exhaust Stack Cross-Section



Velocity sample locations as measured from stack wall (not including 1.25" sample port)

Pt. #	in.
1	0.83
2	2.73
3	5.04
4	8.37
5	17.6
6	21.0
7	23.3
8	25.2

7/18/2017 ALR	Attachment 1 – Core Energy, LLC Engine No. 3 Sampling Location		
	Scale None	Sheet 1 of 1	ICT