EXECUTIVE SUMMARY

RWDI USA LLC (RWDI) was retained by Hyundai-Kia America Technical Center (HATCI) to complete the source testing program located in Superior Township, Michigan. HATCI operates engine test cells under the Flexible Group FG-Dynos. Under FG-Dynos, there are four 4) noted Emission Units noted as EU-Dyno1, EU-Dyno2, EU-Dyno3 and EU-Dyno4. Testing was performed at a representative (single cell) test cell exhaust of EU-Dyno4. The test program was conducted to fulfill the requirements of the Renewable Operating Permit (ROP) MI-ROP-N7886-2020. The test included measurements of total oxides of nitrogen (NOx) and carbon monoxide (CO) under controlled and uncontrolled condition. These emissions were calculated for each condition and based on sampling of three (3) 1-hour tests with each test spanning different engine cycles within a 60 minute test run. And lastly, exhaust air flow rate was determined at the exhaust test ports.

All testing was conducted on November 12th, 2020.

The following table represents a summary of the stack testing results.

EU-Dyno4 Controlled Condition

	Symbol	Units	Test #1	Test #2	Test #3	Average	ROP EF
Nitrogen Oxides Concentration	NO_x	ppmvd	0.4	0.4	0.4	0.4	-
Carbon Monoxide Concentration	CO	ppmvd	43.8	45.9	49.3	46.3	-
Oxygen Concentration	O_2	%	20.8	20.9	20.8	20.8	-
Nitrogen Oxides Concentration	NO_x	g/kW-hr	0.1	0.2	0.2	0.1	-
Carbon Monoxide Concentration	CO	g/kW-hr	9.26	9.75	10.48	9.83	-
Nitrogen Oxides Concentration	NO_x	lb NOx/gal	0.0037	0.0038	0.0038	0.0038	0.091
Carbon Monoxide Concentration	CO	lb CO/gal	0.232	0.244	0.263	0.246	0.292

EU-Dyno4 UnControlled Condition

	Symbol	Units	Test #1	Test #2	Test #3	Average	Limits
Nitrogen Oxides Concentration	NO_x	ppmvd	16.6	16.3	16.9	16.6	-
Carbon Monoxide Concentration	CO	ppmvd	899.5	900.4	915.4	905.1	-
Oxygen Concentration	O_2	%	20.6	20.6	20.8	20.7	-
Nitrogen Oxides Concentration	NO_x	g/kW-hr	3.6	3.5	3.7	3.6	-
Carbon Monoxide Concentration	CO	g/kW-hr	119.47	119.19	122.28	120.31	-
Nitrogen Oxides Concentration	NO_x	lb NOx/gal	0.078	0.077	0.081	0.079	0.20
Carbon Monoxide Concentration	CO	lb CO/gal	2.59	2.59	2.66	2.62	5.09

1 INTRODUCTION

RWDI USA LLC (RWDI) was retained by Hyundai-Kia America Technical Center (HATCI) to complete the source testing program located at Superior Township, Michigan. The HATCI research and development facility operates four (4) engine dynamometer test cells to develop, characterize, and test four-cylinder vehicle engines. The test program was conducted in order to fulfill the requirements of the Renewable Operating Permit (ROP) MI-ROP-N7886-2020. The test program included measurements of total oxides of nitrogen (NOx and carbon monoxide (CO) on EU-Dyno4 for both uncontrolled and controlled operating scenarios as defined in the approved test protocol. See Appendix A for the Test Protocol and State of Michigan Department Environment, Great Lakes & Energy (EGLE) Correspondence. Emissions from the test cell vary depending on the type of engine testing load profile. Exhaust air flow rate was determined for both conditions during each of the tests. Testing was conducted on November 12th, 2020. Results from the sampling program are presented in the **Tables Section** of the report, with more detailed sampling results provided in the **Appendices**.

A test protocol for this testing program was submitted on October 12th, 2020 to the Michigan Department of Environment, Great Lakes, and Energy (EGLE) for their review. Approval for the testing program was granted by EGLE on November 6th, 2020. Copies of the approval letter and related correspondence are provided in **Appendix A**.

This stack testing study consisted of the following parameters:

- Velocity, flow rate and temperature;
- Nitrogen oxides (NO_X);
- Carbon Monoxide (CO);
- Oxygen (O_2) and;
- Moisture (%).

2 SOURCE DESCRIPTION

2.1 Facility Description

The HATCI research and development facility operates four engine dynamometer test cells to develop, characterize, and test four-cylinder vehicle engines that combust unleaded gasoline and ethanol. The tested engines are primarily four-cylinder design and combust unleaded gasoline. Emissions from the test cells vary based on the type of engine and engine test cycle. During this emissions test program, a representative engine was tested under varying speed and load conditions representing daily operational engine testing. All engines are equipped with a catalytic converter that controls engine exhaust before venting into the atmosphere. The load profile used for every test run is detailed in **Figure 1**.

For the purposes of the testing plan, exhaust from the test cell EU-Dyno4 was measured and tested for CO and NOx to determine compliance with the air permit. Testing was performed on FG-Dyno dynamometer#4 (EU-Dyno4) single exhaust stack in controlled and uncontrolled mode either using unleaded gasoline.

No	Speed	Load (BMEP)	Sample	
	rpm	bar	Minutes	Note:
0	1500	2.00	N/A	Standard Engine Warm-up until Coolant and Oil reach 90 Deg. C
1a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point/Start Stack Sampling
1	1600	4.00	5.00	Engine at point
2a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
2	1600	5.00	5.00	Engine at point
3a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
3	1800	4.00	5.00	Engine at point
4a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
4	2000	4.00	5.00	Engine at point
5a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
5	2000	5.00	5.00	Engine at point
6a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
6	2000	6.00	5.00	Engine at point
7a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
7	2400	4.00	5.00	Engine at point
8a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
8	2500	4.00	5.00	Engine at point
9a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
9	3000	5.00	5.00	Engine at point
10a	Speed/Load Change		1.00	Engine set-point change/Stabilization to Point
10	6300	WOT	5.00	Engine at point/End Stack Sampling/Datalogging at end of point
EOT		Total Time	60.00	

Figure 1: Engine test load profile (2.5L)

3 SAMPLING LOCATION

3.1 Sample Location Description

The sampling locations for each source is located outside. Engine emissions operating in the EU-Dyno4 test cell are directed down through the floor of the room and into a duct that connects to a fan that exhausts to the atmosphere through a stack, SV-4, on the roof. Exhaust was analyzed for CO, O_2, NOx, flows and moisture. Samples were extracted from sampling ports in the exhaust stack. The nearest upstream and downstream disturbances met the minimum distance criteria specified in EPA Method 1. **Figure 2** shows the approximate location of the exhaust sampling test ports.

Figure 2: Photo of Stack Location

The sampling point selection and stratification test was performed in accordance with EPA Reference Method 7E section 8.1.2. (applicable to instrumental analyzer methods).

4 SAMPLING METHODOLOGY

The following section provides an overview of the sampling methodologies used in this program. **Table 1**, located in the **Tables Section**, summarizes the testing parameters and corresponding methodologies.

4.1 Stack Velocity, Temperature, and Volumetric Flow Rate Determination

The exhaust velocities and flow rates were determined following the US EPA Method 2, "Determination of Stack Gas Velocity and Flow Rate (Type S Pitot Tube)". Velocity measurements were taken with a pre-calibrated S-Type pitot tube and incline manometer. Volumetric flow rates were determined following the equal area method as outlined in US EPA Method 1. Temperature measurements were made simultaneously with the velocity measurements and will be conducted using a chromel-alumel type "k" thermocouple in conjunction with a digital temperature indicator.

The dry molecular weight of the stack gas was determined following calculations outlined in US EPA Method 3, "Determination of Molecular Weight of Dry Stack Gas". Stack moisture content was determined using an extractive Fourier Transform Infrared (FTIR) spectroscopy and according to US EPA Method 320, "Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR Spectroscopy)". Moisture was collected at a single point during each test.

4.2 Continuous Emissions Monitoring for O_2, CO and NOx

Testing for O_2, CO and NO_X were accomplished using continuous emission monitors (CEM) system and the FTIR. The exhaust gas sample was sampled by drawing a sample stream of flue gases through a heated stainless steel probe attached to a heated filter and a heated sample line that is attached to the Automated Sampling Console (ASC-10ST). The ASC-10ST sampling console delivers a continuous sample to the MKS MultiGas 2030 FTIR for analysis. The heated filter and line were maintained at approximately 375°F and the MKS MultiGas 2030 FTIR and MAX Analytical ASC-10ST gas components were at 375ºF. The end of the probe was connected to a heated Teflon sample line, which delivers the sample gases from the stack to the FTIR system. The heated sample line was maintained at 375°F in order to prevent condensation of stack gas moisture within the line. The sample was then routed through a manifold system and introduced to the individual CEM's for measurement. As recommended by EGLE, the sample line and heated filter were heated to 375ºF.

Oxygen measurements were taken continuously following USEPA Method 3A on the outlet (using a wet oxygen analyzer or equivalent). A schematic of the sampling system setup is depicted in **Figure 3**.

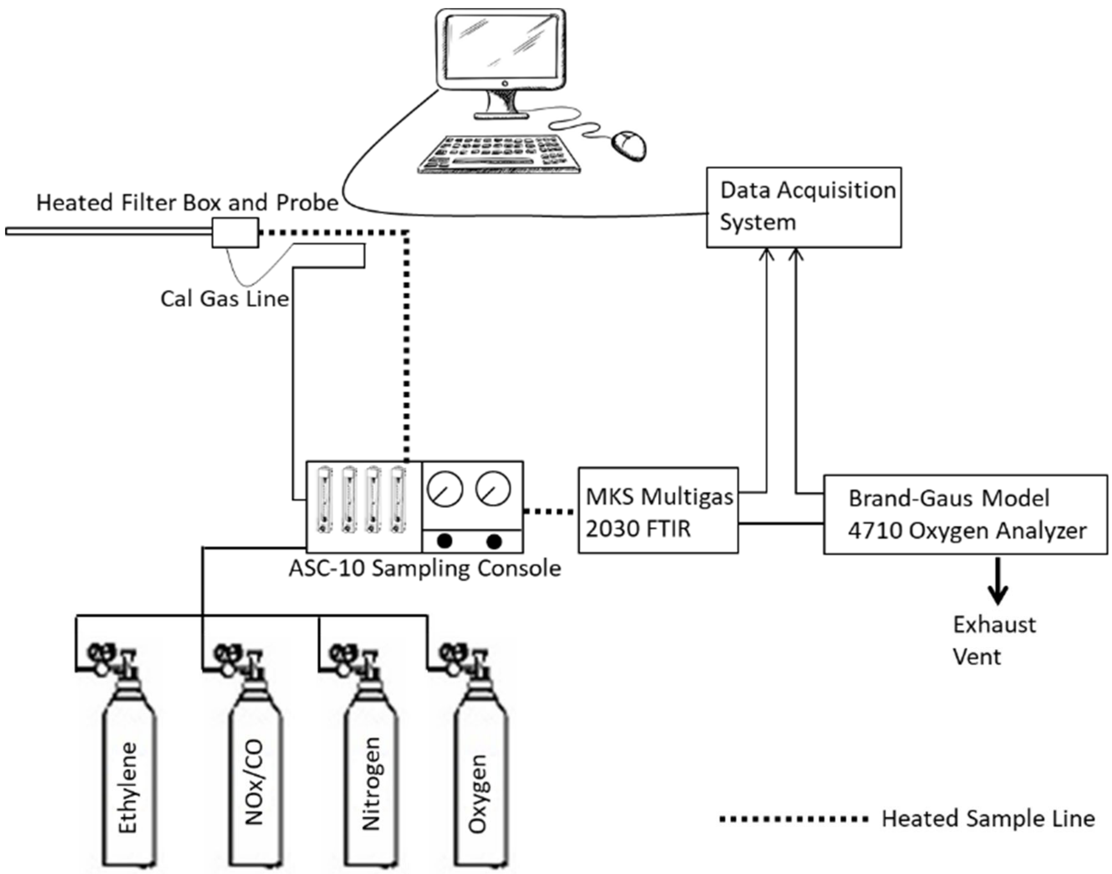

Figure 3: MKS 2030 Multigas FTIR/ASC-10ST/Model 4710 Oxygen analyzer sampling system schematic

The ASC-10ST was used to deliver calibration gases (Calibration Transfer Standard (CTS), QA Spike and Nitrogen) to the FTIR in direct (to analyzer) and system (to probe) modes.

A laptop computer was utilized for operating the MKS MultiGas 2030 FTIR and MAX Analytical ASC-10ST sampling console and logging the multi-gas FTIR data. Data was logged as one minute averages for the actual test period (FTIR PRN files and Spectra). All concentration data were determined using the MKS 2030 MultiGas FTIR software. A typical MKS 2030 FTIR and ASC-10 ST configuration is depicted in **Figure 4**.

For oxygen measurement, prior to testing, sample system bias checks and instrument linearity checks (calibration error) were completed. A data logger system programmed to collect and record data at 1- second intervals was used to compute and record one-minute average concentrations.

The calibration error check was performed by introducing zero, mid and high level calibration gases directly into the analyzer. The calibration error check was performed to confirm that the analyzer response is within ±2% of the certified calibration gas introduced. In addition, the analyser was calibrated (zeroed and span checked) at the completion of each run. Prior to each test run, a system-bias test was performed where known concentrations of calibration gases will be introduced at the probe tip to measure if the analyzers response will be within ±5% of the introduced calibration gas concentrations. At the conclusion of each test run a system-bias check was performed to evaluate the percent drift from pre and post-test system bias checks. The system bias checks were used to confirm that the analyzer did not drift greater than ±3% throughout a test run. The analyzer measured the respective gas concentrations on a wet volumetric basis which was then mathematically converted to a dry volumetric number within the MKS MultiGas FTIR software.

Figure 4: MKS MultiGas 2030 FTIR and ASC-10ST

4.3 Quality Assurance/Quality Control Activities

Applicable quality assurance measures were implemented during the sampling program to ensure the integrity of the results. These measures included detailed documentation of field data, equipment calibrations for all measured parameters, completion of Chain of Custody forms when submitting laboratory samples, and submission of field blank samples to laboratories, where applicable.

Quality control procedures specific to the CEM monitoring equipment included linearity checks to determine the instrument performance and reproducibility checks prior to its use in the field. Regular performance checks on the analyser were also carried out during the testing program by performing hourly zero checks and span calibration checks using primary gas standards. Sample system bias checks were also conducted prior to and after each test run. These checks were used to verify the ongoing accuracy of the monitor and sampling system over time. Pollutant-free (zero) air was introduced to perform the zero checks, followed by a known calibration (span) gas into the monitor. The response of the monitor to pollutant-free air and the corresponding sensitivity to the span gas were recorded regularly during the tests.

Leak checks were performed on the sampling system by plugging the sample inlet and pulling a representative vacuum. This check was done before and after each test. Similar leak check procedures for pitot tube and pressure lines were also conducted. Daily temperature sensor audits were completed by noting the ambient temperature, as measured by a reference thermometer, and comparing these values to those obtained from the stack sensor.

The FTIR test method follows the US EPA Method 320 test procedures. The primary control check for the FTIR (EPA Method 320) is a Calibration Transfer Standard (CTS) check which was performed before and after each test run.

Initial background spectrum using dry nitrogen gas was obtained per Section 8.5 of EPA Method 320. A CTS was performed pre-test using procedures outlined in Section 8.6.1 of EPA Method 320. A post-test CTS per source was also performed. CTS result averages were measured to be within ±5% of the calibration gas standard.

In addition, a known calibration spike was introduced into the FTIR once per day for the source to confirm the FTIR is working properly and verify the ability to quantify the target analytes in the presence of the stack gas. Three replicate data sets of QA spike was measured during the testing period.

A known calibration spike gas will be introduced prior to the first run to measure FTIR analyzer response as part of the quality assurance (QA) spiking procedure. The FTIR analyzer response will need to be between 70% and 130% of the expected value and as such determined to be acceptable (Section 8.6.2 of EPA Method 320 requires the average QA spiked percent recovery to be between 70% and 130%). Results of this procedure are provided in Appendix B.

CO/NOx (mixed with SF_6 as a tracer) were used as the spiked recovery gas for CO/NOx testing. Also, ethylene was used as the CTS gas.

Finally, the off-site QA/QC included a data review and a data comparison using MKS "Method Analyzer" software. Method validation was conducted for each test run by pulling a random spectrum sample and results have been included in the appendices.

5 RESULTS

The flow and emissions data for this study are presented in the '**Tables**' section of this report. Detailed information regarding each test run can be found in the corresponding appendix. Below is a summary of the applicable Table ID for each corresponding test parameter.

Parameter	Table	Appendix
Stack Gas Characteristics	3 & 4	B and C
Nitrogen Oxides	1 & 2	B
Carbon Monoxide	1 & 2	B
Oxygen	1 & 2	B

Field notes are presented in **Appendix D**. All calibration information for the equipment used for the program is included in **Appendix E**.

5.1 Discussion of Results

The measured concentrations for all contaminants were less than the maximum limits outlined in Michigan Department of Environmental Quality (MDEQ) ROP MI-ROP-N7886-2020.

Results for CO and NOx for both controlled and uncontrolled conditions are lower in comparison to the emissions factors used to develop the permit. See Section 5.1 tables for a summary of the testing results for both controlled and uncontrolled operating scenarios.

For controlled condition, the engine load profile erroneously included wide open throttle (WOT), which is defined in HATCI ROP FG-Dynos Special Condition IV.2 as being uncontrolled. After consulting and receiving approval with the EGLE representative Mr. Mark Dziadosz on site regarding WOT operations during the controlled operating scenario, all test runs were conducted with the last load step no.9 at 3000RPM and 5BMEP (brake mean effective pressure) being extended for an extra 5 minutes to complete the 60 minute test run. By completing all test runs under controlled condition and all emissions routed through the catalytic converter, the emission results are representative of the controlled operating scenario.**EU-Dyno4 Controlled Condition**

	Symbol	Units	Test #1	Test #2	Test #3	Average	ROP EF
Nitrogen Oxides Concentration	NO_x	ppmvd	0.4	0.4	0.4	0.4	-
Carbon Monoxide Concentration	CO	ppmvd	43.8	45.9	49.3	46.3	-
Oxygen Concentration	O_2	%	20.8	20.9	20.8	20.8	-
Nitrogen Oxides Concentration	NO_x	g/kW-hr	0.1	0.2	0.2	0.1	-
Carbon Monoxide Concentration	CO	g/kW-hr	9.26	9.75	10.48	9.83	-
Nitrogen Oxides Concentration	NO_x	lb NOx/gal	0.0037	0.0038	0.0038	0.0038	0.091
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EU-Dyno4 UnControlled Condition

	Symbol	Units	Test #1	Test #2	Test #3	Average	Limits
Nitrogen Oxides Concentration	NO_x	ppmvd	16.6	16.3	16.9	16.6	-
Carbon Monoxide Concentration	CO	ppmvd	899.5	900.4	915.4	905.1	-
Oxygen Concentration	O_2	%	20.6	20.6	20.8	20.7	-
Nitrogen Oxides Concentration	NO_x	g/kW-hr	3.6	3.5	3.7	3.6	-
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Nitrogen Oxides Concentration	NO_x	lb NOx/gal	0.078	0.077	0.081	0.079	0.20
Carbon Monoxide Concentration	CO	lb CO/gal	2.59	2.59	2.66	2.62	5.09

6 OPERATING CONDITIONS

Operating conditions during the sampling were monitored by HATCI Operations. HATCI Operations recorded the power output (either HP or kW), fuel usage (gallons), fuel consumption rate (g-kW-hr), test cell atmospheric pressure (kPa), engine speed (RPM), engines torque (ft-lb), catalyst temperature (inlet and outlet, if available) and air to fuel ratio. All process data is provided in **Appendix F**.

Radio contact was maintained between the process operators and the sampling team throughout the testing. A member of the RWDI sampling team contacted the operator before each test, to ensure that the process was at normal operating conditions.

7 CONCLUSIONS

Testing was successfully completed on November 12th of 2020. All sources were tested in accordance with referenced methodologies following the EGLE approved test protocol.

All specified pollutants were quantified using methods set forth 40 CFR 60 Part A and measured concentrations were within compliance limits.