Final Report

Validation of the New PM Index Formula: Vehicle Testing Phase

Project RW-107-3

Submitted to:

Coordinating Research Council
5755 North Point Parkway, Suite 265
Alpharetta, GA 30022
Attention: Amber Leland

April 2023

POWERTRAIN ENGINEERING DIVISION

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Southwest Research Institute® Final Report
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FOREWORD

This report covers testing conducted by Southwest Research Institute (SwRI) for Coordinating Research Council (CRC). The Project, performed under CRC contract RW-107-3, was performed between October of 2020 and February of 2022. The project was based on SwRI's technical proposal to CRC dated October 13, 2020. The internal SwRI project number was 03.26322. The CRC project oversight was led by Amber Leland. The SwRI project manager was Matt Blanks, assisted in testing and development by Peter Lobato and Michael Kader. Laboratory emissions testing were overseen by David Zamarripa. Tim Martinez was the driver for all tests and Kevin Hohn operated the chassis dynamometer and laboratory emissions equipment for this project. All fuel-related and mileage accumulation tasks were managed by Kevin Brunner. This report provides the basic test results and documents the technical effort required to collect the data. Statistical conclusions relating test results to fuel PMI are given in the CRC report for Project RW-107-3a, prepared under a separate CRC contract with Rincon Ranch Consulting, and are not presented in this report.

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1.0 EXECUTIVE SUMMARY

This report documents a project conducted by Southwest Research Institute (SwRI) on behalf of Coordinating Research Council (CRC). The project investigated exhaust particulate emissions from a matrix of vehicles and fuels to validate a new Particulate Matter Index (PMI) formula. This project was conducted in parallel with CRC Projects E-122-2 and E-133 to take advantage of commonalities. LA92 Phase 1 emissions were collected during those projects and are presented in this report. This project was not designed as a stand-alone project; the objective was to provide a fresh, independent dataset for the purpose of validating the new PMI formula developed in CRC Project RW-107-2. The PMI formula validation work was performed by Rincon Ranch Consulting under CRC Project RW-107-3a.

This project evaluated exhaust emissions from four light-duty vehicles using thirteen test fuels. Six of the fuels were commercially available market fuels and six of the fuels were produced by splash blending ethanol with a market fuel to produce new E10 and E15 fuels. The last fuel was an emissions-grade certification gasoline. The matrix of fuel-vehicle combinations was evaluated based on the Design Of Experiments (DOE) initially determined under E-122-2 and E-133. Many of the test fuels were also procured under E-122-2 and E-133. With guidance provided by the CRC committee, SwRI oversaw procurement of two new market fuels and two new splash-blended fuels unique to this project.

The four test vehicles were procured under E-122-2. The vehicles were selected to include targeted engine and vehicle technologies. One vehicle was provided by CRC and the other three were procured by SwRI from local dealerships. New vehicles were driven on milage accumulation dynamometers (MADS) to an odometer reading of 4,000 miles. The oil and oil filter were changed on all vehicles and 500 miles was accumulated to de-green the new oil before emission tests were conducted. Results in this report are blinded to vehicle identifications.

Duplicate cold-start LA92 drive cycles were used for each fuel-vehicle combination with a third test conducted if repeatability of the first two tests did not meet predetermined criteria. Approximately 144 cold-start chassis dynamometer emission tests were conducted for this project. Figure 1 shows vehicle particulate mass (PM) emissions compared to the fuel PMI value. All vehicles gave an increasing trend in particulate mass with increasing fuel PMI, although, statistical analysis was not conducted to evaluate significance of the trends.

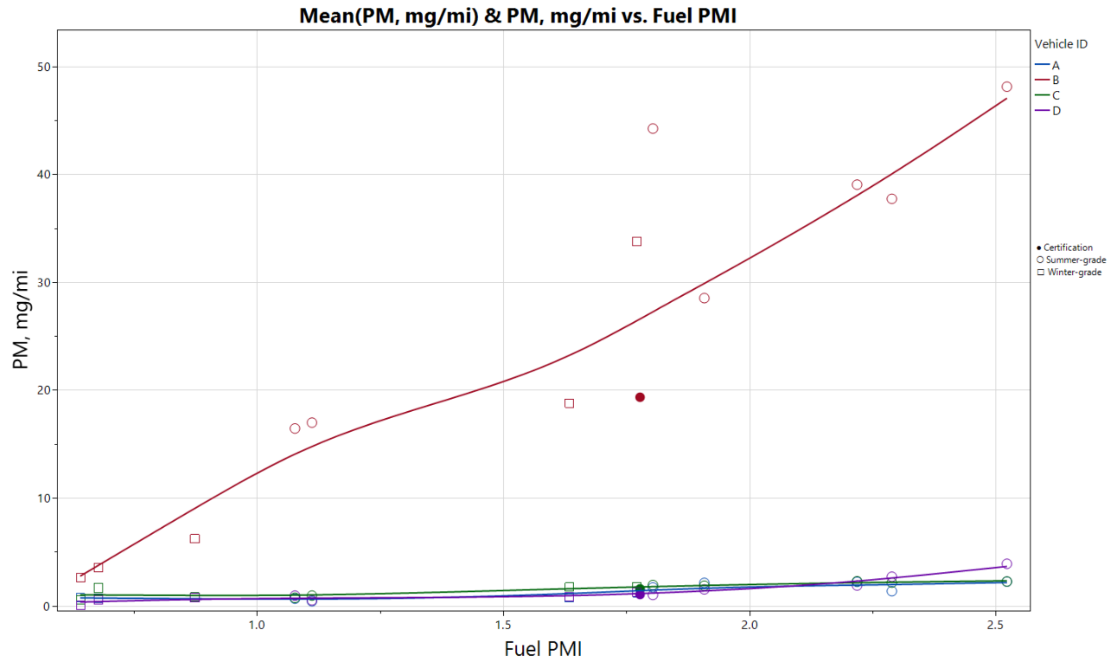

FIGURE 1. LA92 PHASE 1, PM EMISSIONS VS FUEL PMI

2.0 INTRODUCTION

A previous CRC Project, RW-107, revealed that the original Particulate Matter Index (PMI) exhibited an ethanol bias. A more robust PMI formulation was developed in CRC project RW-107-2, in which correlation with measured PM was improved, and the ethanol bias eliminated. The new formulation incorporated multiple enhancements. A fresh dataset is required to validate this new form of the PM Index equation, preferably including a range of PMI values, vehicle technologies, and fuel formulations. The project was initiated on October 20, 2020 and official testing began on October 28, 2020. Testing with the final fuel concluded over two years later, January 17, 2022.

3.0 PROJECT SETUP

All tests were conducted at SwRI's light-duty vehicle laboratory. Tim Martinez was the driver and Kevin Hohn operated the test facility and laboratory emissions equipment for the entire project. The following sections detail test fuels, test vehicles, and the emission test procedure.

3.1 Test Fuels

Five of the test fuels were located and procured under CRC Project E-122-2. Four of these fuels were market fuels, comprised of summer and winter grades, each having a low and high Particulate Matter Index (PMI). For this project, a PMI rating of 1.0 was considered low and a rating of 2.0 was considered high. Although not all collinearities in fuel properties were investigated, PMI was highly correlated with back-end distillation (especially final boiling point). Thus, trends observed in this data for a response variable (such as PM emissions) over the range of PMI investigated may be due to PMI, or to one or more other correlated properties.

Emissions-grade certification fuel was also procured from Haltermann Solutions under that project. All market fuels were 87 Anti-Knock Index (AKI) E10 regular unleaded (RUL), except for the winter-grade, high PMI fuel. This fuel was a 93 AKI E10 premium unleaded (PUL), because a RUL winter-grade fuel, meeting the Reid Vapor Pressure (RVP) and PMI requirements, could not be located. The PUL fuel was supplied by a major refiner unadditized but was additized at the minimum TOP TIER® treat rate before use. The four E10 market fuels were then splash blended with ethanol to E15, under CRC Project E-133, to give nine initial fuels. Acquisition of these market fuels occurred over a one-year period since no winter fuels of the desired PMI level were located within the 2020 high vapor pressure season.

With assistance from CRC members, two new fuels were identified and procured specifically for this project. The first was a summer-grade, high PMI E0, that was procured from a CRC member refinery terminal. The second was a winter-grade, low PMI E0, that was procured from a different CRC member refinery terminal. Each of these E0 fuels were RUL with an AKI of 88. SwRI arranged to transport these fuels using a tanker truck that was steam-cleaned, dried, and inspected before being sealed and dispatched to acquire the fuel. Figure 1 shows examples of seals installed on a tanker truck after being inspected by SwRI. Upon arrival at SwRI, a sample of each fuel was drawn from the tanker and analyzed for key fuel properties. After approval, the fuel was offloaded into pre-inspected epoxy-phenolic lined drums and stored at 70 ºF. Portions of the summer-grade, high PMI E0 were then splash blended to make both an E10 and an E15 test fuel. Results of the key properties from each fuel are shown in Table 1. Fuels J, K, L, and M are the fuels acquired specifically for this project. Detailed analysis results and a full description of the fuel procurement process are given in Appendix A.

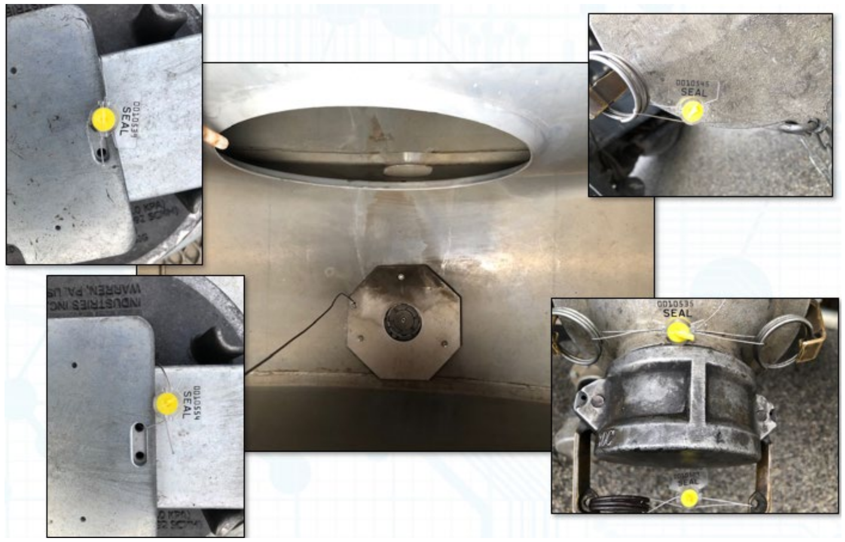

FIGURE 2. FUEL TANKER INSPECTION AND SEALS

TABLE 1. ANALYSIS RESULTS OF KEY FUEL PROPERTIES

ID	Code	Description	Ethanol, vol% (ASTM D4815 / D5599)	PMI (ASTM D6729)	RVP, PSI (ASTM D5191)	FBP, °F (ASTM D86)	Total Aromatics, wt% (ASTM D6729)	Notes
A	EM-10967	Certification E10	9.7	1.8	9.2	388	27.6	EPA Tier 3 EEE
B	GA-10940	Summer Low PMI E10	9.7	1.1	9.0	367	24.4	
C	GA-10920	Summer High PMI E10	9.5	1.9	7.7	408	33.2	
D	GA-11027	Winter Low PMI E10	9.6	0.7	15.3	344	25.8	
E	CGB-11093	Winter High PMI E10	10.2	1.8	13.6	392	32.7	PUL
F	CGB-11037	Summer Low PMI E15	15.2	1.1	8.8	373	23.8	Fuel B + Ethanol Splash Blend
G	CGB-11039	Summer High PMI E15	15.0	1.8	7.6	395	31.9	Fuel C + Ethanol Splash Blend
H	CGB-11156	Winter Low PMI E15	15.3	0.6	14.2	344	17.3	Fuel D + Ethanol Splash Blend
I	CGB-11149	Winter High PMI E15	15.3	1.6	13.3	396	30.2	Fuel E + Ethanol Splash Blend
J	GA-10950	Summer High PMI E0	<0.2	2.5	8.7	427	43.1	
K	GA-11026	Winter Low PMI E0	<0.2	0.9	14.5	361	26.1	
L	CGB-11147	Summer High PMI E10	10.1	2.3	9.4	417	38.8	Fuel J + Ethanol Splash Blend
M	CGB-11148	Summer High PMI E15	15.1	2.2	9.4	421	37.2	Fuel J + Ethanol Splash Blend

3.2 Test Vehicles

Four vehicles were used in this project. CRC supplied one vehicle and SwRI purchased the other vehicles from local dealerships under CRC Project E-122-2. Table 2 gives a description of each vehicle listing key properties that were targeted for each selection. These technologies include Port Fuel Injection (PFI), Direct Injection (DI), turbo charging, electric hybrid, and engine Start/Stop.

Along with vehicle descriptions, this section discusses vehicle-specific topics that include the following:

- Tasks performed with each vehicle after purchase
- Initial checkout tests and results
- Problems encountered with individual vehicles while testing

TABLE 2. TEST VEHICLES

Test ID	A	B	C	D
Year	2019	2013	2019	2019
Engine Type	PFI NA	DI Turbo	PFI NA	PFI NA
Transmission	6-Speed AT	6-Speed AT	9-Speed AT	e-CVT
Fuel Type	Premium Gasoline (recommended)	Regular Gasoline	Regular Gasoline	Regular Gasoline
Flex Fuel	No	No	No	No
Start/Stop	No	No	Yes	Hybrid
EPA Cert	T3B125 LDV	T2B5 LDV	T3B30 LDT	T3B30 LDV
CA Cert	ULEV125 PC	ULEV II PC	SULEV30 LDT	SULEV30 PC
Weight with Empty Tank, lbs	4,096	3,677	4,320	3,324

After purchase, the following tasks were performed with each vehicle.

- Each vehicle was added to SwRI's test vehicle insurance policy
- New vehicles were driven to a 4,000-mile odometer reading on a chassis dynamometer using the US EPA Standard Road Cycle (SRC) drive profile and E10 RUL gasoline
- The oil was changed and 500 miles of the SRC was accumulated for oil degreening using RUL E10 gasoline
- Reports were run to check for powertrain recalls, TSBs (Technical Service Bulletins), DTCs (Diagnostic Trouble Codes), and required vehicle software updates
- The coolant freeze-point and fill level were checked
- Tires were inspected

3.2.1 Emissions Verification Test

Prior to the start of testing, each vehicle was flushed with certification-grade fuel and tested over a single FTP-75 cycle to determine if the vehicle's emission control system was working properly. Regulated emissions (Non-Methane Hydrocarbons (NMHC), CO, CO_2, NO_X, and PM) were measured and provided to CRC for final approval of the vehicles. All vehicles produced emissions well below their certification level. Table 3 gives the results from each checkout test.

TABLE 3. CHECKOUT EMISSION RESULTS

			CO, g/mi	NMOG+NOx, g/mi	PM, mg/mi
Vehicle A	EPA Tier 3 Bin 125 Certification Standard		2.1	0.125	3
	FTP-75 Checkout Results		0.26	0.029	0.7
Vehicle C	EPA Tier 3 Bin 30 Certification Standard		1	0.03	3
	FTP-75 Checkout Results		0.334	0.005	0.6
Vehicle D	EPA Tier 3 Bin 30 Certification Standard		1	0.03	3
	FTP-75 Checkout Results		0.12	0.017	0.6
		NMOG, g/mi	CO, g/mi	NO_X, g/mi	PM, mg/mi
Vehicle B	EPA Tier 2 Bin 5 Certification Standard	0.09	4.2	0.07	10
	FTP-75 Checkout Results	0.027	0.195	0.024	4.9

3.2.2 Test Vehicle Issues

Several problems were encountered with individual vehicles early in the program. All problems were overcome, and void tests were repeated when necessary. This section describes each problem and the resulting solution.

During the first test set, Vehicle D did not operate correctly in hybrid vehicle mode (HV) as originally planned. Instrumentation installed to measure tractive battery voltage triggered a fault code and forced the vehicle to operate in charge depleting mode (EV) rather than HV. Those tests were repeated during the second interval with that particular fuel (Fuel B). Additionally, Vehicle D experienced an HEV fault during one of the LA92 tests and could not complete the cycle. This test was also repeated.

Vehicle C's engine start/stop feature did not function properly for the first set of tests. The team investigated and found that start/stop would not operate correctly when driven on a two-wheel drive chassis dynamometer. SwRI installed circuitry to measure the wheel speed from the front wheels and emulate the measured speed to the ECU, in place of the rear wheel speed sensors. This temporarily allowed start/stop to function correctly; however, start/stop would revert to being inoperable after one or two tests on the dynamometer. This problem was remedied by using OEM software to initiate vehicle rolls mode. This allows for start/stop to operate correctly on the dynamometer. Tests conducted with start/stop inoperable were rerun.

3.3 Test Cycle

A 3-Phase cold-start LA92 drive schedule was used for all tests in this project. Figure 2 shows the first two phases of this schedule. The LA92 is run in the following manner: Phase 1 and Phase 2 are run consecutively, followed by a ten-minute hot soak, then Phase 3 is run, which is a duplicate of Phase 1. Only Phase 1 particulate emissions data was measured and used for the PMI model validation, however, gaseous emissions from all three phases were measured.

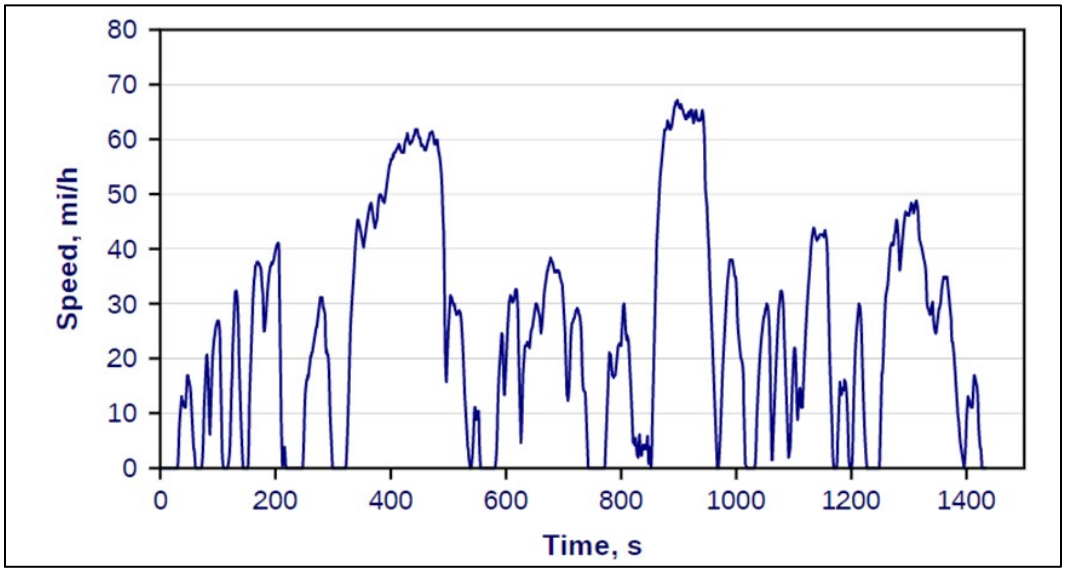

FIGURE 3. PHASE 1 AND 2 OF THE LA92 DRIVE CYCLE

3.4 Chassis Dynamometer

Emissions testing was conducted on a Horiba 48-inch single-roll chassis dynamometer. The dynamometer can electrically simulate inertia weights up to 15,000 lb over the FTP-75, and provide programmable road-load simulation of up to 200 hp continuous at 65 mph. SwRI derived set road load coefficients using inertia settings and target road-load coefficients from the EPA database for each test vehicle. Table 4 gives the target and derived set road-load coefficients for each vehicle. The same chassis dynamometer and driver were used for all testing in this project. During the soak periods, conventional vehicles were fitted with a trickle charger to maintain battery condition. Vehicle D (hybrid) was connected to a level two charger during soak periods.

TABLE 4. CHASSIS DYNAMOMETER LOAD SETTINGS

Vehicle ID	A	B	C	D
Target				
ETW (lbs)	4750	4000	4750	3625
A (lbf)	26.79	26.347	38.24	18.816
B (lbf/mph)	0.6021	0.40519	0.2803	0.38689
C (lbf/mph**2)	0.0166	0.021578	0.02328	0.012501
Set				
ETW (lbs)	4750	4000	4750	3625
A (lbf)	11.62	9.67	19.81	9.79
B (lbf/mph)	0.0765	0.079	0.1647	-0.0465
C (lbf/mph**2)	0.01998	0.02195	0.02167	0.01684

3.5 Laboratory Emissions Sampling Systems

For determination of exhaust emissions and fuel economy by the carbon balance method, bagged exhaust emission concentrations of THC, CO, methane (CH_4) (for determination of NMHC), NO_X, and CO_2 were determined in a manner consistent with light-duty vehicle testing protocols given in 40 CFR Part 1066. A Horiba Constant Volume Sampler (CVS) was used to collect dilute exhaust in Kynar bags. For the determination of PM emissions, a proportional sample of dilute exhaust was drawn through a 47mm Whatman Teflon membrane filter following Part 1066 protocols. PM was measured for Phase 1 of the LA92 cycle only. Gaseous measurements were taken for all phases. Partway through the project, in January 2021, measurement of exhaust soot was added as a cross check for PM. Soot was measured from dilute exhaust using an AVL Micro Soot Sensor (MSS). The pollutants were analyzed as follows:

Constituent	Analysis Method
Total Hydrocarbon	Flame Ionization Detector
Methane	Gas Chromatograph
Carbon Monoxide	Non-Dispersive Infrared Detector
Carbon Dioxide	Non-Dispersive Infrared Detector
Oxides of Nitrogen	Chemiluminescent Detector
Particulate Mass	Gravimetric Measurement
Soot (added Jan 2021)	AVL Micro Soot Sensor

Figure 3 shows the test cell layout for this project.

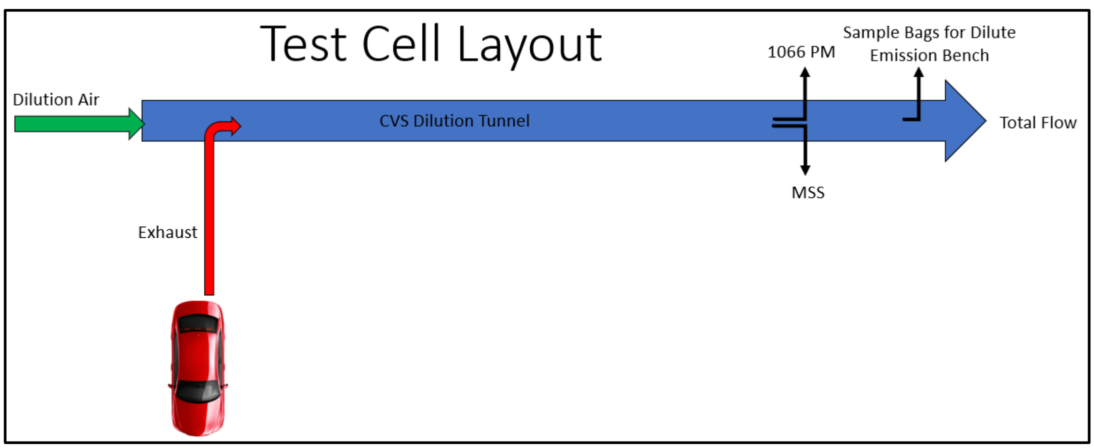

FIGURE 4. TEST CELL LAYOUT

3.6 On-Board Diagnostic (OBD)

On-board Diagnostic (OBD) data was recorded throughout each test. Below is a list of recorded OBD channels. Not all channels were available for each vehicle.

- Engine coolant temperature
- Fuel flow rate
- Engine speed
- Intake air temperature
- Mass air flow rate
- Fuel rail pressure
- Barometric pressure
- Ambient air temperature
- Engine oil temperature
- Engine fuel rate
- Lambda
- Engine load
- Torque
- Accelerator pedal position
- Fuel rail pressure

3.7 Test Procedure and Experimental Design

This project was conducted in parallel with E-122-2 and E-133 when a common fuel was tested. Those projects were originally scheduled to run a single LA92 cycle as one of the preconditioning steps during a fuel change sequence. RW-107-3 added the previously discussed emission measurements to the original LA92 cycle along with one or two additional LA92 cycles, depending on repeatability of the first two tests. The repeatability criteria was 30% for THC and 50% for both CO and NO_X. If any of these criteria failed, then the vehicle was tested a third time. Each fuel was tested using the steps below. Steps 9 through 13 indicate tasks added by RW-107-3, when run in parallel with E-122-2 or E-133. When a fuel unique to RW-107-3 was tested, all steps were conducted under this project.

Test Procedure Steps:

Original E-122-2 and E-133 Preconditioning Sequence

1. Conduct a fuel drain/fill using test fuel
2. Conduct a sulfur purge
3. Conduct vehicle coast downs
4. Conduct a 2^{nd} and 3^{rd} drain/fill using test fuel
5. Soak vehicle for 12 hours
6. Conduct prep cycles (UDDS + HwFET + US06)
7. Soak vehicle for 12 hours
8. Conduct 1^{st} cold-start LA92 with gaseous and PM emission measurement

Steps added for RW-107-3

9. Soak vehicle for 12 hours
10. Conduct 2^{nd} cold-start LA92 with gaseous and PM emission measurement
11. Review data against predetermine criterion
12. If required, Soak vehicle for 12 hours
13. If required, Conduct a 3^{rd} cold-start LA92 with gaseous and PM emission measurement

Details for fuel change, sulfur purge, and vehicle conditioning sequences are given in Appendix B. Each fuel-vehicle combination was tested twice or three times following steps 1-13. Because of commonalities with those projects, RW-107-3 was conducted using the same fuel-vehicle run order. Table 5 gives the run order for each vehicle and fuel combination. Steps 1-13 represent a single block in the matrix. The summer matrix began in November 2020 and was followed by the winter matrix which began in July of 2021. The fuels unique to this project were tested beginning in December 2021, with the last test conducted on January 17, 2022.

TABLE 5: VEHICLE-FUEL RUN ORDER

Run Order	Summer Fuels Test Matrix					Winter Fuels Test Matrix					Additional Matrix			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Vehicle ID	A	B	C	A	C	C	D	A	A	D	B	A	D	B
	D	C	D	D	A	A	B	D	B	C	A	C	B	A
	C	A	B	C	B	D	A	C	D	A	C	D	A	C
	B	D	A	A	D	B	C	B	C	B	D	B	C	D

E10 Market Fuels
Tier 3 Certification Fuel
Summer E10, High PMI
Summer E10, Low PMI
Winter E10, High PMI
Winter E10, Low PMI

E10 Market Fuels Blended to E15
Summer E10, Blended to E15 High PMI
Summer E10 Blended to E15, Low PMI
Winter E10 Blended to E15, High PMI
Winter E10 Blended to E15, Low PMI

E0 Fuels and E10 & E15 Blends
Summer E0, High PMI
Winter E0, Low PMI
Summer E0 Blend to E10, High PMI
Summer E0 Blend to E15, High PMI

4.0 RESULTS

Figure 4 and Figure 5 show the relationship between particulate mass emissions (PM) and exhaust soot emissions (MSS) from Phase 1 of the LA92 cycle. The first figure includes all vehicles with each vehicle indicated by a different color. The PM and MSS emission rate from the Tier 2 vehicle, Vehicle B, was much higher compared to the other vehicles that were all certified to a Tier 3 standard. Linear regression lines are included for each vehicle. Vehicle B has the best linear regression fit with an R-squared value of 0.99. The other vehicles have a weaker fit, which could be caused by the lower span and range of PM and soot values. The second figure shows the same data with Vehicle B removed to improve resolution of the Tier 3 vehicle results. For all plots in this section, winter-grade, summer-grade, and certification fuels are identified with different marks styles to allow approximate identification of fuel RVP.

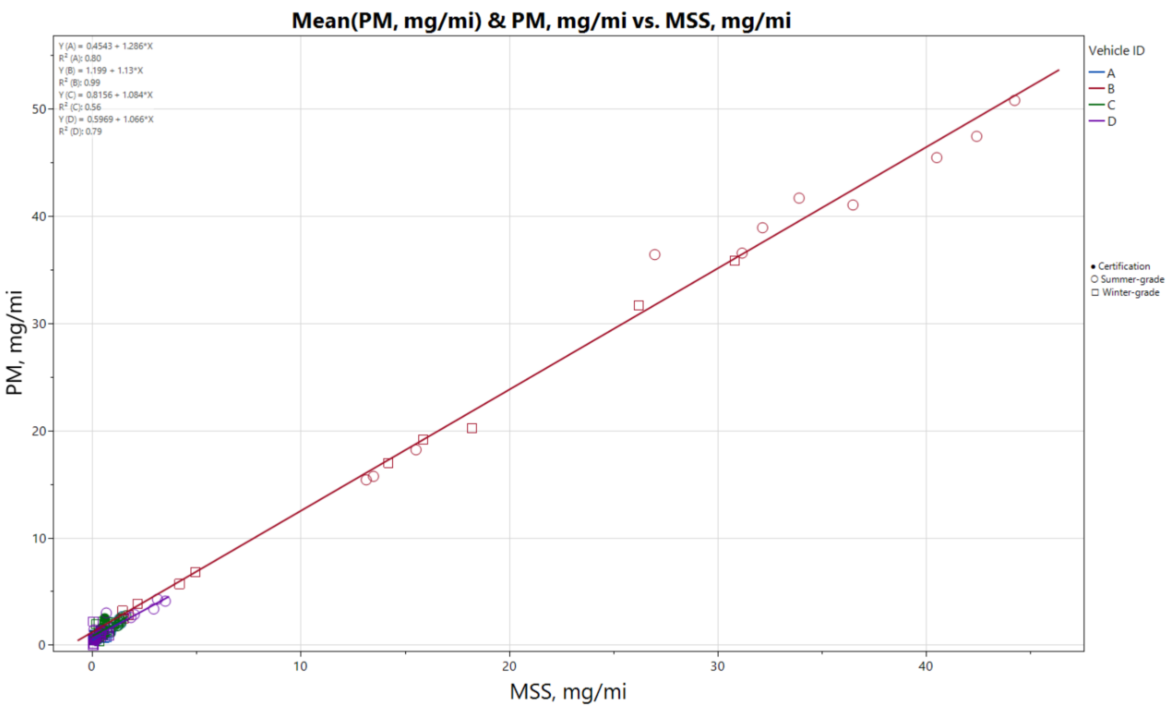

FIGURE 5. PHASE 1, MSS VS PM, ALL VEHICLES

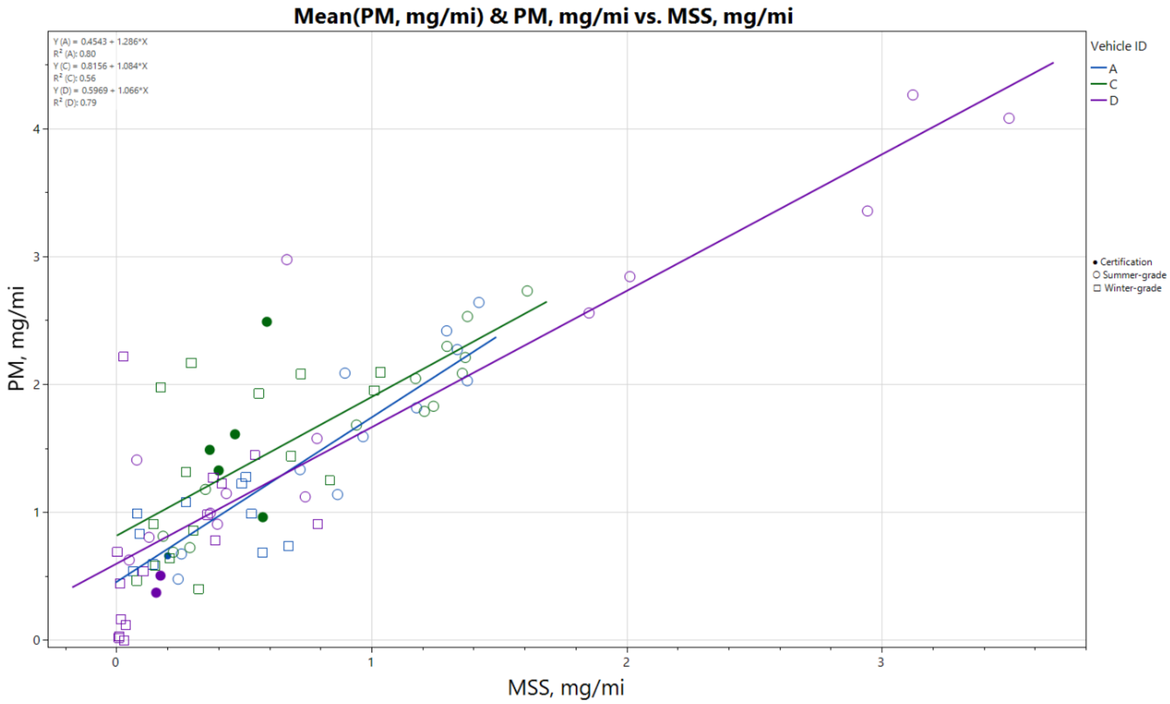

FIGURE 6. PHASE 1, MSS VS PM, WITHOUT VEHICLE B

Figure 6 through Figure 9 show either PM or MSS results from Phase 1 plotted against the test fuel PMI. A moving average line was added to indicate loose trends; however, these lines should not be used to draw robust statistical conclusions. Plots are given both with and without Vehicle B included due to the large magnitude difference previously discussed. All vehicles show an increasing trend in particulate mass and soot emissions with increasing fuel PMI, although, statistical analysis was not conducted to evaluate significance of the trend.

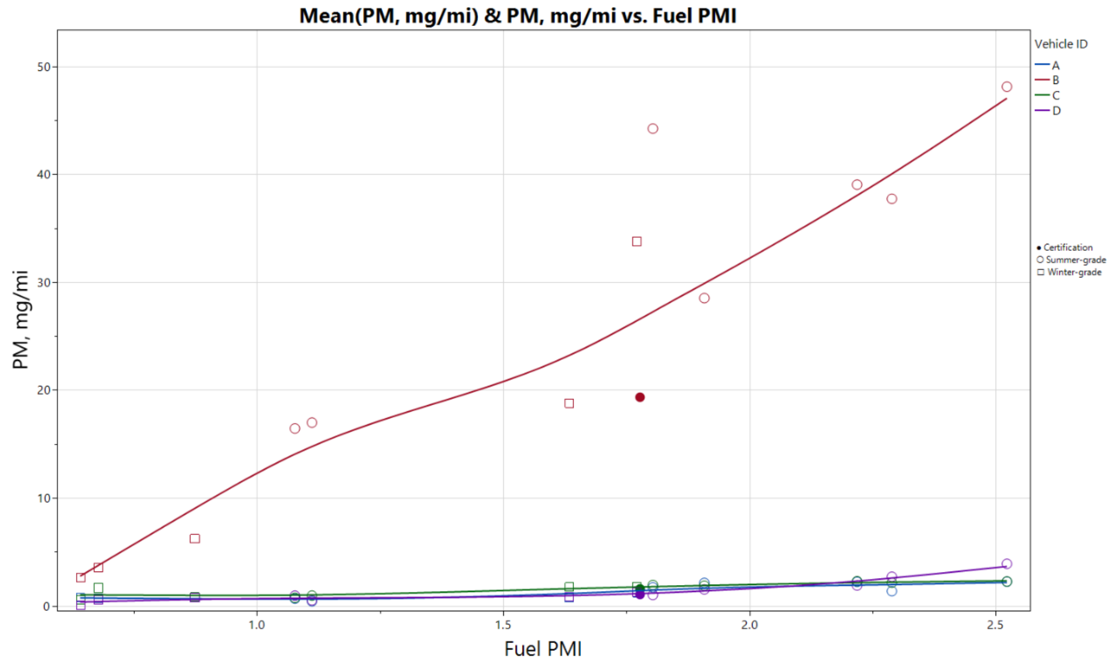

FIGURE 7. PHASE 1, FUEL PMI VS PM, ALL VEHICLES

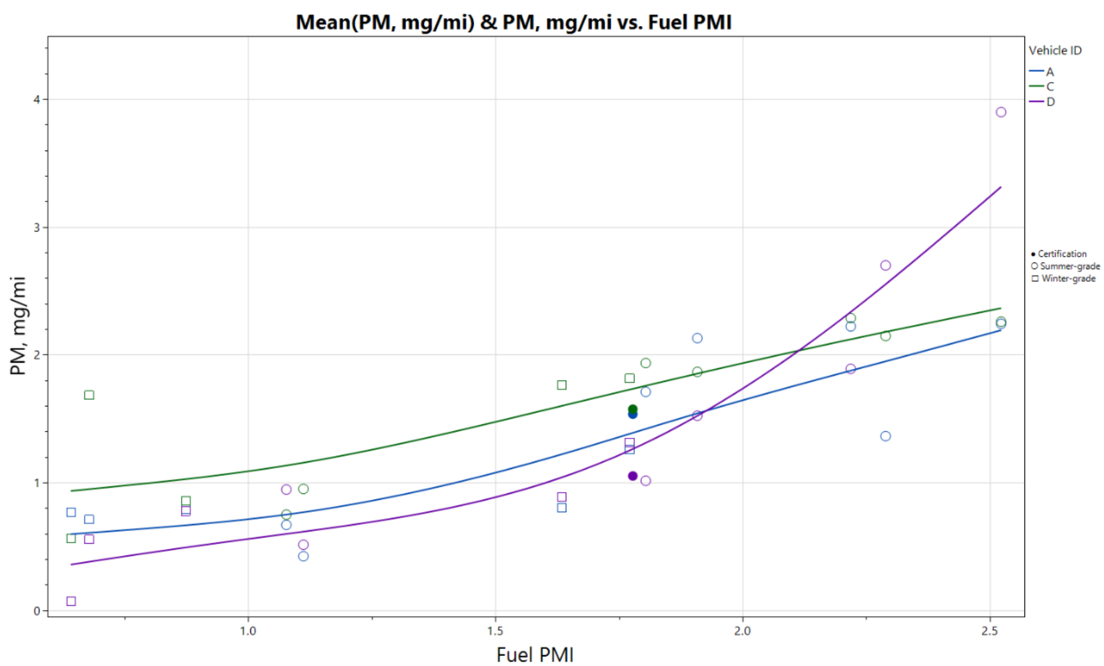

FIGURE 8. PHASE 1, FUEL PMI VS PM, WITHOUT VEHICLE B

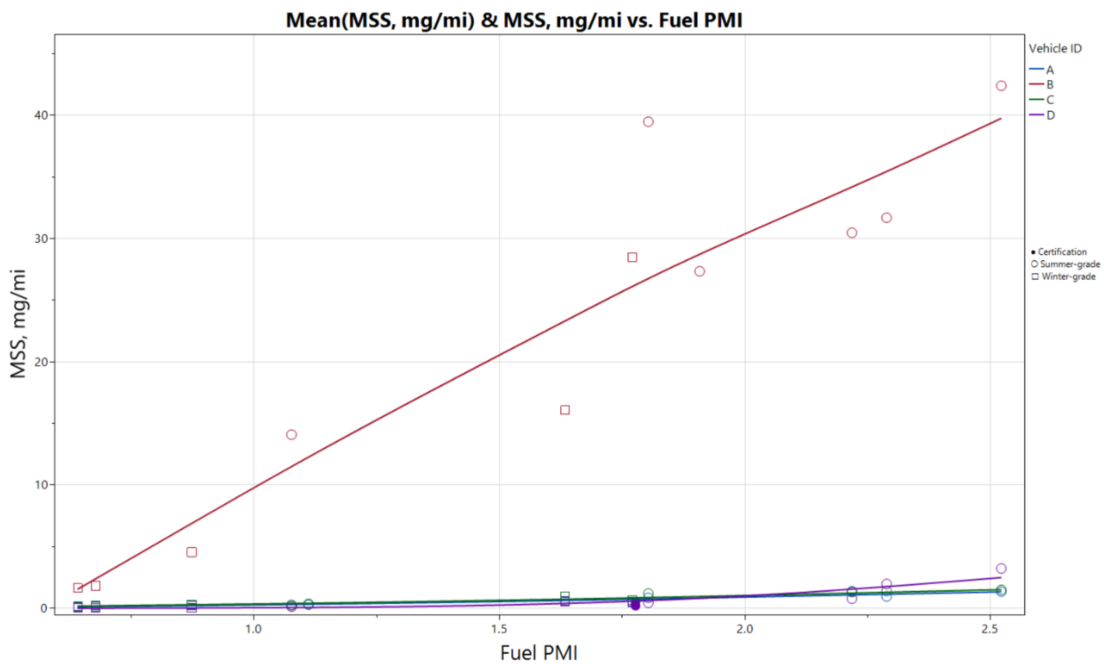

FIGURE 9. PHASE 1, FUEL PMI VS MSS, ALL VEHICLES

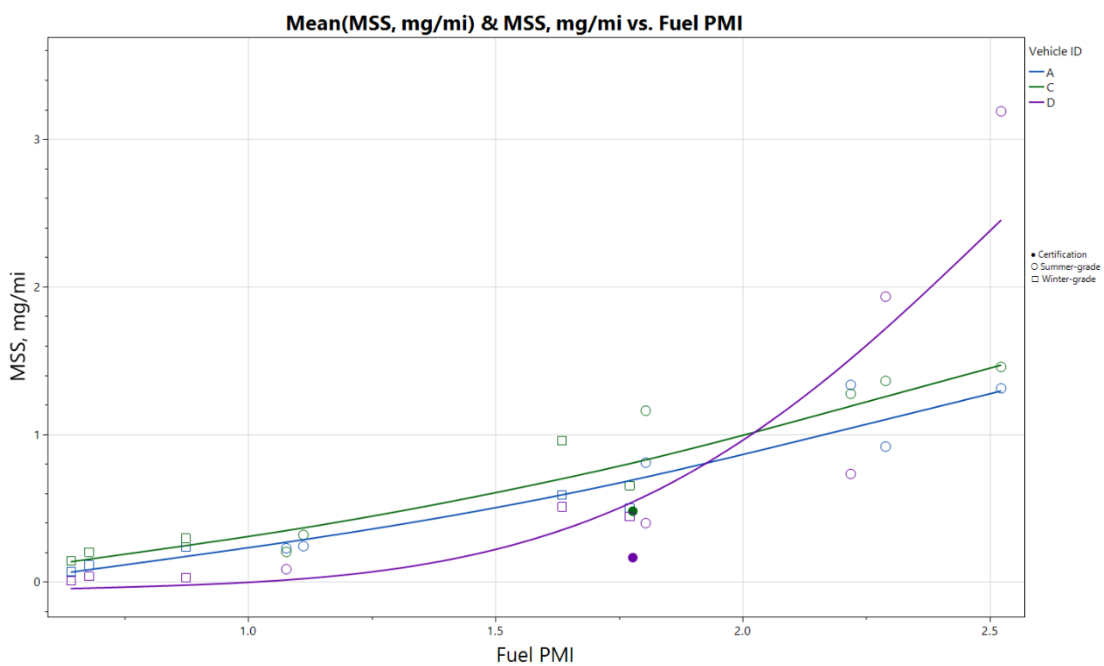

FIGURE 10. PHASE 1, FUEL PMI VS MSS, WITHOUT VEHICLE B

Figure 10 through Figure 14 give gaseous emissions from Phase 1 of the LA92 plotted against fuel PMI and Figure 15 gives the carbon balance fuel economy for this phase calculated from THC, CO, and CO_2. CO emissions appear to decrease with increasing PMI for all vehicles except Vehicle D. Fuel economy was very stable over the approximately 27-month test duration.

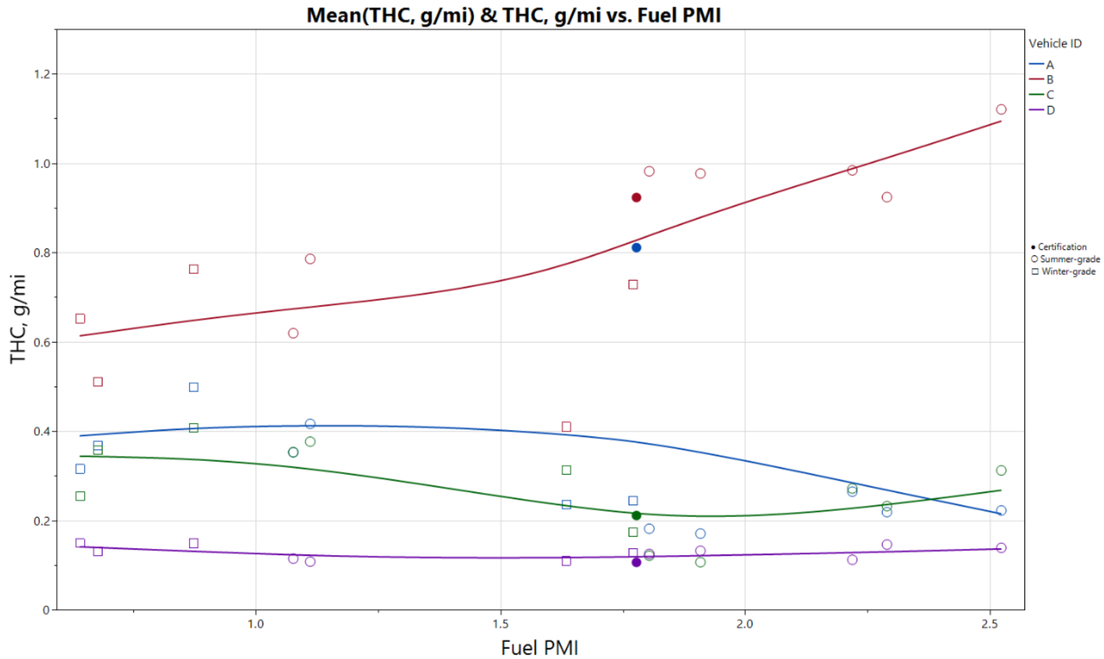

FIGURE 11. PHASE 1, FUEL PMI VS THC, ALL VEHICLES

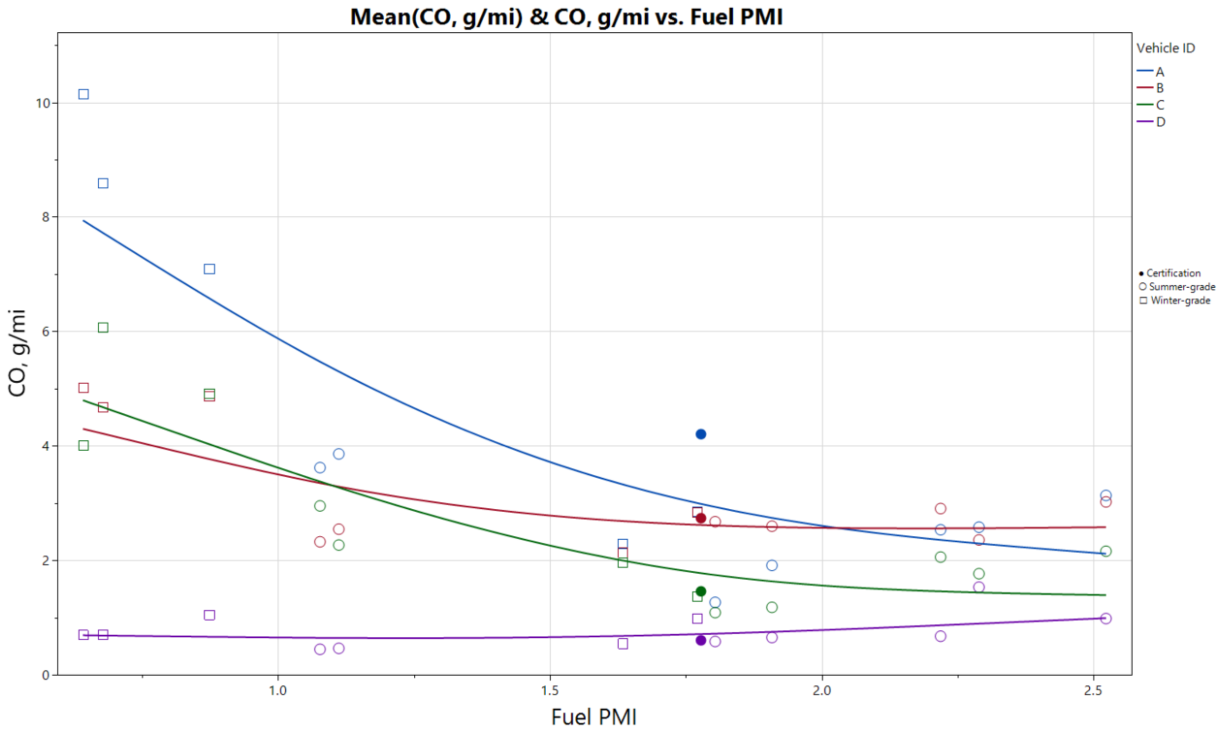

FIGURE 12. PHASE 1, FUEL PMI VS CO, ALL VEHICLES

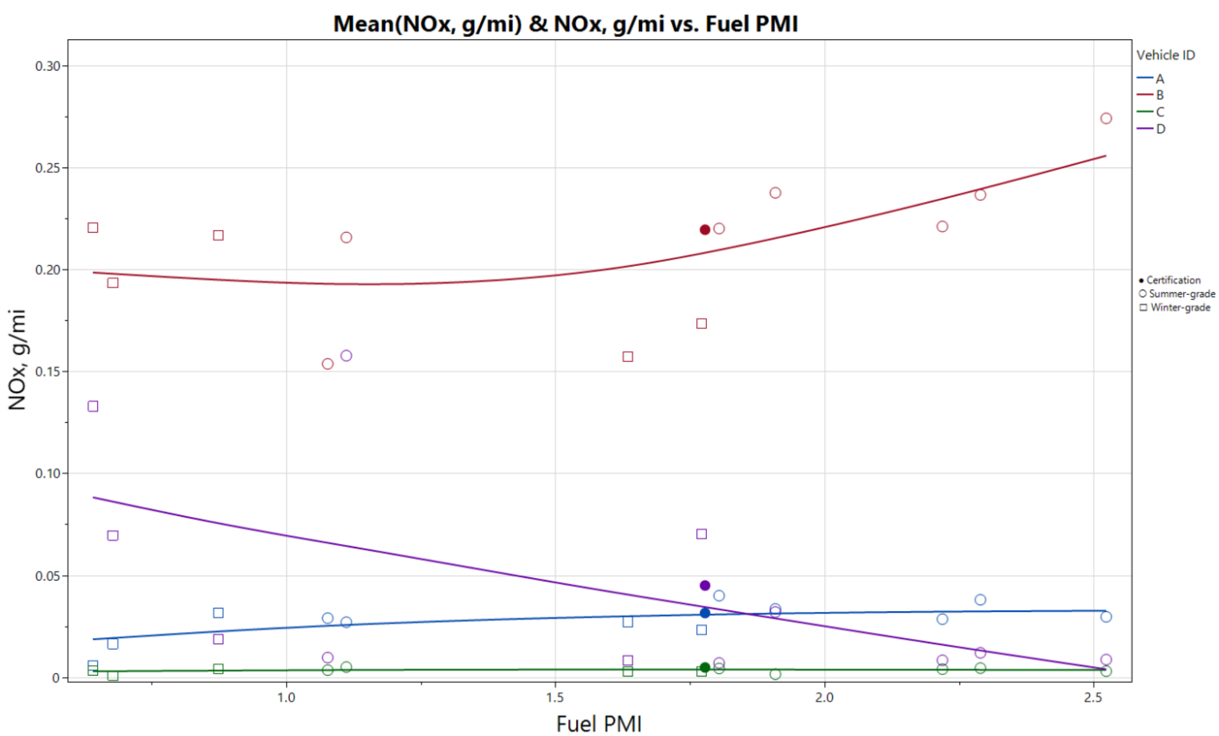

FIGURE 13. PHASE 1, FUEL PMI VS NOX, ALL VEHICLES

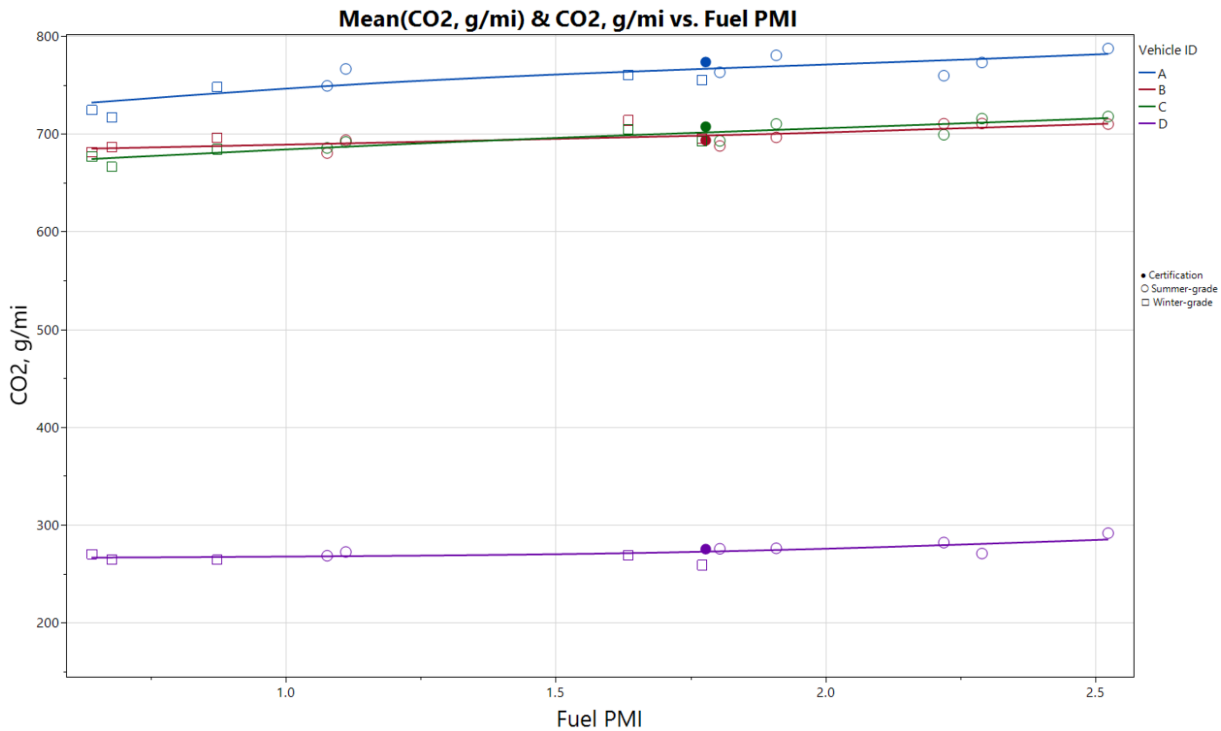

FIGURE 14. PHASE 1, FUEL PMI VS CO2, ALL VEHICLES

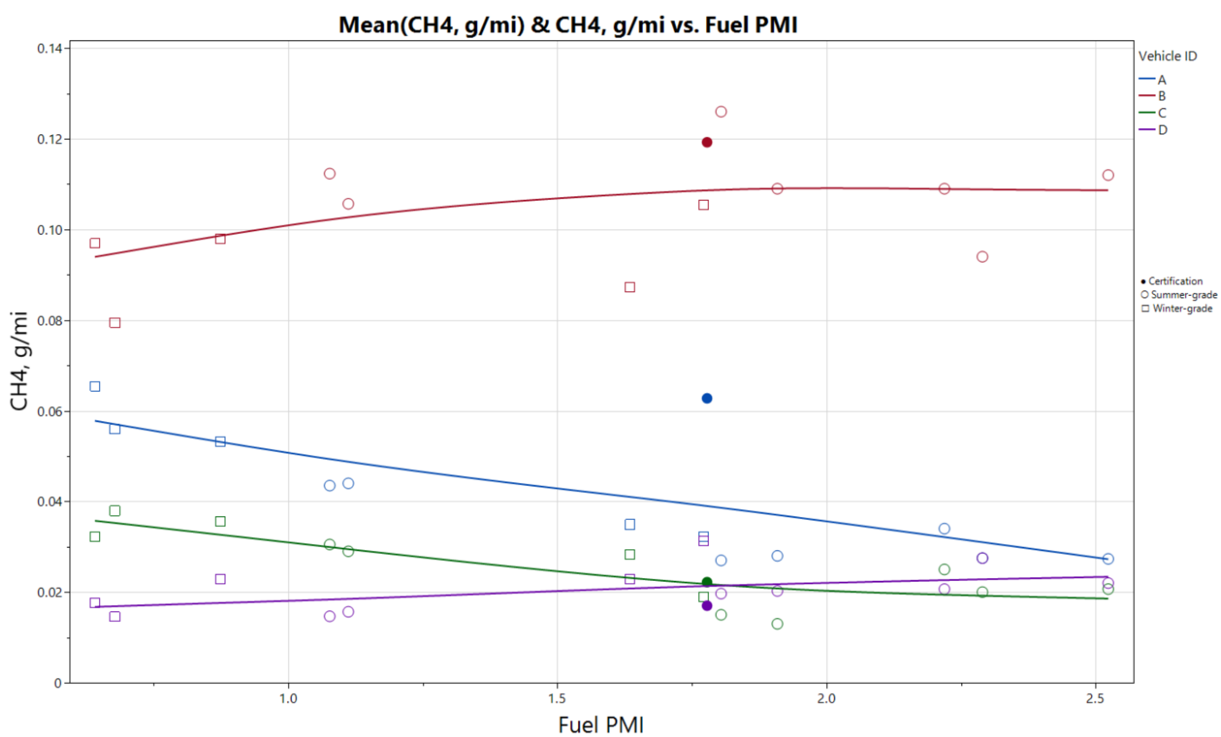

FIGURE 15. PHASE 1, FUEL PMI VS CH4, ALL VEHICLES

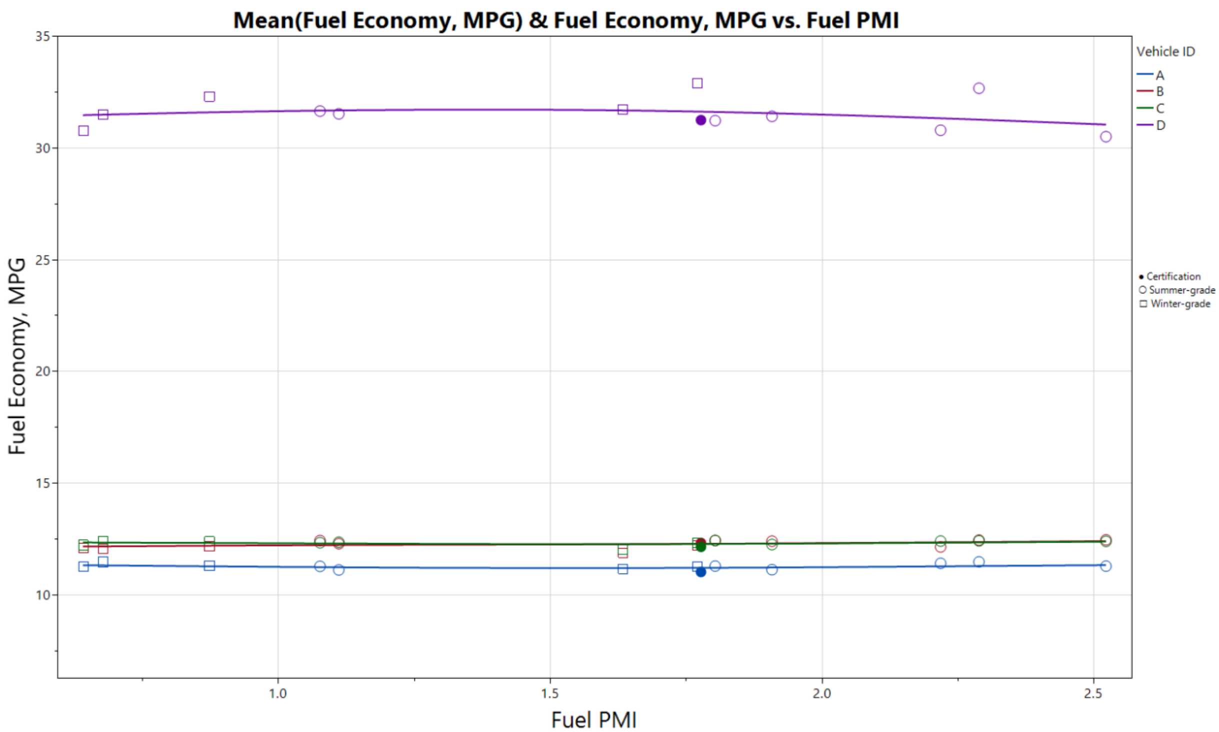

FIGURE 16. PHASE 1, FUEL PMI VS FUEL ECONOMY, ALL VEHICLES

Results from all valid tests are given in table form in Appendix C. This table provides phases 1, 2, 3, and the total LA92 result separately. As previously discussed, statistical analysis of the results was conducted by a separate contractor and conclusions from that analysis are reported separately from this document.

APPENDIX A

TEST FUEL ACQUISITION AND ANALYSES

Appendix A. Test Fuel Acquisition and Analyses

Six commercial test fuels were obtained by SwRI for this program. The fuels were differentiated by a winter batch and a summer batch. Both high and low PMI fuels were obtained for each batch. SwRI acquired these fuels with the help of CRC members who identified locations based on internal analyses. For the first four E10 fuels CRC initially targeted 1,700 gallons of each fuel but then increased this volume to 2,200 gallons. For the summer E0 batch CRC requested that 650 gallons be purchased and for the winter E0 batch only 200 gallons was requested by CRC to be purchased.

Winter Fuels:

- 2,164 gallons of low PMI RUL E10 from CRC member fuel terminal
- 2,182 gallons of high PMI PUL E10 from CRC member fuel terminal
- 200 gallons of low PMI RUL E0 from CRC member fuel terminal

Summer Fuels:

- 2,152 gallons of low PMI RUL E10 from CRC member fuel terminal
- 1,686 gallons of high PMI RUL E10 from CRC member fuel terminal
- 650 gallons of high PMI E0 RUL from CRC member fuel terminal

The procedure to acquire the fuels included the following steps:

1. Steam-clean and dry a tanker truck compartment
2. Drive tanker to terminal and rinse lines and compartment with 50 gallons of desired gasoline
3. Immediately fill the rinsed compartment with the desired gasoline
4. Deliver fuel to SwRI for analysis and off-loading
5. Repeat for additional batches of fuel

Each fuel was analyzed according to the following list of analyses.

- D5191 Reid Vapor Pressure
- D4815 Oxygenates
- D5453 Sulfur
- D86 Distillation
- D381 Existent Gum
- D240 Net Heat of Combustion
- D5291 Carbon / Hydrogen
- D4052 Specific Gravity
- D2699 Research Octane Number
- D2700 Motor Octane Number
- D6729 Detailed Hydrocarbon Analyses
- D4814 Driveability Index

			CRC E-122-2 Fuels				
			Summer Fuels		Winter Fuels		
		Fuel Description	Low PMI E10 RUL	High PMI E10 RUL	E10 Low PMI RUL	E10 High PMI PUL	
		CRC Fuel ID	Fuel B	Fuel C	Fuel D	Fuel E	
		Fuel Source	Marathon Terminal (Salt Lake City)	Motiva Terminal (San Antonio)	Marathon Terminal (Salt Lake City)	Chevron Richmond Technology Center	
		SwRI Fuel Code	GA-10940	GA-10920	GA-11027	CGA-11053	CGB-11093
		Sample Code	FLRD-3606	FLRD-3560	FLRD-3914	FLRD-3979	FLRD-3788
		Sample Source	Drum Sample after Tanker Offloading	Tanker Manifold Sample	Tanker Manifold Sample	Drum Sample after Tanker Offloading	Sample after TOP TIER Additive Treatment
		Date of Sample	7/20/2020	5/29/2020	1/15/2021	3/26/2021	6/18/2021
		Current Volume	2,152 gallons	1,686 gallons	2,164 gallons	2,182 gallons	2,182 gallons
ASTM Method	**Test Request**	**Test Units**	**Results**	**Results**	**Results**	**Results**	**Results**
D6729	Detailed Hydrocarbon Analysis	--	completed	completed	completed	completed	completed
PMI	PM Index	*calculated*	1.1115	1.9085	0.6772	1.7708	n/a
D86	Distillation						
	IBP	Deg. F	96	103	81	78	n/a
	5%	Deg. F	121	125	93	100	n/a
	10%	Deg. F	130	131	103	109	n/a
	15%	Deg. F	136	135	112	117	n/a
	20%	Deg. F	141	139	120	125	n/a
	30%	Deg. F	150	146	134	141	n/a
	40%	Deg. F	158	153	146	155	n/a
	50%	Deg. F	203	198	154	173	n/a
	60%	Deg. F	227	235	194	242	n/a
	70%	Deg. F	246	264	224	268	n/a
	80%	Deg. F	273	297	248	302	n/a
	90%	Deg. F	306	330	281	338	n/a
	95%	Deg. F	333	351	303	367	n/a
	FBP	Deg. F	367	408	344	392	n/a
	Recovered	mL	98	98.4	97	97	n/a
	Residue	mL	0.9	0.7	0.7	0.7	n/a
	Loss	mL	1.6	0.9	2.2	2.0	n/a
D86	Driveability Index	--	1109.8	1119.5	896.7	971.2	n/a
D5191	Vapor Pressure (Mini Method)						
	RVP (EPA Equation)	psi	8.98	7.73	15.25	13.64	n/a
	DVPE (ASTM Equation)	psi	8.87	7.61	15.2	13.57	n/a
D240	Heat of Combustion						
	GROSS	BTU/lb	19244	19147	19494	19225	n/a
	GROSS	MJ/kg	44.760	44.536	45.344	44.717	n/a
	GROSS	cal/g	10690.8	10637.2	10830.3	10680.6	n/a
D240	Heat of Combustion						
	NET	BTU/lb	17982	17917	18204	17968	n/a
	NET	MJ/kg	41.827	41.675	42.341	41.794	n/a
	NET	cal/g	9990.3	9953.9	10113.1	9982.2	n/a
D2699	Research Octane Number (RON	--	92.5	91.2	91	97.2	n/a
D2700	Motor Octane Number (MON)	--	83.7	82.7	82.9	87.9	n/a
D381	Existent Gums Content						
	Unwashed Wt	mg/100 mL	9.5	16.0	9.5	1.5	20.0
	Washed Wt	mg/100 mL	<0.5	<0.5	<0.5	0.5	0.5
D4052	API Gravity	--	60.1	57.5	66.1	60.7	n/a
	Specific Gravity	--	0.7386	0.7486	0.7161	0.7362	n/a
	Density @ 15°C	g/mL	0.7384	0.7484	0.7160	0.7360	n/a
D4815	Oxygenates and Oxygen Content						
	Methanol (MeOH)	vol%	<0.3	<0.2	<0.2	<0.2	n/a
	Ethanol (EtOH)	vol%	9.71	9.50	9.55	10.19	n/a
	Isopropanol (iPA)	vol%	<0.2	<0.2	10.58	<0.2	n/a
	tert-Butanol (tBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	n-Propanol (nPA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Methyl tert-butylether (MTBE	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	sec-Butanol (sBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Diisopropylether (DIPE)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Isobutanol (iBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Ethyl tert-butylether (ETBE)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	tert-Pentanol (tPA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	n-Butanol (nBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	tert-amyl methylether (TAME	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Ethanol (EtOH)	wt%	10.43	10.07	<0.2	10.99	n/a
	Total Oxygen	wt%	3.62	3.49	3.67	3.81	n/a
D5291	Carbon Content	wt%	82.32	83.12	82.30	82.33	n/a
	Hydrogen Content	wt%	13.83	13.48	14.15	13.78	n/a
D5453	Sulfur by UV	ppm	7.1	6.2	11.4	5.1	n/a

			CRC E-122-2 Fuels				
			Summer Fuels		Winter Fuels		
		Fuel Description	Low PMI E10 RUL	High PMI E10 RUL	E10 Low PMI RUL	E10 High PMI PUL	
		CRC Fuel ID	Fuel B	Fuel C	Fuel D	Fuel E	
		Fuel Source	Marathon Terminal (Salt Lake City)	Motiva Terminal (San Antonio)	Marathon Terminal (Salt Lake City)	Chevron Richmond Technology Center	
		SwRI Fuel Code	GA-10940	GA-10920	GA-11027	CGA-11053	CGB-11093
		Sample Code	FLRD-3606	FLRD-3560	FLRD-3914	FLRD-3979	FLRD-3788
		Sample Source	Drum Sample after Tanker Offloading	Tanker Manifold Sample	Tanker Manifold Sample	Drum Sample after Tanker Offloading	Sample after TOP TIER Additive Treatment
		Date of Sample	7/20/2020	5/29/2020	1/15/2021	3/26/2021	6/18/2021
		Current Volume	2,152 gallons	1,686 gallons	2,164 gallons	2,182 gallons	2,182 gallons
ASTM Method	**Test Request**	**Test Units**	**Results**	**Results**	**Results**	**Results**	**Results**
D6729	Detailed Hydrocarbon Analysis	--	completed	completed	completed	completed	completed
PMI	PM Index	*calculated*	1.1115	1.9085	0.6772	1.7708	n/a
D86	Distillation						
	IBP	Deg. F	96	103	81	78	n/a
	5%	Deg. F	121	125	93	100	n/a
	10%	Deg. F	130	131	103	109	n/a
	15%	Deg. F	136	135	112	117	n/a
	20%	Deg. F	141	139	120	125	n/a
	30%	Deg. F	150	146	134	141	n/a
	40%	Deg. F	158	153	146	155	n/a
	50%	Deg. F	203	198	154	173	n/a
	60%	Deg. F	227	235	194	242	n/a
	70%	Deg. F	246	264	224	268	n/a
	80%	Deg. F	273	297	248	302	n/a
	90%	Deg. F	306	330	281	338	n/a
	95%	Deg. F	333	351	303	367	n/a
	FBP	Deg. F	367	408	344	392	n/a
	Recovered	mL	98	98.4	97	97	n/a
	Residue	mL	0.9	0.7	0.7	0.7	n/a
	Loss	mL	1.6	0.9	2.2	2.0	n/a
D86	Driveability Index	--	1109.8	1119.5	896.7	971.2	n/a
D5191	Vapor Pressure (Mini Method)						
	RVP (EPA Equation)	psi	8.98	7.73	15.25	13.64	n/a
	DVPE (ASTM Equation)	psi	8.87	7.61	15.2	13.57	n/a
D240	Heat of Combustion						
	GROSS	BTU/lb	19244	19147	19494	19225	n/a
	GROSS	MJ/kg	44.760	44.536	45.344	44.717	n/a
	GROSS	cal/g	10690.8	10637.2	10830.3	10680.6	n/a
D240	Heat of Combustion						
	NET	BTU/lb	17982	17917	18204	17968	n/a
	NET	MJ/kg	41.827	41.675	42.341	41.794	n/a
	NET	cal/g	9990.3	9953.9	10113.1	9982.2	n/a
D2699	Research Octane Number (RON	--	92.5	91.2	91	97.2	n/a
D2700	Motor Octane Number (MON)	--	83.7	82.7	82.9	87.9	n/a
D381	Existent Gums Content						
	Unwashed Wt	mg/100 mL	9.5	16.0	9.5	1.5	20.0
	Washed Wt	mg/100 mL	<0.5	<0.5	<0.5	0.5	0.5
D4052	API Gravity	--	60.1	57.5	66.1	60.7	n/a
	Specific Gravity	--	0.7386	0.7486	0.7161	0.7362	n/a
	Density @ 15°C	g/mL	0.7384	0.7484	0.7160	0.7360	n/a
D4815	Oxygenates and Oxygen Content						
	Methanol (MeOH)	vol%	<0.3	<0.2	<0.2	<0.2	n/a
	Ethanol (EtOH)	vol%	9.71	9.50	9.55	10.19	n/a
	Isopropanol (iPA)	vol%	<0.2	<0.2	10.58	<0.2	n/a
	tert-Butanol (tBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	n-Propanol (nPA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Methyl tert-butylether (MTBE	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	sec-Butanol (sBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Diisopropylether (DIPE)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Isobutanol (iBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Ethyl tert-butylether (ETBE)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	tert-Pentanol (tPA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	n-Butanol (nBA)	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	tert-amyl methylether (TAME	vol%	<0.2	<0.2	<0.2	<0.2	n/a
	Ethanol (EtOH)	wt%	10.43	10.07	<0.2	10.99	n/a
	Total Oxygen	wt%	3.62	3.49	3.67	3.81	n/a
D5291	Carbon Content	wt%	82.32	83.12	82.30	82.33	n/a
	Hydrogen Content	wt%	13.83	13.48	14.15	13.78	n/a
D5453	Sulfur by UV	ppm	7.1	6.2	11.4	5.1	n/a

			CRC E-133 Fuels			
			Summer Fuels		Winter Fuels	
		Fuel Description	Low PMI E15	High PMI E15	Low PMI E15	High PMI E15
		Fuel Name	Fuel F (splash blend of Fuel B)	Fuel G (splash blend of Fuel C)	Fuel H (splash blend of Fuel D)	Fuel I (splash blend of Fuel E)
		SwRI Fuel Code	CGB-11037	CGB-11039	CGB-11156	CGB-11149
		Fuel Blend Number	2021-005	2021-006	2021-031	2021-032
		Sample Location	Tote 08-030S	Tote 08-037S	Tote 08-038s	Tote 08-030s
		Sample Code	FLRD-3938/FLRD-3945/FLRD-4250	FLRD-3939/FLRD-3946/FLRD-4251	FLRD-4209 / FLRD-4213	FLRD-4190 / FLRD-4199
		Sample Dates	3/1/2021- 3/5/2021 - 11/02/21	3/3/2021 - 3/5/2021 - 11/02/21	9/27/01 & 10/4/2021	9/7/2021 & 9/20/2021
ASTM Method	**Test Request**	**Test Units**	**Results**	**Results**	**Results**	**Results**
D5191	Vapor Pressure (Mini Method)					
	RVP (EPA Equation)	psi	8.74	7.58	14.21	13.3
	DVPE (ASTM Equation)	psi	8.63	7.45	14.15	13.22
D4052	API Gravity	--	59.2	56.8	63.2	59.8
	Specific Gravity	--	0.7419	0.7514	0.7268	0.7396
	Density @ 15°C	g/mL	0.7417	0.7511	0.7265	0.7393
	Density @ 15°C	g/L	741.7	751.1	726.5	739.3
D5599	Oxygenates and Oxygen Content					
	Diisopropylether (DIPE)	vol%	<0.1	<0.1	<0.1	<0.1
	Ethyl tert-butylether (ETBE)	vol%	<0.1	<0.1	<0.1	<0.1
	Ethanol (EtOH)	vol%	15.23	14.95	15.31	15.27
	Ethanol (EtOH)	WT%	16.30	15.80	16.83	16.39
	Isobutanol (iBA)	vol%	<0.1	<0.1	<0.1	<0.1
	Isopropanol (iPA)	vol%	<0.1	<0.1	<0.1	<0.1
	Methanol (MeOH)	vol%	<0.1	<0.1	<0.1	<0.1
	Methyl tert-butylether (MTBE)	vol%	<0.1	<0.1	<0.1	<0.1
	n-Butanol (nBA)	vol%	<0.1	<0.1	<0.1	<0.1
	n-Propanol (nPA)	vol%	<0.1	<0.1	<0.1	<0.1
	sec-Butanol (sBA)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-amyl methylether (TAME)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-Butanol (tBA)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-Pentanol (tPA)	vol%	<0.1	<0.1	<0.1	<0.1
	Total Oxygen	WT%	5.66	5.48	5.84	5.69
D5599	Oxygenates and Oxygen Content					
duplicate	Diisopropylether (DIPE)	vol%	<0.1	<0.1	<0.1	<0.1
	Ethyl tert-butylether (ETBE)	vol%	<0.1	<0.1	<0.1	<0.1
	Ethanol (EtOH)	vol%	14.81	15.09	15.14	15.31
	Ethanol (EtOH)	WT%	15.85	15.94	16.53	16.39
	Isobutanol (iBA)	vol%	<0.1	<0.1	<0.1	<0.1
	Isopropanol (iPA)	vol%	<0.1	<0.1	<0.1	<0.1
	Methanol (MeOH)	vol%	<0.1	<0.1	<0.1	<0.1
	Methyl tert-butylether (MTBE)	vol%	<0.1	<0.1	<0.1	<0.1
	n-Butanol (nBA)	vol%	<0.1	<0.1	<0.1	<0.1
	n-Propanol (nPA)	vol%	<0.1	<0.1	<0.1	<0.1
	sec-Butanol (sBA)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-amyl methylether (TAME)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-Butanol (tBA)	vol%	<0.1	<0.1	<0.1	<0.1
	tert-Pentanol (tPA)	vol%	<0.1	<0.1	<0.1	<0.1
	Total Oxygen	WT%	5.5	5.53	5.74	5.69
D240	Heat of Combustion					
	GROSS	BTU/lb	18870	18720	18989	18736
	GROSS	MJ/kg	43.89	43.543	44.168	43.579
	GROSS	cal/g	10483	10400	10549.4	10408.6
D240	Heat of Combustion					
	NET	BTU/lb	17596	17492	17705	17484
	NET	MJ/kg	40.929	40.685	41.182	40.667
	NET	cal/g	9775.8	9717.5	9836.1	9713.1
D2622	Sulfur by X-ray	ppm	8.5	8.0	10.9	5.3
D2699	Research Octane Number (RON)	--	94.3	93.8	94.7	99.7
D2700	Motor Octane Number (MON)	--	84.7	84.4	84	88.7
D5291	Carbon Content	wt%	80.66	80.58	79.88	80.61
	Hydrogen Content	wt%	13.95	13.46	14.08	13.72
D6729	DHA Analysis	--	Complete	Complete	Complete	Complete
PMI	Particulate Matter Index	--	1.0769	1.8040	0.6408	1.6348
D86	Distillation					
	IBP	Deg. F	95	101	80	80
	5%	Deg. F	123	126	94	99
	10%	Deg. F	132	133	106	109
	15%	Deg. F	139	137	115	117
	20%	Deg. F	144	141	123	125
	30%	Deg. F	152	149	138	142
	40%	Deg. F	157	156	149	156
	50%	Deg. F	161	161	156	164
	60%	Deg. F	217	213	161	195
	70%	Deg. F	242	256	215	261
	80%	Deg. F	269	290	245	292
	90%	Deg. F	305	325	280	329
	95%	Deg. F	330	348	306	352
	FBP	Deg. F	373	395	344	396
	Recovered	mL	98.4	98.3	96.3	97.8
	Residue	mL	0.7	0.8	0.9	1.0
	Loss	mL	0.9	0.9	2.8	1.2
D86	Driveability Index	--	987.2	1007.3	905.9	985.2

			CRC RW-107-3 Fuels			
			Summer Fuels			Winter Fuel
		Fuel Description	High PMI E0 RUL	High PMI E10 RUL	High PMI E15 RUL	Low PMI E0 RUL
		CRC Fuel ID	Fuel J	Fuel L	Fuel M	Fuel K
		Fuel Source	Phillips 66 Terminal (Westlake)	Fuel J, Splash-Blend E10	Fuel J, Splash-Blend E15	Marathon Terminal (Salt Lake City)
		SwRI Fuel Code	GA-10950	CGB-11147	CGB-11148	GA-11026
		Sample Code	FLRD-3627	FLRD-4191, FLRD-4200	FLRD-4192, FLRD-4201	FLRD-3909
		Sample Source	Tanker Manifold Sample	Tote Sample	Tote Sample	Tanker Manifold Sample
		Date of Sample	7/20/2020	9/7/2021 / 9/20/2021	9/7/2021 / 9/20/2021	1/11/2021
		Current Volume	527 gallons	256 gallons	259 gallons	195 gallons
ASTM Method	**Test Request**	**Test Units**	**Results**	**Results**	**Results**	**Results**
D6729	Detailed Hydrocarbon Analysis	--	completed	completed	completed	completed
PMI	PM Index	*calculated*	2.5231	2.2894	2.2189	0.8728
D86	Distillation					
	IBP	Deg. F	88	93	98	73
	5%	Deg. F	114	116	119	82
	10%	Deg. F	126	123	126	97
	15%	Deg. F	134	129	131	108
	20%	Deg. F	143	134	137	120
	30%	Deg. F	162	144	146	148
	40%	Deg. F	188	153	156	179
	50%	Deg. F	219	180	163	205
	60%	Deg. F	247	237	213	224
	70%	Deg. F	272	264	261	240
	80%	Deg. F	300	293	290	260
	90%	Deg. F	338	333	326	289
	95%	Deg. F	368	365	360	312
	FBP	Deg. F	427	417	421	361
	Recovered	mL	99	98	99	96
	Residue	mL	0.9	1.1	0.7	0.5
	Loss	mL	0.6	0.8	0.6	3.3
D86	Driveability Index	--	1183.5	1058.1	1002.1	1050.6
D5191	Vapor Pressure (Mini Method)					
	RVP (EPA Equation)	psi	8.71	9.39	9.36	14.48
	DVPE (ASTM Equation)	psi	8.59	9.28	9.25	14.42
D240	Heat of Combustion					
	GROSS	BTU/lb	19762	18566	18569	20238
	GROSS	MJ/kg	45.965	43.185	43.191	47.072
	GROSS	cal/g	10978.6	10314.4	10316.1	11243.1
D240	Heat of Combustion					
	NET	BTU/lb	18564	17380	17381	18928
	NET	MJ/kg	43.181	40.426	40.428	44.025
	NET	cal/g	10313.6	9655.6	9656.1	10515.3
D2622	Sulfur by X-ray	ppm	-	4.64	4.86	-
D2699	Research Octane Number (RON)	--	93.0	96.2	97.6	92.7
D2700	Motor Octane Number (MON)	--	83.3	85.5	86.4	84.7
D381	Existent Gums Content					
	Unwashed Wt	mg/100 mL	5.5	n/a	n/a	5.0
	Washed Wt	mg/100 mL	<0.5	n/a	n/a	<0.5
D4052	API Gravity	--	56.8	55.4	55.0	66.9
	Specific Gravity	--	0.7513	0.7570	0.7586	0.7134
	Density @ 15°C	g/mL	0.7510	0.7568	0.7583	0.7132
D4815	Oxygenates and Oxygen Content					
	Methanol (MeOH)	vol%	<0.2	-	-	<0.2
	Ethanol (EtOH)	vol%	<0.2	-	-	<0.2
	Isopropanol (iPA)	vol%	<0.2	-	-	<0.2
	tert-Butanol (tBA)	vol%	<0.2	-	-	<0.2
	n-Propanol (nPA)	vol%	<0.2	-	-	<0.2
	Methyl tert-butylether (MTBE)	vol%	<0.2	-	-	<0.2
	sec-Butanol (sBA)	vol%	<0.2	-	-	<0.2
	Diisopropylether (DIPE)	vol%	<0.2	-	-	<0.2
	Isobutanol (iBA)	vol%	<0.2	-	-	<0.2
	Ethyl tert-butylether (ETBE)	vol%	<0.2	-	-	<0.2
	tert-Pentanol (tPA)	vol%	<0.2	-	-	<0.2
	n-Butanol (nBA)	vol%	<0.2	-	-	<0.2
	tert-amyl methylether (TAME)	vol%	<0.2	-	-	<0.2
	Ethanol (EtOH)	wt%	<0.2	-	-	<0.2
	Total Oxygen	wt%	0	-	-	0
D5291	Carbon Content	wt%	86.88	83.08	81.12	86.34
	Hydrogen Content	wt%	13.12	13.00	13.02	14.36
D5453	Sulfur by UV	ppm	4.1	4.6	4.9	11.0
D5599	Oxygenates and Oxygen Content					
	Diisopropylether (DIPE)	vol%	n/a	<0.1	<0.1	n/a
	Ethyl tert-butylether (ETBE)	vol%	n/a	<0.1	<0.1	n/a
	Ethanol (EtOH)	vol%	n/a	10.07	15.09	n/a
	Ethanol (EtOH)	WT%	n/a	10.56	15.80	n/a
	Isobutanol (iBA)	vol%	n/a	<0.1	<0.1	n/a
	Isopropanol (iPA)	vol%	n/a	<0.1	<0.1	n/a
	Methanol (MeOH)	vol%	n/a	<0.1	<0.1	n/a
	Methyl tert-butylether (MTBE)	vol%	n/a	<0.1	<0.1	n/a
	n-Butanol (nBA)	vol%	n/a	<0.1	<0.1	n/a
	n-Propanol (nPA)	vol%	n/a	<0.1	<0.1	n/a
	sec-Butanol (sBA)	vol%	n/a	<0.1	<0.1	n/a
	tert-amyl methylether (TAME)	vol%	n/a	<0.1	<0.1	n/a
	tert-Butanol (tBA)	vol%	n/a	<0.1	<0.1	n/a
	tert-Pentanol (tPA)	vol%	n/a	<0.1	<0.1	n/a
	Total Oxygen	WT%	n/a	3.67	5.48	n/a

EM-10967-F

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Certificate of Analysis

FAX: (281) 457-1469

PRODUCT:	EPA Tier 3 EEE Emission Certification Fuel, General Testing - Regular	Batch No.:	HH2921LT10-10
		Tank No.:	TK107
Specification No.:	HF2021	Date:	10/10/2019

TEST	METHOD	UNITS	SPECIFICATIONS MIN	TARGET	MAX	RESULTS
Distillation - IBP	ASTM D86[2]	°F				96.5
5%		°F				120.2
10%		°F	120		140	129.0
20%		°F				138.5
30%		°F				147.3
40%		°F				154.3
50%		°F	190		210	195.1
60%		°F				233.2
70%		°F				256.0
80%		°F				282.0
90%		°F	315		335	322.2
95%		°F				341.5
Distillation - EP		°F	380		420	387.7
Recovery		%		Report		97.1
Residue		ml			2.0	0.8
Loss		%		Report		2.1
Gravity @ 60° F	ASTM D4052[2]	°API		Report		58.90
Density @ 15.56° C	ASTM D4052[2]	kg/l		Report		0.7425
Reid Vapor Pressure EPA Equation	ASTM D5191[2]	psi	8.7		9.2	9.2
Carbon	ASTM D5291[2]	wt fraction		Report		0.8239
Hydrogen	ASTM D5291[2]	wt fraction		Report		0.1387
Hydrogen/Carbon ratio	ASTM D5291[2]	mole/mole		Report		2.006
Oxygen	ASTM D4815[2]	wt %		Report		3.74
Ethanol content	ASTM D5599-00[2]	vol %	9.6		10.0	9.7
Total oxygenates other than ethanol	ASTM D4815[2]	vol %			0.1	None Detected
Sulfur	ASTM D5453[2]	mg/kg	8.0		11.0	9.2
Phosphorus	ASTM D3231[2]	g/l			0.0013	None Detected
Lead	ASTM D3237[2]	g/l			0.0026	None Detected
Composition, aromatics	ASTM D5769[1]	vol %	21.0		25.0	22.2
C6 aromatics (benzene)	ASTM D5769[1]	vol %	0.5		0.7	0.6
C7 aromatics (toluene)	ASTM D5769[1]	vol %	5.2		6.4	5.6
C8 aromatics	ASTM D5769[1]	vol %	5.2		6.4	5.5
C9 aromatics	ASTM D5769[1]	vol %	5.2		6.4	5.5
C10+ aromatics	ASTM D5769[1]	vol %	4.4		5.6	5.0
Composition, olefins	ASTM D6550[2]	wt %	4.0		10.0	7.0
Oxidation Stability	ASTM D525[2]	minutes	1000			1000+
Copper Corrosion	ASTM D130[2]				1	1a
Existent gum, washed	ASTM D381[2]	mg/100mls			3.0	1.0
Existent gum, unwashed	ASTM D381[2]	mg/100mls		Report		2.0
Research Octane Number	ASTM D2699[2]			Report		92.3
Motor Octane Number	ASTM D2700[2]			Report		84.5
R+M/2	D2699/2700[2]		87.0		88.4	88.4
Sensitivity	D2699/2700[2]		7.5			7.8
Net Heat of Combustion	ASTM D240[2]	BTU/lb		Report		17914

Quality Assurance Technician

ANAB ACCREDITED TESTING LABORATORY

[1] Haltermann Solutions is accredited to ISO/IEC 17025 by ANAB for the tests referred to with this footnote.

[2] Tested by ISO/IEC 17025 accredited subcontractor.

Main Lab, 15600 West Hardy Rd., Houston, TX 77060 USA

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APPENDIX B

DETAILED TEST PROCEDURES

Fuel Change Procedure

1. Drain vehicle fuel completely via fuel rail whenever possible.
2. Turn vehicle ignition to RUN position for 30 seconds allowing fuel level reading to stabilize. Confirm the return of fuel gauge reading to zero.
3. Turn ignition off. Fill fuel tank to 40% with next test fuel in sequence. Fill-up fuel temperature must be less than 50°F.
4. Start vehicle and execute catalyst sulfur removal procedure described in Appendix B. Apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. Engine oil temperature in the sump will be measured and recorded during the sulfur removal cycle.
5. Perform four vehicle coast downs from 70 to 30 mph, with the last two measured. The vehicle will be checked for any obvious and gross source of change in the vehicle's mechanical friction if the individual run fails to meet the following repeatability criteria: 1) maximum difference of 0.5 seconds between back-to-back coastdown runs from 70 to 30 mph; and 2) maximum ±7 percent difference in average 70 to 30 mph coastdown time from the running average for a given vehicle.
6. Drain fuel and refill to 40% with test fuel. Fill-up fuel should be at approximately 50°F.
7. Drain fuel again and refill to 40% with test fuel. Fill-up fuel should be at approximately 50°F.
8. Soak vehicle for at least 12 hours to allow fuel temperature to stabilize to the test temperature.

Catalyst Sulfur Purge Cycle

This procedure is designed to cause the vehicle to transiently run rich at high catalyst temperature, to remove accumulated sulfur from the catalyst, via hydrogen sulfide formation. The catalyst inlet temperature will be monitored during this procedure. It is required to demonstrate that the catalyst inlet temperature exceeds 700°C during the WOT accelerations and that rich fuel/air mixtures are achieved during WOT. If these parameters are not achieved, increased loading on the dynamometer could be added for this protocol (but not during the emissions test). Increased loading is not included in this proposal.

1. Drive the vehicle from idle to 55 mph and hold speed for 5 minutes (to bring catalyst to full working temperature).
2. Reduce vehicle speed to 30 mph and hold speed for one minute.
3. Accelerate at WOT (wide-open throttle) for a minimum of 5 seconds, to achieve a speed greater than 70 mph. Continue WOT above 70 mph, if necessary to achieve 5-second acceleration duration. Hold the peak speed for 15 seconds and then decelerate to 30 mph.
4. Maintain 30 mph for one minute.
5. Repeat steps 3 and 4 to achieve 5 WOT excursions.
6. One sulfur removal cycle has been completed.
7. Repeat steps 1 to 5 for the second sulfur removal cycle.
8. The protocol is complete if the necessary parameters have been achieved.

Vehicle Conditioning

1. Move vehicle to test area without starting engine. Start vehicle and perform the EPA Urban Dynamometer Driving Schedule (UDDS) followed by two Highway Fuel Economy Driving Schedules (HWFET) followed by a US06 Supplemental FTP Driving Schedule (US06) test. During the prep cycle, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system. Following the first two prep cycles, allow vehicle to idle in park for two minutes, then shut-down the engine for 2-5 minutes. Following the last prep cycle, allow the vehicle to idle for two minutes, then shut down the engine in preparation for the soak.
2. Move vehicle to test area without starting engine.
3. Park vehicle in soak area at proper temperature (75 °F) for 12-36 hours. During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device.
4. Move vehicle to test area without starting engine.
5. Conduct LA-92 prep cycle and then soak vehicle for 12-36 hours.

APPENDIX C

Test results are provided in a separate file
CRC RW-107-3 Results Appendix C.csv