CRC Report No. E-94-2

EVALUATION AND INVESTIGATION OF FUEL EFFECTS ON GASEOUS AND PARTICULATE EMISSIONS ON SIDI IN-USE VEHICLES

March 2017

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CRC Project E-94-2

FINAL REPORT

SwRI® Project No. 03.20955

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FOREWORD

This work was funded by the Coordinating Research Council (CRC), Inc. The Southwest Research Institute® Project Manager was Mr. Peter Morgan, Principal Engineer, Advanced Powertrain and Emission. Technical staff members who contributed to this work were Mr. Ian Smith, Engineer, Spark Ignited Engine Research and Development; Mr. Kevin Whitney, Manager, Advanced Powertrain and Emissions; Dr. Imad Abdul-Khalek, Sr. Program Manager, Particle Science; Mr. Vinay Premnath, Research Engineer, Particle Science; Ms. Svitlana Kroll, Sr. Research Scientist, Emissions R&D; and Mr. Brent Shoffner, Manager, Fuels and Driveline Lubricants Research. The statistical analysis of the emissions data was conducted by Mr. Robert Crawford of Rincon Ranch Consulting. Mr. Michael Viola from General Motors and Mr. Scott Mason from Phillips 66 served as the CRC technical contacts for this project, and Dr. Christopher J. Tennant represented the project sponsor, CRC.

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LIST OF ACRONYMS

AKI ....Anti Knock Index
CAFE ....Corporate Average Fuel Economy
CARB.............California Air Resources Board
CH_4.................Methane
CO ....Carbon Monoxide
CO_2.................Carbon Dioxide
CPC ....Condensation Particle Counter
CRC................Coordinating Research Council
CVS ....Constant Volume Sampling
CVT................Continuously Variable Transmission
DBE................Double Bond Equivalent
DOE ....Department of Energy
DTC................Diagnostic Trouble Code
EC ....Elemental Carbon
ECD................Electron Capture Detector
EEPS ....Engine Exhaust Particle Sizer
EISA...............Energy Independence and Security Act
EPA ....Environmental Protection Agency
EtOH ....Ethanol Content
FID ....Flame Ionization Detector
GHG...............Greenhouse Gas
MON ....Motor Octane Number
MSS................Microsoot Sensor
NA..................Naturally Aspirated
NMHC............Non-Methane Hydrocarbon
NO_x ....Oxides of Nitrogen
N_2O ....Nitrous Oxide
OC ....Organic Carbon
OEM...............Original Equipment Manufacturer
PM..................Particulate Matter
PMI ....Particulate Mass Index
PMP................Particle Measurement Program
PN ....Particle Number
RON ....Research Octane Number
RVP................Reid Vapor Pressure
SIDI................Spark-Ignited Direct-Injection
SPNMS ....Solid Particle Number Measuring System
SPSS...............Solid Particle Sampling System
SRC ....Standard Road Cycle
SwRI ....Southwest Research Institute
THC................Total Hydrocarbon
TOR................Thermal/Optical Reflectance
UDC ....Unified Drive Cycle
VIN ....Vehicle Identification Number

EXECUTIVE SUMMARY

The Corporate Average Fuel Economy (CAFE) and Greenhouse Gas (GHG) emissions standards for model year 2017-2025 light-duty vehicles are significantly more stringent than those applicable to vehicles manufactured prior to model year 2017. This has influenced manufacturers to develop new engine technologies, such as spark ignited direct injection (SIDI) gasoline engines, to improve fuel economy. Currently, many manufacturers are producing both naturally aspirated (NA) and turbo-charged SIDI engines in light-duty vehicles and are meeting both gaseous and particulate matter (PM) emissions standards with E0 certification fuel. Europe is implementing, for the first time, a particle number (PN) standard starting with EURO VI emissions regulations. There is an interest to investigate the impacts of various fuel parameters on regulated and unregulated gaseous and particulate (mass and number) exhaust emissions from in-use vehicles with SIDI engines.

This project, Coordinating Research Council (CRC) E-94-2, was conducted by Southwest Research Institute (SwRI) in order to investigate variations in regulated gaseous, greenhouse gas, PM and PN emissions from vehicles equipped with SIDI engines over a range of fuel properties. Project E-94-2 is a continuation of work completed in CRC Projects E-94-1 and E-94-1a.

Eight fuels were provided for this test program, with variations in the following fuel properties: octane number represented as the anti-knock index (AKI), Particulate Matter Index (PMI), and ethanol content (EtOH). The fuels matrix was selected to represent high and low values for each of these fuel properties. The AKI ranged from 87.1 to 94.1, the PMI ranged from 1.26 to 2.65, and the ethanol content ranged from 0% to 9.56% by volume. The target value for the high ethanol content fuel was 9.5%, so all high ethanol content fuels will be referred to as 9.5% by volume. AKI values reported are the average of measurements performed by Labs A, B, and D. Ethanol content and PMI values reported are measurements from Lab C only to ensure consistency between values reported for E-94-2 and E-94-3. Fuel properties and test order can be seen in Table ES-1 and Figure ES-1.

TABLE ES-1. FUEL AKI, PMI AND ETOH CONTENT

AKI[1]	Ethanol[2] (EtOH), vol%	PMI[2]	Fuel Letter	Fuel Test Order
87.2	9.55	1.42	A	1
88.2	0	2.61	D	2
87.1	9.56	2.65	B	3
93.8	0	1.26	G	4
93.7	9.51	2.54	F	5
87.9	0	1.40	C	6
93.6	9.56	1.28	E	7
94.1	0	2.31	H	8

[1] Average of measurements by Labs: A, B and D.
[2] Measurement performed by Lab C

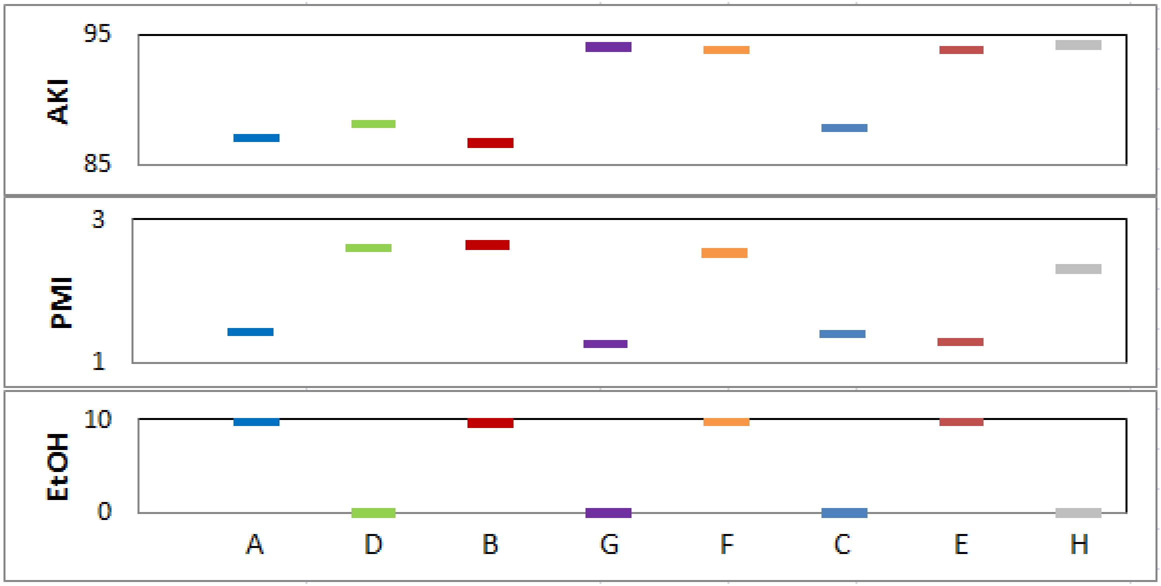


FIGURE ES-1. GRAPHICAL REPRESENTATION OF AKI, PMI, AND ETOH CONTENT FOR EACH FUEL

The test fleet included twelve modern vehicles equipped with SIDI engines. These vehicles were deemed representative of the spectrum of models commonly available in the U.S. based on weight class and engine configuration. Table ES-2 shows an overview of the twelve vehicles used in this program. The model names of these vehicles have been blinded in the report with the randomly generated assignation of the following letter codes: A, B, C, D, E, F, G, H, I, J, K and L.

TABLE ES-2. VEHICLES USED IN E-94-2 PROGRAM

Vehicle	Engine Type	Certification Group
2011 Chevrolet Equinox	2.4L Naturally Aspirated, I4	EPA Tier 2 Bin 4; California ULEV qualified
2013 Chevrolet Malibu	2.0L Turbocharged, I4	EPA Tier 2 Bin 4
2013 Chevrolet Malibu	2.5L Naturally Aspirated, I4	EPA Tier 2 Bin 4
2013 Ford F150XL	3.5L Turbocharged, V6	EPA Tier 2 Bin 5 LDT2; California not certified for sale
2013 Honda Accord	2.4L Naturally Aspirated, I4	EPA Tier 2 Bin 5
2013 Hyundai Santa Fe	2.0L Turbocharged, I4	EPA Tier 2 Bin 5
2013 Hyundai Santa Fe	2.4L Naturally Aspirated, I4	EPA Tier 2 Bin 5
2015 Lexus NX200t	2.0L Turbocharged, I4	EPA Tier 2 Bin 5 LDT2; California LEVIII-ULEV125-LDT2
2014 Mazda Mazda6	2.5L Naturally Aspirated, I4	EPA Tier 2 Bin 5
2013 Mercedes-Benz GLK350	3.5L Naturally Aspirated, V6	EPA Tier 2 Bin 4
2010 Nissan Juke	1.6L Turbocharged, I4	EPA Tier 2 Bin 5
2012 VW Jetta GLI	2.0L Turbocharged, I4	EPA Tier 2 Bin 5; California ULEV II

The twelve vehicles were split into groups of four; each group completed testing on all eight fuels before the next group of vehicles was tested. Each vehicle was tested twice over the LA92 drive cycle. During this drive cycle, non-methane hydrocarbons (NMHC), carbon monoxide (CO), oxides of nitrogen (NO_X), and nitrous oxide (N_2O), elemental carbon (EC), organic carbon (OC), particulate mass (PM), soot mass, particle size and fuel economy were determined. Upon completion of two tests a repeatability check was run on total hydrocarbons (THC), CO and NO_X, with the following criteria: less than a 30% difference in THC (g/mi), and less than a 50% difference in CO (g/mi) and NO_X (g/mi). If any of these criteria failed then the vehicle was tested a third time and the results reported.

Upon completion of the testing, a statistical analysis was conducted to determine how the variation of AKI, PMI, and EtOH among the fuels affected the particulate and gaseous emissions of the vehicles in the test program. The particulate emissions examined were the weighted-average LA92 emissions for PN, PM and EC, plus the Phase 1 PM emissions. of the vehicles. The gaseous emissions examined were the weighted-average emissions for THC, CO, NO_X and carbon dioxide (CO_2).

The specific questions of interest in the analysis were the following:

1. Can the effects of AKI, PMI and EtOH be observed in all of the vehicles tested? If present, is sensitivity to these factors wide-spread in the test fleet or associated with only a few vehicles?
2. What are the effects of fuel on emissions for the overall test fleet? Are the effects seen in subsets of the data including: the 4-cylinder engines grouped by air induction type (NA versus turbocharged) and all twelve vehicles grouped into Low, Mid and High PM emitting vehicles by their average PM emissions?
3. Can the fuel effects observed in the entire test fleet also be observed in Low PM emitting vehicles, or are the effects too small at low PM levels to be detected?
4. Are the results of the study influenced by any of the 22 additional fuel parameters (other than AKI, PMI and EtOH) that were measured?

Throughout the analysis, PMI had the strongest effect on particulate emissions, whether measured as LA92 PN, PM, Phase 1 PM, or EC (see Table ES-2). Increasing PMI from low (1.3) to high (2.5) was found to nearly double, or more than double, LA92 PM and other measures of particulate emissions. The addition of 9.5% ethanol (E10) increased particulate emissions by 12 to 57 percent versus the baseline E0. This effect was clearly observed in three of the four fuel pairs with matched AKI and PMI, but was generally not seen in the AKI 94 High PMI fuels. Conversely, fuel octane number (AKI) was found to have no effect on particulate emissions in the entire test fleet or in any of its subgroups. Figure ES-3 illustrates the impact of PMI, ethanol content and AKI on PM emissions from the test fleet. The percent changes shown for fuels reflect the average vehicle in the test fleet, and, thus, refer to the changes in the mean emission levels between the fuels.

TABLE ES-3. EFFECT OF FUELS ON PARTICULATE EMISSIONS OF THE TEST FLEET

Fuel Change	PN	PM	Phase 1 PM	EC
PMI 1.3 -> 2.5	↑ PN by 73-117% in all fuels Larger effect in 4-cyl naturally aspirated vehicles	↑ PM by 106-142% in all fuels Larger effect in 4-cyl naturally aspirated vehicles	↑ Phase 1 PM by 62-150% in all fuels Smaller effect in 4-cyl naturally aspirated vehicles	↑ EC by 114-173% in all fuels Similar effects in 4-cyl vehicles by air induction type
EtOH 0% -> 9.5%	↑ PN by 14-39% in all fuels	↑ PM by 18-46% (except AKI 94 High PMI)	↑ Phase 1 PM by 12-57% (except AKI 94 High PMI)	↑ EC by 12-57% (except AKI 94 High PMI)
AKI 87 -> 94	No Effect	No Effect	No Effect	No Effect

Note: The ranges cited for the percentage changes caused by fuels refer to the lowest and highest percentage effects found for the test fleet overall or in any of the subgroups examined (by air induction type for 4-cylinder engines and by average PM level for all vehicles).

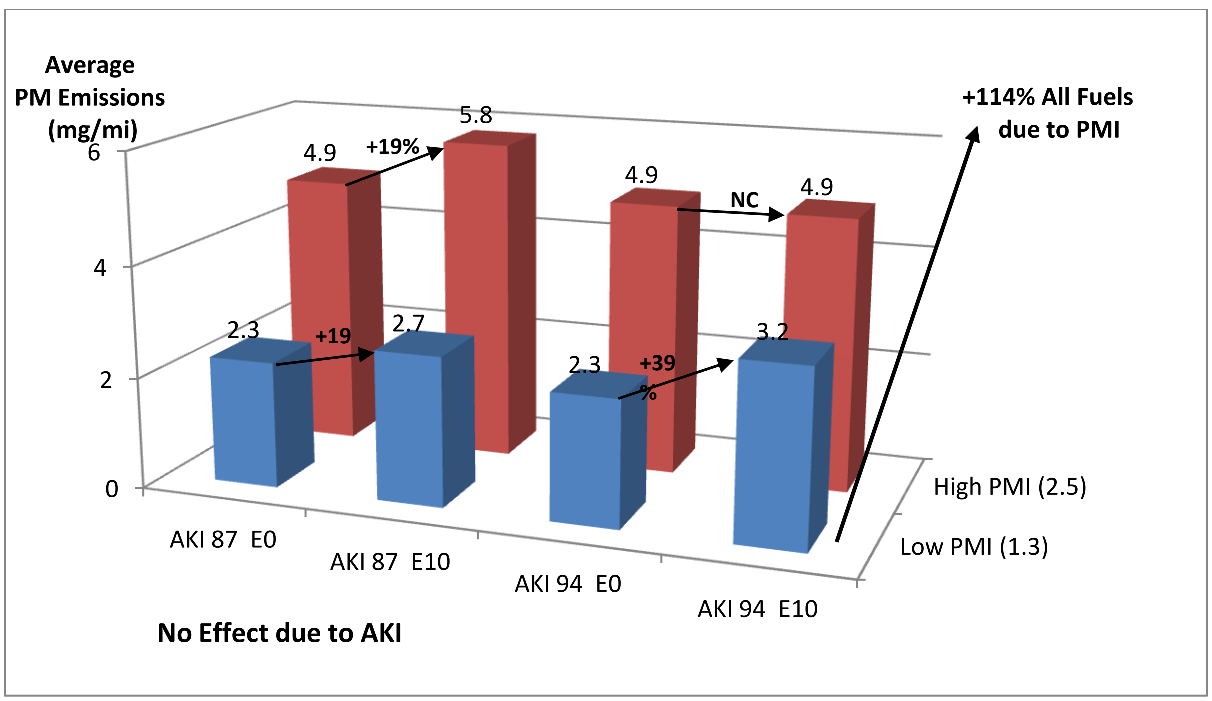


FIGURE ES-2. THE EFFECT OF AKI, PMI, AND ETOH ON PM EMISSIONS OF THE TEST FLEET. EMISSIONS SHOWN FOR THE AVERAGE VEHICLE.

The fuel effects due to PMI and EtOH are seen not only in the entire test fleet, but also in the individual vehicles and in the subgroups by air induction type (naturally aspirated and turbocharged 4-cylinder engines only) and vehicle PM level (low, medium, and high emitting for all vehicles). For the vehicles individually, the magnitude of the emissions response to PMI and EtOH can vary due to individual vehicle performance. The influence of PMI and EtOH is also observed in low PM emitting vehicles. The emission increases associated with high PMI fuels in low PM emitting vehicles is large enough to be easily measured in all cases, while EtOH effects are smaller and not always detected.

PMI had no effect on any of the four gaseous pollutants, with one exception (for THC) that was traced to the performance of an individual vehicle. Ethanol content at E10 was found to *decrease* CO emissions, but *increase* CO_2 emissions by small amounts (0.5-0.8%), in the subgroup of 4-cylinder NA vehicles, but not in turbocharged vehicles. Increasing octane from 87 to 94 AKI was found to *decrease* THC emissions of the 4-cylinder NA vehicles. No octane effect on THC emissions was seen in the 4-cylinder turbocharged vehicles. This suggests that in addition to fuel effects, vehicle hardware design and vehicle-to-vehicle variability can contribute to overall emissions.

Subsequent to this study, CRC is undertaking program E-94-3 to test whether the method of blending fuels has a substantial effect on the emissions that are observed. In E-94-3, four splash-blended E10 fuels will be tested on four of the vehicles used in this study. The comparison of emissions in E-94-3 to those observed here at comparable ethanol levels will test the effect of two fuel blending techniques on the emission results.

1.0 BACKGROUND

The Corporate Average Fuel Economy (CAFE) and Greenhouse Gas (GHG) emissions standards for 2017-2025 model year light-duty vehicles are significantly more stringent than the current standards. This has influenced manufacturers to develop new engine technologies, such as spark ignited direct injection (SIDI) gasoline engines, to improve fuel economy. Currently many manufacturers are producing both naturally aspirated (NA) and turbo-charged SIDI engines in light-duty vehicles and are meeting both gaseous and particulate matter (PM) emissions standards with 0% ethanol (E0) certification fuel. Europe has implemented, for the first time, a particle number (PN) standard starting with the EURO VI emissions regulations. The California Air Resources Board (CARB) is also investigating using a PN standard.

In conversations with CRC, there has been interest in the effects of the particulate mass index (PMI) of a fuel on the performance of an SIDI-equipped vehicle. This index, developed by Aikawa, Sakurai and Jetter[3], is described as being a predictive model which is "based on the weight fraction, vapor pressure, and double bond equivalent (DBE) value of each component in the fuel" from which the PMI could predict the "total PM mass, regardless of engine type or test cycle." That is, the PM Index is proportional to the total PM mass. The octane number and ethanol content were also varied to study their effects on the performance and emissions of an SIDI-equipped vehicle. This work is a continuation of previous projects, E-94-1[4] and E-94-1a[5], and is a much more comprehensive evaluation of the interplay between fuel properties and SIDI technology.

[3] Aikawa, K., T. Sakurai, J. Jetter, "Development of a Predictive Model for Gasoline Vehicle Particulate Matter Emissions," SAE Paper Number 2010-01-2115, October 25, 2010.
[4] P. Morgan, P. Lobato, V. Premnath, and S. Kroll, "CRC Report No. E-94-1: Evaluation and Investigation of Gaseous and Particulate Emissions on SIDI In-Use Vehicles with Higher Ethanol Blend Fuels."
[5] P. Morgan, P. Lobato, V. Premnath, and S. Kroll, "CRC Report No. E-94-1a: Determination and Evaluation of New Prep Cycle On the Fuel Effects of Gaseous Emissions on SIDI In-Use Vehicles."

2.0 INTRODUCTION

In this program, CRC was interested in investigating how octane number, ethanol concentration, and PMI levels in match blended fuel affect particulate mass, particle number, fuel economy, and emissions in naturally aspirated and turbocharged SIDI vehicles.

To address how these fuel properties affect emissions from modern SIDI engines, twelve representative vehicles were selected, with three vehicles being used from CRC E-94-1 and CRC E-94-1a. LA92 drive cycles were conducted while collecting gaseous, particulate mass, elemental carbon, organic carbon, and particle number emissions data.

Three properties were varied for each fuel: AKI, PMI, and ethanol content. Eight fuels were match-blended in order to keep as many properties (T50, T90, sulfur, benzene, etc) relatively unchanged while varying between high and low values for EtOH, AKI, and PMI. EtOH ranged from a low value of 0% to high value of 9.56% (for the purposes of reporting all high ethanol content fuels, E10, will be referred to as 9.5% ethanol), AKI ranged from a low value of 87.1 to a high value of 94.1 and PMI ranged from a low value of 1.24 to a high value of 2.65. AKI values reported are the average of measurements performed by Labs A, B, and D. Ethanol content and PMI values reported are measurements from Lab C only to ensure consistency between values reported for E-94-2 and E-94-3. Fuel properties and test order can be seen in Figure 1.

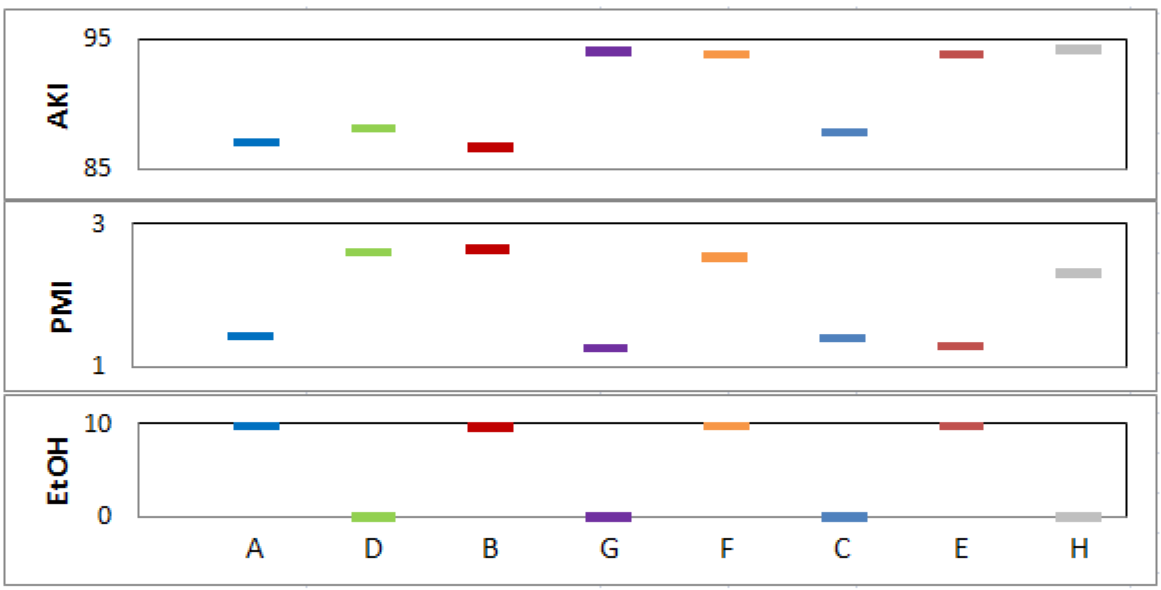


FIGURE 1. GRAPHICAL REPRESENTATION OF AKI, PMI, AND ETOH CONTENT FOR EACH FUEL

Due to the large number of fuels and vehicles that were tested the vehicle set was broken up into three groups of four vehicles. Each vehicle group was tested with each fuel consecutively, with one fuel being tested a week. Gaseous exhaust emissions, particulate mass, particle number, elemental carbon, organic carbon, and fuel economy were measured over two

LA92 drive cycles conducted on consecutive days. The results of these two tests were then compared for repeatability; namely the repeatability of measured THC, CO, and NO_X. Repeatability criteria of less than a 30% difference between for THC (g/mi), and less than a 50% difference for CO (g/mi) and NO_X (g/mi), evaluated on the weighted average results for the first and second tests, were required. If any of these repeatability criteria were not met then a third test was conducted. The formula for percent difference can be seen below, where T_1 is the value of THC, CO or NO_X for the first test and T_2 is the value for the second test.

$$\%\ \text{Difference} = \left(\frac{T_1 - T_2}{\frac{T_1+T_2}{2}}\right) \times 100\%$$

3.0 TEST SETUP

3.1 Fuels

3.1.1 Types of Fuel Used

Eight fuels were received for this program. The fuels were designed to meet a range of high and low targeted values for ethanol content, octane, and PMI. The mid-range distillation and vapor pressure characteristics of all eight fuels were matched, and other parameters (e.g. olefin, total aromatics, and sulfur content) were also held within a narrow band of values in order to limit the number of properties that differed between similar fuels. Match blending provides significantly more control over fuel properties than does splash blending. Match blending is the process by which the base fuel is altered such that when ethanol is added the other fuel properties (e.g. effective octane rating, vapor pressure, etc.) more closely match the desired specifications. Splash blending consists of adding ethanol to the base fuel without any alterations to keep fuel properties unchanged. Honda collected a large set of data and compiled a histogram (Figure 2) showing the PMI of fuels found in the U.S. These data are unpublished at the time of this report and are used with permission from Honda R&D. The averages of the high and low PMI fuels used in this study are shown below. These averages fall within the typical PMI range for fuel found in the United States.

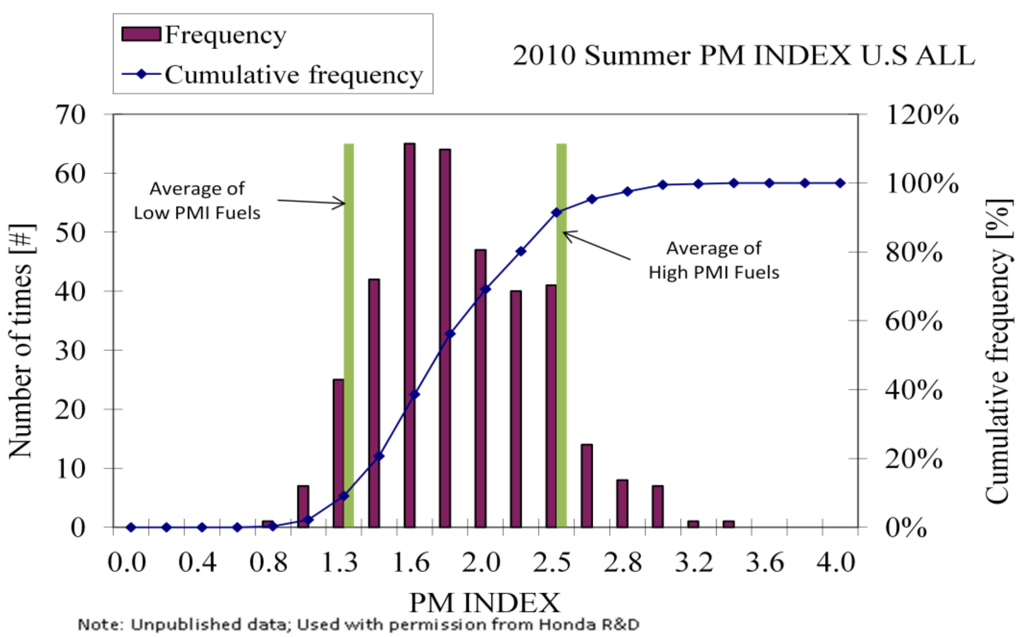


FIGURE 2. HISTOGRAM OF FUEL PMI IN THE UNITED STATES[6]

To calculate a particulate matter index number, the following equation was used, which takes into account the effects of molecular structure, volatility, vapor pressure, wetting, and stratification properties of the fuel.

[6] Unpublished data; used with permission from Honda R&D

$$PMI = \sum_{i=1}^{n} \frac{DBE_i + 1}{VP_{(443\ K)_i}} Wt_i$$

"Regarding the generation of soot, which can be considered the bulk of the PM emission increment measured in the test, it generally increases as DBE increases. Also taken into consideration is the fact that the lower the boiling point of the substance, the higher its vapor pressure and the greater its chances of evaporating into the gas phase, thereby mitigating the formation of soot. Here, Wt indicates the weight fraction of the added substance. The weight fraction factor reflects the fact that a component's concentration is proportional to the effect it will have upon PN emissions"[7] DBE represents the double bond equivalent, and VP is the vapor pressure, at 443 °K. The numerator is "DBE+1 because paraffins, whose DBE is 0, are assumed to form no PM but still must be accounted for. That is, to allow the values of paraffins to be used as the reference, 1 was added to their DBE in the evaluation"[7].

3.1.2 Fuel Blending

The CRC provided fuel specifications used for match blending all eight fuels, which can be seen in Table 1 and Table 2. These specifications were provided to a fuel supplier and each fuel had a complete analysis performed on it to ensure it met specifications.

TABLE 1. CRC-PROVIDED FUEL SPECIFICATIONS FOR FUELS A THROUGH D

		Tolerance	Fuel A	Fuel B	Fuel C	Fuel D
RON		0.5	91	91	91	91
MON			83	83	83	83
AKI			87	87	87	87
Sensitivity		-	8.5	8.5	8.5	8.5
Aromatics	vol. %	2	25	25	25	25
PMI	Honda Eq	0.2	1.4 Max	2.4 Min	1.4 Max	2.4 Min
RVP	psi		6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5
Ethanol	vol. %	0.5	10	10	0	0
Sulfur	ppmw	2	10	10	10	10
Benzene	vol. %	0.2	0.6	0.6	0.6	0.6
Olefins	vol. %	2	4.0-6.0	4.0-6.0	4.0-6.0	4.0-6.0
T50	deg F	10	170-210	170-210	170-210	170-210
T90	deg F	10	280-320	320-350	280-320	320-350
FBP	deg F	10	360-400	400-440	360-400	400-440
C10+ Aromatics	vol. %	1	<4	>8	<4	>8

[7] Aikawa, K., T. Sakurai, J. Jetter, "Development of a Predictive Model for Gasoline Vehicle Particulate Matter Emissions," SAE Paper Number 2010-01-2115, October 25, 2010.

TABLE 2. CRC-PROVIDED FUEL SPECIFICATIONS FOR FUELS E THROUGH H

Fuel		Tolerance	Fuel E	Fuel F	Fuel G	Fuel H
RON		0.5	98	98	98	98
MON			88	88	88	88
AKI			93	93	93	93
Sensitivity		-	8.5	8.5	8.5	8.5
Aromatics	vol. %	2	25	25	25	25
PMI	Honda Eq	0.2	1.4 Max	2.4 Min	1.4 Max	2.4 Min
RVP	psi		6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5
Ethanol	vol. %	0.5	10	10	0	0
Sulfur	ppmw	2	10	10	10	10
Benzene	vol. %	0.2	0.6	0.6	0.6	0.6
Olefins	vol. %	2	4.0-6.0	4.0-6.0	4.0-6.0	4.0-6.0
T50	deg F	10	170-210	170-210	170-210	170-210
T90	deg F	10	280-320	320-350	280-320	320-350
FBP	deg F	10	360-400	400-440	360-400	400-440
C10+ Aromatics	vol. %	1	<4	>8	<4	>8

The eight fuels were analyzed for RON, MON, sulfur, olefins, aromatics, oxygen, benzene, ethanol, water content, carbon/hydrogen ratio, RVP and fuel boiling range (distillation). Fuel analyses were performed by four separate labs to ensure that there were minimal differences in laboratory measurement of fuel properties. For the purposes of this report, data generated by Lab C were used in the analysis for ethanol and PMI. Each fuel met the specifications provided to the fuel supplier and a summary of the anti-knock index value, ethanol content and PMI for each can be found in Table 3. The complete analyses of all eight fuels used in this program are listed in Appendix A. Properties of the EEE certification fuel used for initial vehicle checkout are listed in Appendix A as well.

TABLE 3. FUEL OCTANE, ETHANOL, AND PMI SUMMARY

Fuel Letter	Fuel Test Order	AKI[8]	Ethanol (EtOH)[9], vol%	PMI[9]
A	1	87.2	9.55	1.42
D	2	88.2	0	2.61
B	3	87.1	9.56	2.65
G	4	93.8	0	1.26
F	5	93.7	9.51	2.54
C	6	87.9	0	1.40
E	7	93.6	9.56	1.28
H	8	94.1	0	2.31

[8] Average of measurements by Labs: A, B and D.
[9] Measurement performed by Lab C.

These fuel blends were provided in standard drums. The drums remained in a temperature-controlled facility until the morning of a fuel change procedure for a given test vehicle, at which point fuel was dispensed as needed. After the fuel change procedure, the fuel was allowed to soak in the vehicle in a temperature-controlled environment for a day to stabilize the temperatures of the vehicle and fuel before the preconditioning procedure. Further details on this fuel change, preconditioning and testing procedure are provided in Appendix B.

3.2 Test Vehicles

Twelve vehicles were selected for this program, the details of which are shown in Table 4 through Table 6. These vehicles were selected because they were available, widely used in the U.S. and were equipped with engines using gasoline direct injection. Note that while all of these vehicles utilize direct injection, the Lexus NX200t utilizes both direct injection and port injection. All vehicles were two-wheel drive, and all testing was conducted on a two-wheel drive dynamometer. There was interest in selecting vehicles representing both turbocharged and naturally aspirated engine designs as well as vehicles of different weight classes. To further examine the difference between turbocharged and naturally aspirated engines two Hyundai Santa Fes and two Chevrolet Malibus that differed in engine type were included in the test vehicle set. Both the Honda Accord and Nissan Juke were equipped with continuously variable transmissions (CVTs). The Honda Accord required an additional controller, provided by the Original Equipment Manufacturer (OEM), to drive properly on the dynamometer. The Nissan Juke also required a new, replacement controller which was provided by the OEM.

TABLE 4. DESCRIPTION OF VEHICLE IN FIRST VEHICLE TEST GROUP

Vehicle make		Hyundai	Hyundai	VW	Mazda
Vehicle model		Santa Fe	Santa Fe	Jetta – GLI	Mazda6
Model year		2013	2013	2012	2014
Engine family		DHYXV02.01TE	DHYSV02.41UE	CADXJ02.03UA	ETKXV02.55NM
Engine evap. code		DHYXR0135PDM	DHYXR0135PDM	CADXR0110238	ETKXR0120GAK
Engine displacement		2.0L Turbocharged, I4	2.4L Naturally Aspirated, I4	2.0L Turbocharged, I4	2.5L Naturally Aspirated, I4
Transmission		6-speed Automatic	6-speed Automatic	6-speed Automatic	6-speed Automatic
Odometer, miles (as received)		22,671	24,126	8,141	11,752
Emissions Class		EPA Tier 2 Bin 5	EPA Tier 2 Bin 5	EPA Tier 2 Bin 5; California ULEV II	EPA Tier 2 Bin 5
Estimated Test Weight Class, lbs		4250	4000	3500	3500
EPA Tier 2 Certification Standard	NMOG, g/mi	0.075	0.075	0.075	0.075
	CO, g/mi	3.4	3.4	3.4	3.4
	NO_X, g/mi	0.05	0.05	0.05	0.05
	PM, g/mi	0.01	0.01	0.01	0.01

TABLE 5. DESCRIPTION OF VEHICLES IN SECOND TEST GROUP

Vehicle make		Chevrolet	Lexus	Mercedes	Ford
Vehicle model		Equinox	NX200t	GLK350	F150XL
Model year		2011	2015	2013	2013 New
Engine family		BGMXJ02.4151	FTYXT02.0KEM	DMBXV03.5BN4	DFMXT03.54DX
Engine evap. code		BGMXR0138813	FTYXR0132A22	DMBXR0155LNS	DFMXR0265NBV
Engine displacement		2.4L Naturally Aspirated, I4	2.0 L Turbocharged, I4	3.5L Naturally Aspirated, V6	3.5L Turbocharged, V6
Transmission		6 speed Automatic	6-speed Automatic	7-speed Automatic	6 speed Automatic
Odometer, miles (as received)		10,591	62*	22,336	5,203
Emissions Class		EPA Tier 2 Bin 4 California: ULEV qualified	EPA Tier 2 Bin 5 LDT2; California LEVIII-ULEV125-LTD2	EPA Tier 2 Bin 4	EPA Tier 2 Bin 5 LTD2 California: not for sale
Estimated Test Weight Class, lbs		4000	4250	4500	6000
EPA Tier 2 Certification Standard	NMOG, g/mi	0.07	0.075	0.07	0.075
	CO, g/mi	2.1	3.4	2.1	3.4
	NO_X, g/mi	0.04	0.05	0.04	0.05
	PM, g/mi	0.01	0.01	0.01	0.01
*Note: 4,000 miles performed on mileage accumulation dynamometer (MAD) for vehicle break-in prior to testing					

TABLE 6. DESCRIPTION OF VEHICLES IN THIRD TEST GROUP

Vehicle make		Honda	Nissan	Chevrolet	Chevrolet
Vehicle model		Accord	Juke	Malibu	Malibu
Model year		2013	2011	2013	2013
Engine family		DHNXV02.4FB3	BNSXV01.6GDA	DGMXVO2.5001	DGMXV02.0021
Engine evap. code		DHNXR0121VEA	BNSXR0090PBB	DGMXR0133810	DGMXR0133810
Engine displacement		2.4L Naturally Aspirated, I4	1.6L Turbocharged, I4	2.5L Naturally Aspirated, I4	2.0L Turbocharged, I4
Transmission		CVT	CVT	6-speed Automatic	6-speed Automatic
Odometer, miles (as received)		21,334	52,911	23,847	26,033
Emissions Class		EPA Tier 2 Bin 5	EPA Tier 2 Bin 5	EPA Tier 2 Bin 4	EPA Tier 2 Bin 4
Estimated Test Weight Class, lbs		3625	3500	3750	4000
EPA Tier 2 Certification Standard	NMOG, g/mi	0.075	0.075	0.07	0.07
	CO, g/mi	3.4	3.4	2.1	2.1
	NO_X, g/mi	0.05	0.05	0.04	0.04
	PM, g/mi	0.01	0.01	0.01	0.01

Used vehicles were selected for this program so that the engines had already been broken in. However, the Lexus NX200t was purchased new. To break in the Lexus NX200t, the vehicle was operated on a mileage accumulation dynamometer (MAD) over the Standard Road Cycle (SRC) for 4,000 miles using commercially-available Top Tier qualified gasoline.

3.2.1 Vehicle Check-In

Upon receipt of the test vehicles, the powertrain control module calibrations were determined with a scanner and reported to the CRC. After the powertrain control module calibration was confirmed, an initial check-in was performed. The following items were included:

1. The vehicle identification number (VIN), test group, and evaporative emissions family were recorded and verified.
2. The vehicles were added to SwRI's test vehicle insurance policy.
3. The vehicles were visually checked for fluid leaks and damage.
4. The exhaust systems were checked for leaks.
5. Fluid levels were checked and topped off as required. The manufacturer's recommended fluids were used for each vehicle.
6. The vehicles were checked for the presence of diagnostic trouble codes (DTCs).
7. A fuel change to EEE[10] certification fuel was performed.

3.2.2 Vehicle Instrumentation and Preparation

Each vehicle was instrumented and prepared as described below:

- A Marmon flange was welded to the rear tailpipe for emissions testing.
- The engine oil was drained using two drains and fills of the crankcase with a Pennzoil GF-4 of the appropriate viscosity as recommended by the manufacturer.
- Each vehicle was operated on a MAD over the SRC for 250 miles to de-green the oil.

3.2.3 Vehicle Emissions Check-Out Test

Following check-in and setup, each vehicle received a single checkout emissions test over a standard FTP-75 driving cycle using EEE certification fuel. Regulated emissions (HC, CO, CO_2, NO_X, and PM) were recorded to confirm proper operation of the emission control systems on the test vehicles. A summary of these results is provided in Table 7. The test results were approved by the CRC-appointed program manager. The complete set of phase-level emissions data is given in Appendix C.

[10] Fuel properties for EEE certification fuel can be found in Appendix A.

TABLE 7. SUMMARY OF VEHICLE CHECKOUT EMISSIONS TESTS

	NMOG*, g/mi	CO, g/mi	NO_X, g/mi	PM, mg/mi
Vehicle A				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.025	0.226	0.028	4.2
Vehicle B				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.016	0.570	0.018	4.5
Vehicle C				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.019	0.337	0.012	2.9
Vehicle D				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.012	0.125	0.016	1.4
Vehicle E				
EPA Tier 2 Bin 4 Certification Standard for FTP-75	0.070	2.1	0.04	10
Checkout Test Weighted Results on FTP-75	0.041	1.953	0.019	10.9
Vehicle F				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.019	0.182	0.009	1.4
Vehicle G				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.042	0.471	0.014	0.4
Vehicle H				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.032	0.709	0.066	5.7
Vehicle I				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.013	0.147	0.027	1.3
Vehicle J				
EPA Tier 2 Bin 5 Certification Standard for FTP-75	0.090	4.2	0.07	10
Checkout Test Weighted Results on FTP-75	0.043	0.532	0.026	11.4
Vehicle K				
EPA Tier 2 Bin 4 Certification Standard for FTP-75	0.070	2.1	0.04	10
Checkout Test Weighted Results on FTP-75	0.008	0.478	0.012	3.5
Vehicle L				
EPA Tier 2 Bin 4 Certification Standard for FTP-75	0.070	2.1	0.04	10
Checkout Test Weighted Results on FTP-75	0.016	0.594	0.011	4.1
*Note: NMOG was determined by multiplying NMHC by 1.04 as per CFR Title 40, Part 86, Subpart S, Section 86.1810-01				

3.3 Vehicle Testing

Each vehicle/fuel combination was prepared, preconditioned, and tested as specified in the Fuel Change, Conditioning and Test Procedure (Appendix B) and the Catalyst Sulfur Purge Cycle (Appendix D). Two repeated emissions tests were conducted on consecutive days where possible; and if a third test was required due to failing the repeatability criteria it was conducted on the third consecutive day. The test protocol for each vehicle/fuel combination is shown in Figure 3.

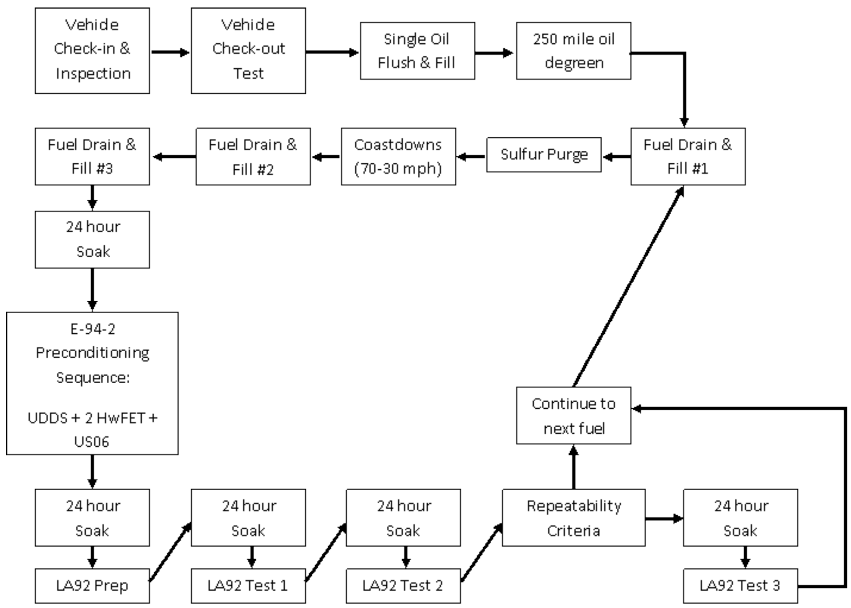


FIGURE 3. TEST PROTOCOL FOR VEHICLE/FUEL COMBINATIONS

The twelve vehicles were broken up into groups of four vehicles each. Each group of vehicles was tested with Fuels A through H. The fuel test order was randomized in an effort to minimize the influence of serial correlation in the final dataset. The order in which the fuels were tested is shown in Table 8 and does not vary from vehicle group to vehicle group. Vehicles were tested in alphabetical order for each vehicle group (e.g., A first and D last for vehicle set 1).

TABLE 8. TEST SEQUENCE

Fuel	Test Order
Fuel A	1
Fuel D	2
Fuel B	3
Fuel G	4
Fuel F	5
Fuel C	6
Fuel E	7
Fuel H	8

The emissions drive cycle was the California Air Resources Board LA92 Dynamometer Driving Schedule, often called the Unified Driving Cycle (UDC). A graphic representation of speed versus time for the LA92 is presented in Figure 4.

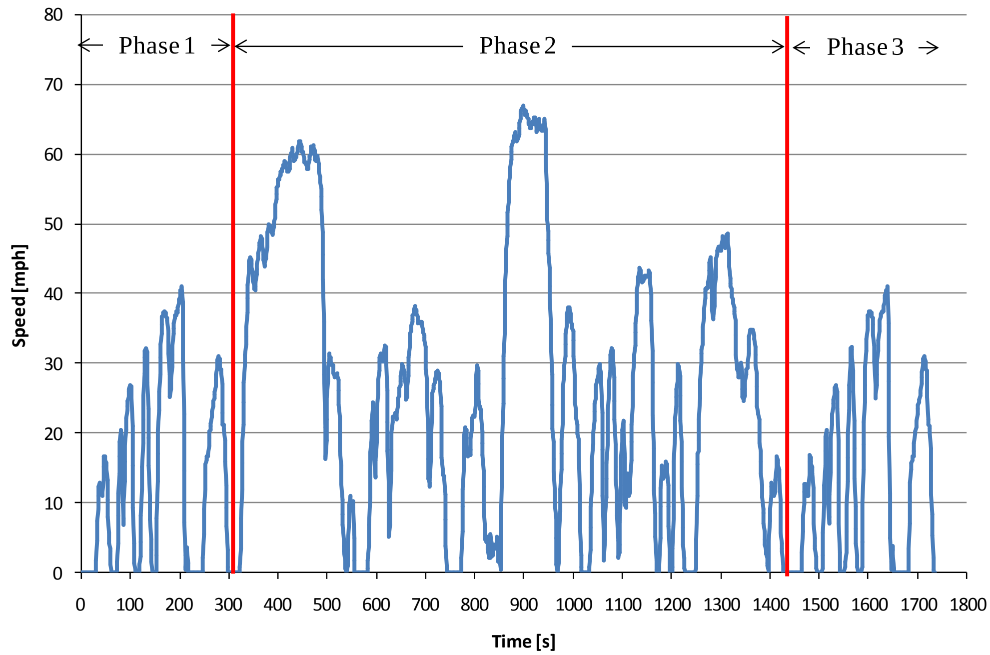


FIGURE 4. LA92 DRIVING CYCLE

For this program the LA92 was conducted as a cold-start, three-phase test, in a manner similar to the light-duty Federal Test Procedure. The LA92 consists of a 300-second cold-start phase (Phase 1) followed by an 1,135-second hot stabilized phase (Phase 2), a 600-second soak, and a hot-start phase (Phase 3) which is a repeat of the first 300-seconds. Overall cycle emissions were calculated in the same manner as the weighted FTP-75 formula, taking actual mileage from the LA92 into account. In this report, the results of the weighted FTP-75 formula will be referred to as the weighted average.

3.3.1 Emissions Chassis Dynamometer Setup

Emissions testing were conducted on a Horiba 48-inch single-roll chassis dynamometer. This dynamometer can electrically simulate inertia weights up to 15,000 lb over the FTP-75, and provides programmable road-load simulation of up to 200 hp continuous at 65 mph. Road-load coefficients provided by engineers from General Motors and Mercedes-Benz were used for the two Chevrolet Malibu's and the Mercedes-Benz GLK350, respectively. Published road-load coefficients from the EPA Test Car List were used for the remaining vehicles

One dynamometer was used for all testing throughout this program. In order to minimize any effects on emissions that can be seen with different drivers, one of two drivers was assigned to each vehicle for the entire program. Each set of tests was conducted on consecutive days where possible. During the overnight soak periods, all vehicles were fitted with a trickle charger to maintain battery conditions. Prior to testing on the dynamometer each day, the vehicle's cold tire pressures were checked and, if needed, set to the manufacturer's specification.

3.3.2 Regulated Emissions

Bagged exhaust emission concentrations of total hydrocarbons (THC), carbon monoxide (CO), methane (for determination of NMHC), oxides of nitrogen (NO_X) and carbon dioxide (CO_2) were measured in a manner consistent with the light-duty vehicle testing protocols given in 40 CFR Part 86. Fuel economy was calculated by the carbon mass balance method as given in 40 CFR Part 600. A Horiba constant volume sampler was used to collect dilute exhaust in inert bags. Dilute exhaust constituents were analyzed as shown in Table 9.

TABLE 9. DILUTE EXHAUST CONSTITUENT ANALYSIS METHODS

Constituent	Analysis Method
Total Hydrocarbon	Heated Flame Ionization Detector (HFID)
Methane	Flame Ionization Detector (FID)
Carbon Monoxide	Non-Dispersive Infrared Detector (NDIR)
Carbon Dioxide	Non-Dispersive Infrared Detector (NDIR)
Oxides of Nitrogen	Chemiluminescent Detector (CLD)
Nitrous Oxide	Gas Chromatograph with Electron Capture Detector (GC-ECD)
Particulate Mass	Gravimetric Measurement

For the determination of PM mass emissions, a proportional sample of dilute exhaust was drawn through a 47 mm Whatman Teflon® membrane filter. The PM sampling method used 40 CFR Part 1065 protocols adapted to light-duty chassis dynamometer testing. The sample zone was maintained at 47 °C ± 5 °C. A PM 2.5 cyclonic separator was used upstream of filter collection. Separate filters were collected for the three phases of the LA92 test cycle.

3.3.3 Unregulated Emissions

Table 10 below shows the analysis methods used for measuring the unregulated emissions. Multiple methods were used for analyzing the particulate emissions to obtain a more detailed characterization of the emissions as well as cross-check.

TABLE 10. UNREGULATED EMISSIONS ANALYSIS METHODS

Constituent	Analysis Method
Nitrous Oxide	Micro-electron Capture Detector (micro-ECD)
Particle Size Distribution	Spectrometer (EEPS and SPSS)
Particle Number	Condensation Particle Counter (CPC) 3790 – particles greater than 23 nm in diameter
	Condensation Particle Counter (CPC) 3025 – particles greater than 3 nm in diameter
PM	Photo-acoustic
EC + OC	Thermo-optical Method

3.3.3.1 Nitrous Oxide

Nitrous Oxide (N_2O) was measured with the micro-electron capture detector (micro-ECD) channel of an Agilent Greenhouse Analyzer, 7890A GC (Figure 5). In this measurement, pre-columns vent heavier components, including water and O_2. The ECD uses a radioactive beta particle (electron) emitter; a metal foil holding 10 millicuries (370 MBq) of the radionuclide nickel-63. The electrons are formed by collision with auxiliary gas. The electrons are attracted to a positively charged anode, generating a steady current. The sample is carried into the detector by carrier gas and mixed with a stream of 5% / 95% Methane / Argon mixture flowing through the detector. Analyte molecules then capture the electrons and reduce the current between the collector anode and a cathode. The N_2O concentration is thus proportional to the degree of electron capture. The decrease in detector current due to the loss of the thermal electrons is converted into the digital signal and quantified. The detection level for N_2O is less than 3.2 ppb (parts per billion). This detection limit is a hundred times lower than the normal concentration of N_2O in the atmosphere. Nitrous oxide was measured for the three phases of the LA92 test cycle. Results were corrected for background.

FIGURE 5. AN AGILENT GREENHOUSE ANALYZER AND SAMPLE INTRODUCTION SYSTEM

3.3.3.2 Engine Exhaust Particle Sizer (EEPS)

TSI's EEPS Model 3090, shown in Figure 6, provides real-time information on particle size distribution. It is capable of measuring particles in the range from 5.6 nm to 560 nm in electrical mobility diameter, and provides this information (particle concentration) in 32 separate size bins. The EEPS was used in conjunction with the SwRI Solid Particle Sampling System (SPSS) described in the next section.

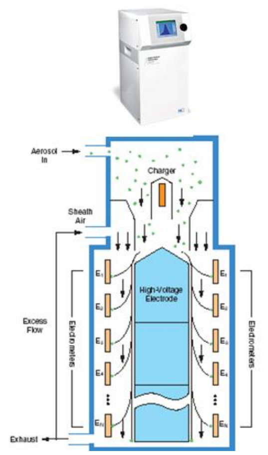


FIGURE 6. ENGINE EXHAUST PARTICLE SIZER (EEPS)

3.3.3.3 Solid Particle Sampling System (SPSS)

The SPSS, similar to the one shown in Figure 7, was used to sample engine exhaust upstream of the EEPS. The SPSS contains a heated catalyst that strips the exhaust sample of its volatile components. It includes a single stage of dilution where the extracted sample is mixed with filtered air. Throughout this program, the EEPS was used in conjunction with the SPSS for measurement of solid particle size distribution. On average, the SPSS extracted sample from engine exhaust with a dilution ratio of ~ 5.50.

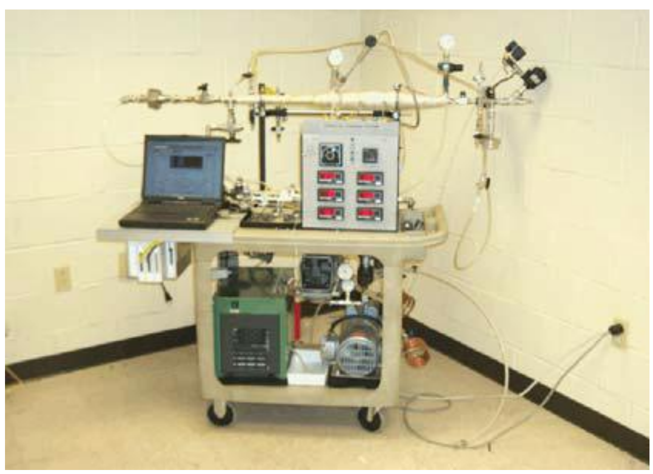


FIGURE 7. SOLID PARTICLE SAMPLING SYSTEM (SPSS)

3.3.3.4 Solid Particle Number Measurement System (SPNMS)

The SwRI Solid Particle Number Measurement System (SPNMS) was utilized to sample solid particles greater than 23 nm in diameter in accordance with the Particle Measurement Program (PMP) protocol. Particles greater than 23 nm in diameter are counted using a TSI model 3790 Condensation Particle Counter (CPC). The CPC 3790 has a 50% counting efficiency for particles less than 23 nm in diameter. Unlike conventional PMP sampling systems, the SPNMS uses a catalytic stripper to remove the volatile particles rather than an evaporation tube. This system is designed to remove volatiles with a very high efficiency while still maintaining a high penetration of solid particles. This is extremely important when measuring particles smaller than 23 nm, which is the lower cut-off point of the PMP systems. It has been shown that using an evaporation tube may lead to the recondensation of particles smaller than 23 nm. The catalytic stripper used in the SPNMS prevents renucleation / condensation by oxidizing the volatile material. In this way, it is possible to attach a TSI CPC 3025A to the SPNMS system and measure solid particles down to 3 nm. The system used for this work consists of the CPC 3790 (for particles greater than 23 nm) and the CPC 3025 (for particles greater than 3 nm); the system is shown in Figure 8. The CPC 3790 is located within the red case, and the CPC 3025 is the white instrument as pictured.

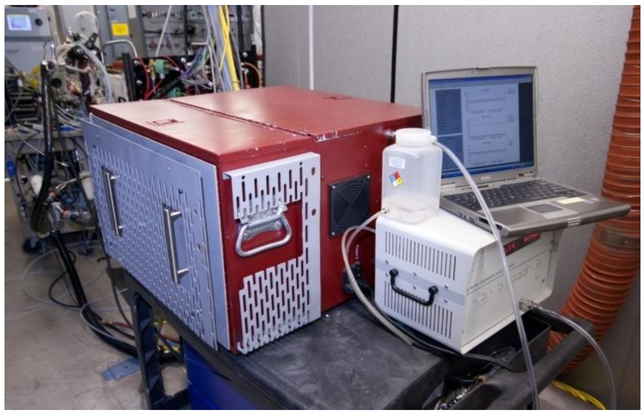


FIGURE 8. SWRI SOLID PARTICLE NUMBERING MEASUREMENT SYSTEM (SPNMS)

3.3.3.5 Micro Soot Sensor (MSS)

An AVL Micro Soot Sensor, shown in Figure 9, utilizes a photo-acoustic measurement scheme to measure the soot mass concentration in the sample flow. In this method, elemental carbon (soot) particles are exposed to laser light. This increases the temperature of these strongly absorbing particles and heats the surrounding gas, leading to the generation of sound waves that are detected by a sensitive microphone. The signal detected by the microphone is proportional to the concentration of soot mass in the measurement cell. The upper and lower limits of its detection capability are 50 mg/m^3 and 5 µg/m^3, respectively. For all experiments carried out as a part of this project, the MSS was operated with a dilution ratio of 2 between the instrument's detector and sampling point, at the CVS.

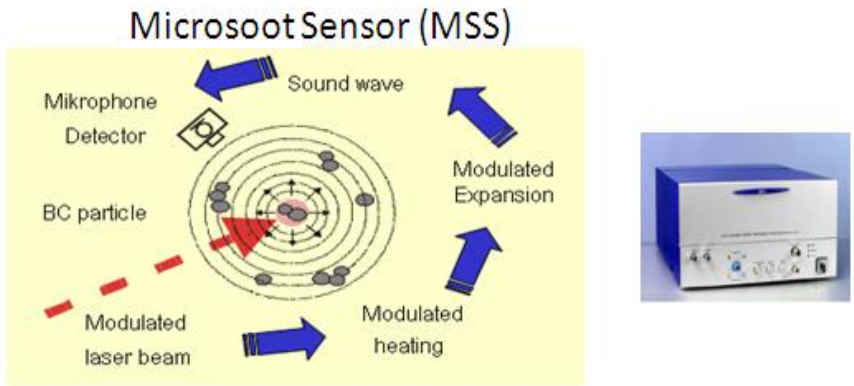


FIGURE 9. AVL MICROSOOT SENSOR (MSS)

3.3.3.6 Elemental Carbon/Organic Carbon

The thermal-optical method was used to measure “organic” (OC) and “elemental” (EC) carbon[11]. This method is based on the principle that different types of carbon-containing particles are converted to gases under different temperature and oxidation conditions. By careful system control and continuous monitoring of the optical absorbance of the sample during analysis, this method is able to quantify the specific forms of carbon in the exhaust.

The sample for this method was taken from a sample probe placed in the Constant Volume Sampling (CVS) tunnel directly after the PM collection unit (Figure 10). PM samples were collected on primary and secondary quartz filters using separate filter holders connected in series (Figure 11). The first quartz filter (primary filter) was used to measure OC and EC directly. The second filter was used for correction of the gas phase OC artifact adsorbed by particulate on the primary filter.

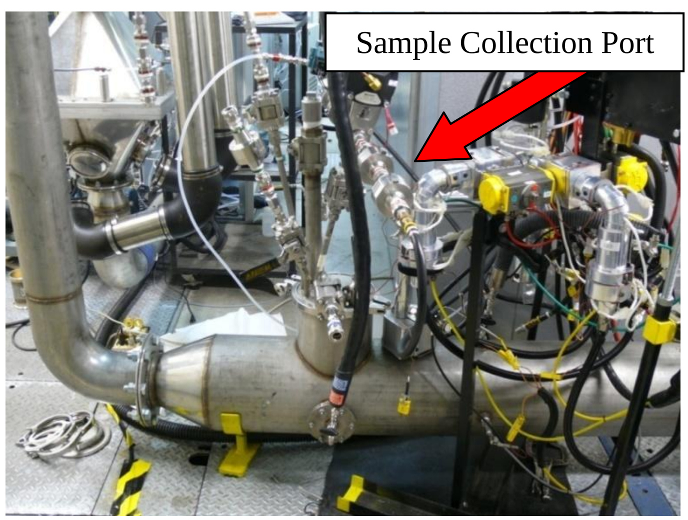


FIGURE 10. EC/OC SAMPLE COLLECTION

[11]M. E. Birch and R. A. Cary (1996), "Elemental Carbon-Based Method for Monitoring Occupational Exposures to Particulate Diesel Exhaust." *Aerosol Science and Technology* **25**, 221-241.

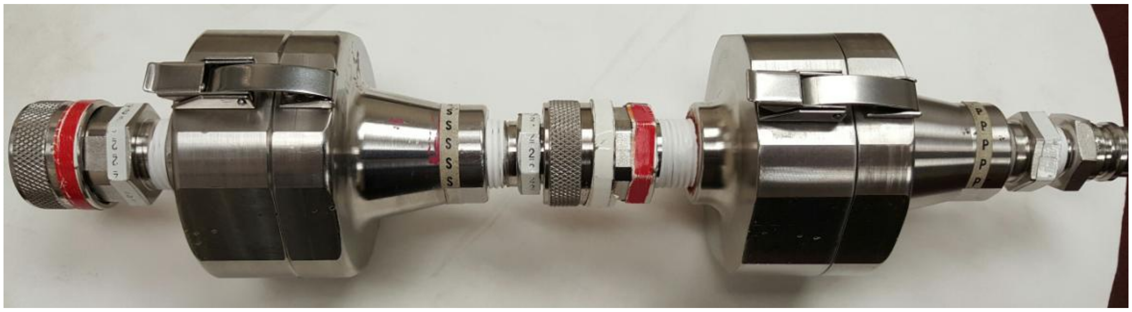


FIGURE 11. PRIMARY AND SECONDARY FILTER ASSEMBLY

Quartz filters were prebaked at 900 °C in an oven filled with inert gas for 8 hours to remove ambient organic contaminants absorbed by the filters. 900 °C is a sufficient temperature to remove all possible interferences with thermal/optical analysis. Following baking, filters were kept in pre-cleaned glass jars purged with nitrogen. To minimize the risk of volatile organic compounds (VOC) contaminating the filters, and to allow faster filter loading at the test cell, they were pre-assembled with Teflon filter rings (Figure 12) inside a weighing chamber equipped with an air filtering system. The two filters (primary and secondary) were collected for each individual phase of the test cycle, and were analyzed on a Sunset Laboratory Inc. Thermal / Optical Carbon Aerosol Analyzer (Figure 13).

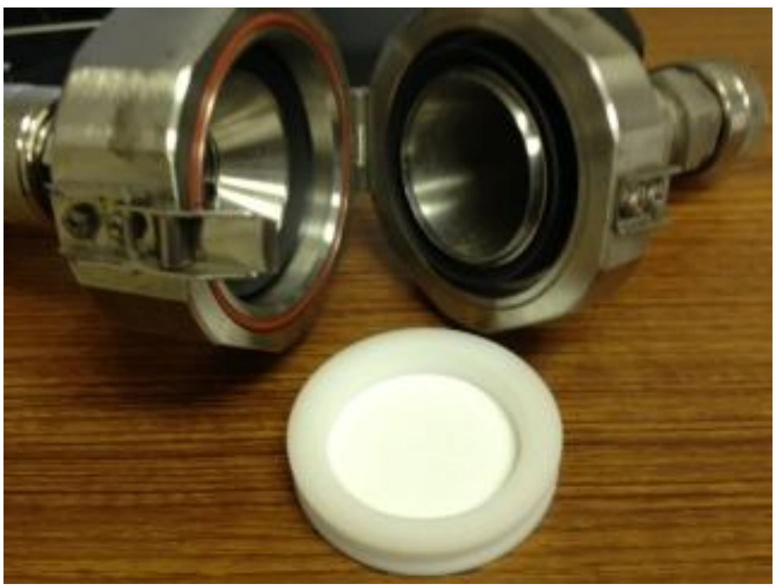


FIGURE 12. PRE-FILTER HOLDER AND PRE-ASSEMBLED FILTER

FIGURE 13. SUNSET LABORATORY THERMAL/OPTICAL LAB CARBON AEROSOL ANALYZER

One filter sample of ambient air (background) and one filter sample of dilution air were taken during the entire test, including the time required to load and unload the primary and secondary filters in the filter holder. These two filters, plus the secondary filters, were used as corrections for background (diluted air), field blank, and gas-phase OC artifact to the overall OC measurement. Results from the previous program, CRC-E-94-1, showed that the filter holder geometry provided sufficient uniformity of the sample to allow a single punch from each filter to be analyzed to determine microgram organic carbon, microgram elemental carbon and total carbon.

3.3.3.7 On-Board Diagnostic Channels

Numerous OBD channels were recorded, if available, continuously throughout the LA92 tests. These channels included short-term fuel trim, long-term fuel trim, engine speed, vehicle speed, coolant temperature, ignition timing, mass air flow (when vehicle was outfitted with MAF sensor), manifold air pressure (when vehicle was outfitted with MAP sensor), throttle position, evaporative purge command percentage, and primary oxygen sensor voltage. OBD data were collected with at least a 90% completeness rate.

4.0 TEST RESULTS

A summary of LA-92 weighted average gaseous emissions results from the twelve test vehicles is provided below in Table 11 through Table 22. Values shown are the average weighted average emissions from multiple tests (either 2 or 3 depending on repeatability of the vehicle/fuel combination). Phase-level gaseous emissions can be found in Appendix E.

TABLE 11. VEHICLE A WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.026	0.215	0.019	0.019
B	87.1	9.56	2.65	0.022	0.166	0.018	0.015
C	87.9	0.00	1.40	0.025	0.192	0.017	0.019
D	88.2	0.00	2.61	0.023	0.175	0.015	0.017
E	93.6	9.56	1.28	0.024	0.190	0.020	0.018
F	93.7	9.51	2.54	0.027	0.215	0.018	0.020
G	93.8	0.00	1.26	0.032	0.241	0.017	0.026
H	94.1	0.00	2.31	0.021	0.175	0.017	0.015

TABLE 12. VEHICLE B WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.018	0.300	0.013	0.015
B	87.1	9.56	2.65	0.013	0.149	0.014	0.011
C	87.9	0.00	1.40	0.020	0.322	0.010	0.017
D	88.2	0.00	2.61	0.015	0.256	0.012	0.012
E	93.6	9.56	1.28	0.015	0.227	0.019	0.012
F	93.7	9.51	2.54	0.013	0.226	0.009	0.011
G	93.8	0.00	1.26	0.016	0.281	0.054	0.013
H	94.1	0.00	2.31	0.014	0.263	0.008	0.012

TABLE 13. VEHICLE C WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.022	0.310	0.008	0.017
B	87.1	9.56	2.65	0.018	0.408	0.007	0.014
C	87.9	0.00	1.40	0.020	0.371	0.007	0.015
D	88.2	0.00	2.61	0.023	0.252	0.022	0.017
E	93.6	9.56	1.28	0.019	0.290	0.010	0.015
F	93.7	9.51	2.54	0.018	0.272	0.007	0.013
G	93.8	0.00	1.26	0.020	0.326	0.006	0.015
H	94.1	0.00	2.31	0.019	0.337	0.008	0.015

TABLE 14. VEHICLE D WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.018	0.118	0.007	0.014
B	87.1	9.56	2.65	0.031	0.120	0.005	0.025
C	87.9	0.00	1.40	0.017	0.107	0.005	0.013
D	88.2	0.00	2.61	0.024	0.124	0.005	0.018
E	93.6	9.56	1.28	0.014	0.129	0.006	0.010
F	93.7	9.51	2.54	0.025	0.166	0.004	0.019
G	93.8	0.00	1.26	0.013	0.089	0.008	0.009
H	94.1	0.00	2.31	0.022	0.133	0.004	0.017

TABLE 15. VEHICLE E WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.023	0.869	0.003	0.015
B	87.1	9.56	2.65	0.037	1.098	0.004	0.027
C	87.9	0.00	1.40	0.026	1.077	0.004	0.018
D	88.2	0.00	2.61	0.027	0.970	0.003	0.018
E	93.6	9.56	1.28	0.021	0.844	0.003	0.015
F	93.7	9.51	2.54	0.025	1.024	0.003	0.017
G	93.8	0.00	1.26	0.022	1.034	0.003	0.014
H	94.1	0.00	2.31	0.025	1.157	0.003	0.017

TABLE 16. VEHICLE F WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.023	0.223	0.009	0.017
B	87.1	9.56	2.65	0.030	0.227	0.011	0.024
C	87.9	0.00	1.40	0.022	0.147	0.008	0.017
D	88.2	0.00	2.61	0.026	0.227	0.010	0.021
E	93.6	9.56	1.28	0.023	0.155	0.010	0.018
F	93.7	9.51	2.54	0.025	0.192	0.008	0.020
G	93.8	0.00	1.26	0.021	0.197	0.007	0.016
H	94.1	0.00	2.31	0.020	0.150	0.015	0.016

TABLE 17. VEHICLE G WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.020	0.410	0.049	0.012
B	87.1	9.56	2.65	0.023	0.447	0.050	0.015
C	87.9	0.00	1.40	0.019	0.322	0.036	0.012
D	88.2	0.00	2.61	0.020	0.395	0.025	0.013
E	93.6	9.56	1.28	0.019	0.392	0.030	0.013
F	93.7	9.51	2.54	0.017	0.402	0.015	0.012
G	93.8	0.00	1.26	0.013	0.334	0.009	0.009
H	94.1	0.00	2.31	0.015	0.333	0.011	0.010

TABLE 18. VEHICLE H WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.038	0.772	0.009	0.026
B	87.1	9.56	2.65	0.046	0.803	0.014	0.032
C	87.9	0.00	1.40	0.039	0.762	0.015	0.026
D	88.2	0.00	2.61	0.045	0.882	0.010	0.031
E	93.6	9.56	1.28	0.053	0.765	0.012	0.039
F	93.7	9.51	2.54	0.034	0.620	0.014	0.022
G	93.8	0.00	1.26	0.034	0.654	0.009	0.024
H	94.1	0.00	2.31	0.038	0.755	0.007	0.026

TABLE 19. VEHICLE I WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.024	0.118	0.022	0.016
B	87.1	9.56	2.65	0.025	0.103	0.019	0.018
C	87.9	0.00	1.40	0.025	0.181	0.018	0.017
D	88.2	0.00	2.61	0.028	0.165	0.019	0.019
E	93.6	9.56	1.28	0.023	0.098	0.020	0.016
F	93.7	9.51	2.54	0.024	0.116	0.016	0.017
G	93.8	0.00	1.26	0.024	0.198	0.018	0.016
H	94.1	0.00	2.31	0.027	0.167	0.019	0.020

TABLE 20. VEHICLE J WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.041	0.276	0.017	0.032
B	87.1	9.56	2.65	0.036	0.261	0.012	0.026
C	87.9	0.00	1.40	0.028	0.328	0.012	0.019
D	88.2	0.00	2.61	0.040	0.254	0.013	0.030
E	93.6	9.56	1.28	0.037	0.317	0.013	0.027
F	93.7	9.51	2.54	0.038	0.311	0.012	0.028
G	93.8	0.00	1.26	0.031	0.312	0.010	0.023
H	94.1	0.00	2.31	0.044	0.390	0.014	0.034

TABLE 21. VEHICLE K WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.014	0.589	0.008	0.008
B	87.1	9.56	2.65	0.011	0.376	0.008	0.007
C	87.9	0.00	1.40	0.010	0.553	0.007	0.006
D	88.2	0.00	2.61	0.011	0.455	0.008	0.006
E	93.6	9.56	1.28	0.010	0.438	0.007	0.007
F	93.7	9.51	2.54	0.010	0.376	0.008	0.007
G	93.8	0.00	1.26	0.009	0.404	0.007	0.006
H	94.1	0.00	2.31	0.009	0.437	0.007	0.006

TABLE 22. VEHICLE L WEIGHTED AVERAGE OF REGULATED GASEOUS EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	THC, [g/mi]	CO, [g/mi]	NO_X, [g/mi]	NMHC, [g/mi]
A	87.2	9.55	1.42	0.042	0.475	0.005	0.023
B	87.1	9.56	2.65	0.038	0.320	0.006	0.027
C	87.9	0.00	1.40	0.077	0.949	0.005	0.022
D	88.2	0.00	2.61	0.053	0.563	0.005	0.024
E	93.6	9.56	1.28	0.061	0.518	0.005	0.021
F	93.7	9.51	2.54	0.083	0.702	0.004	0.025
G	93.8	0.00	1.26	0.034	0.365	0.005	0.020
H	94.1	0.00	2.31	0.066	0.663	0.005	0.022

4.1 Regulated Gaseous Emissions

Table 11 through Table 22 show the weighted average regulated gaseous (THC, CO, NO_X, and NMHC) for Vehicles A through L for all fuels tested. The fuel properties are also located on the left side of the table for reference. AKI values reported are the average of measurements from Lab A, B and D. Ethanol and PMI values reported are from Lab C only. Phase-level and weighted average LA92 regulated gaseous emissions plots for vehicles A through L can be found in Appendix E.

4.2 Particulate Emissions

A summary of weighted average particulate emissions results from the twelve test vehicles is provided below in Table 23 through Table 34. Values shown are the average weighted emissions from multiple tests (either 2 or 3 depending on repeatability of the vehicle/fuel combination). Here particulate mass (PM), total carbon (EC+OC), soot mass (MSS), particle number greater than 3 nm (CPC 3025) and particle number greater than 23 nm (CPC 3790) are shown. For reference, the fuel properties have been included in each table on the left side. AKI values reported are the average of measurements from Lab A, B and D. Ethanol and PMI values reported are from Lab C only.

TABLE 23. VEHICLE A WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	3.96	3.86	3.02	1.05E+13	8.30E+12
B	87.1	9.56	2.65	7.47	6.65	5.78	1.51E+13	1.26E+13
C	87.9	0.00	1.40	3.12	2.67	2.21	8.08E+12	6.22E+12
D	88.2	0.00	2.61	6.38	5.96	5.09	1.26E+13	1.05E+13
E	93.6	9.56	1.28	4.17	3.51	2.98	1.02E+13	8.04E+12
F	93.7	9.51	2.54	7.04	6.47	5.38	1.45E+13	1.21E+13
G	93.8	0.00	1.26	1.95	1.61	1.21	6.07E+12	4.45E+12
H	94.1	0.00	2.31	6.15	5.37	4.68	1.21E+13	9.97E+12

TABLE 24. VEHICLE B WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	4.52	4.24	3.55	8.01E+12	6.83E+12
B	87.1	9.56	2.65	8.93	8.14	7.00	1.47E+13	1.28E+13
C	87.9	0.00	1.40	3.45	3.08	2.51	6.06E+12	5.20E+12
D	88.2	0.00	2.61	7.03	6.00	5.54	1.16E+13	1.03E+13
E	93.6	9.56	1.28	4.87	4.42	3.77	7.94E+12	6.89E+12
F	93.7	9.51	2.54	6.82	6.37	5.48	1.22E+13	1.08E+13
G	93.8	0.00	1.26	3.26	2.83	2.46	5.78E+12	4.89E+12
H	94.1	0.00	2.31	6.13	5.89	4.98	1.10E+13	9.63E+12

TABLE 25. VEHICLE C WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	3.05	2.80	2.36	7.84E+12	6.62E+12
B	87.1	9.56	2.65	6.42	5.13	4.65	1.20E+13	1.03E+13
C	87.9	0.00	1.40	2.68	2.35	1.99	6.71E+12	5.70E+12
D	88.2	0.00	2.61	5.56	4.61	4.20	1.08E+13	9.24E+12
E	93.6	9.56	1.28	2.96	2.43	2.04	6.64E+12	5.62E+12
F	93.7	9.51	2.54	5.57	5.19	4.40	1.16E+13	1.03E+13
G	93.8	0.00	1.26	2.70	2.13	1.97	6.24E+12	5.30E+12
H	94.1	0.00	2.31	4.24	3.38	3.07	9.20E+12	7.90E+12

TABLE 26. VEHICLE D WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	0.97	1.00	0.40	1.44E+12	1.18E+12
B	87.1	9.56	2.65	2.32	2.57	1.47	3.34E+12	2.78E+12
C	87.9	0.00	1.40	0.89	0.57	0.26	1.10E+12	8.99E+11
D	88.2	0.00	2.61	1.85	1.92	1.16	2.59E+12	2.21E+12
E	93.6	9.56	1.28	0.95	0.87	0.44	1.42E+12	1.17E+12
F	93.7	9.51	2.54	1.82	1.46	1.18	2.64E+12	2.25E+12
G	93.8	0.00	1.26	0.68	0.52	0.29	1.08E+12	8.75E+11
H	94.1	0.00	2.31	1.56	1.55	0.99	2.55E+12	2.15E+12

TABLE 27. VEHICLE E WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	10.82	9.54	8.81	1.58E+13	1.46E+13
B	87.1	9.56	2.65	23.31	21.28	20.42	2.53E+13	2.44E+13
C	87.9	0.00	1.40	7.12	6.84	6.19	1.08E+13	9.97E+12
D	88.2	0.00	2.61	14.68	13.73	12.82	1.88E+13	1.77E+13
E	93.6	9.56	1.28	10.56	9.81	9.06	1.39E+13	1.32E+13
F	93.7	9.51	2.54	16.25	15.44	14.38	2.04E+13	1.93E+13
G	93.8	0.00	1.26	8.47	7.58	7.20	1.34E+13	1.22E+13
H	94.1	0.00	2.31	11.58	11.02	10.05	1.60E+13	1.46E+13

TABLE 28. VEHICLE F WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	1.23	1.11	0.79	2.86E+12	2.17E+12
B	87.1	9.56	2.65	3.40	3.13	2.39	5.73E+12	4.43E+12
C	87.9	0.00	1.40	1.11	0.75	0.46	2.12E+12	1.56E+12
D	88.2	0.00	2.61	2.31	2.37	1.58	4.61E+12	3.50E+12
E	93.6	9.56	1.28	1.40	1.24	0.83	2.59E+12	1.98E+12
F	93.7	9.51	2.54	2.06	1.90	1.43	4.20E+12	3.20E+12
G	93.8	0.00	1.26	0.96	0.85	0.46	1.93E+12	1.40E+12
H	94.1	0.00	2.31	1.60	1.33	0.94	3.27E+12	2.40E+12

TABLE 29. VEHICLE G WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	0.39	0.68	0.06	1.62E+12	1.08E+12
B	87.1	9.56	2.65	0.65	0.80	0.32	2.83E+12	1.96E+12
C	87.9	0.00	1.40	0.59	0.48	0.06	1.17E+12	7.24E+11
D	88.2	0.00	2.61	0.60	0.56	0.18	2.45E+12	1.66E+12
E	93.6	9.56	1.28	0.47	0.54	0.09	1.76E+12	1.15E+12
F	93.7	9.51	2.54	0.67	0.41	0.21	2.63E+12	1.81E+12
G	93.8	0.00	1.26	0.71	0.35	0.07	1.17E+12	7.28E+11
H	94.1	0.00	2.31	0.68	0.54	0.10	1.94E+12	1.28E+12

TABLE 30. VEHICLE H WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	5.26	4.89	3.88	1.03E+13	8.88E+12
B	87.1	9.56	2.65	13.65	12.87	10.50	1.95E+13	1.74E+13
C	87.9	0.00	1.40	3.71	3.42	2.63	7.34E+12	6.30E+12
D	88.2	0.00	2.61	11.04	10.90	8.75	1.68E+13	1.49E+13
E	93.6	9.56	1.28	5.87	5.60	4.42	9.85E+12	8.73E+12
F	93.7	9.51	2.54	10.90	10.15	8.33	1.61E+13	1.43E+13
G	93.8	0.00	1.26	4.04	3.58	2.71	7.32E+12	6.19E+12
H	94.1	0.00	2.31	8.76	8.07	6.81	1.32E+13	1.17E+13

TABLE 31. VEHICLE I WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	1.68	1.21	0.88	5.92E+12	4.15E+12
B	87.1	9.56	2.65	2.79	3.04	1.80	6.92E+12	5.26E+12
C	87.9	0.00	1.40	1.22	1.29	0.50	2.87E+12	2.02E+12
D	88.2	0.00	2.61	2.64	2.69	1.70	6.92E+12	5.25E+12
E	93.6	9.56	1.28	1.61	1.17	0.64	4.00E+12	2.80E+12
F	93.7	9.51	2.54	2.20	2.02	1.46	6.51E+12	4.91E+12
G	93.8	0.00	1.26	0.98	0.84	0.39	2.69E+12	1.84E+12
H	94.1	0.00	2.31	1.76	1.78	1.09	4.10E+12	3.04E+12

TABLE 32. VEHICLE J WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	9.08	8.57	7.30	1.19E+13	1.10E+13
B	87.1	9.56	2.65	14.86	15.26	12.57	1.65E+13	1.58E+13
C	87.9	0.00	1.40	6.73	5.97	5.33	9.69E+12	8.97E+12
D	88.2	0.00	2.61	12.72	12.56	10.34	1.37E+13	1.30E+13
E	93.6	9.56	1.28	9.14	8.82	7.43	1.20E+13	1.13E+13
F	93.7	9.51	2.54	14.03	13.78	11.70	1.59E+13	1.53E+13
G	93.8	0.00	1.26	6.41	6.30	5.12	9.26E+12	8.60E+12
H	94.1	0.00	2.31	11.57	11.49	9.30	1.28E+13	1.22E+13

TABLE 33. VEHICLE K WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	6.17	5.61	5.11	9.36E+12	8.60E+12
B	87.1	9.56	2.65	13.29	14.00	11.28	1.74E+13	1.67E+13
C	87.9	0.00	1.40	3.96	3.69	3.11	6.22E+12	5.72E+12
D	88.2	0.00	2.61	12.05	12.63	10.57	1.64E+13	1.56E+13
E	93.6	9.56	1.28	6.87	6.46	5.20	8.34E+12	7.87E+12
F	93.7	9.51	2.54	11.40	11.41	9.46	1.61E+13	1.54E+13
G	93.8	0.00	1.26	4.31	4.35	3.55	6.93E+12	6.33E+12
H	94.1	0.00	2.31	8.68	8.61	7.03	1.32E+13	1.25E+13

TABLE 34. VEHICLE L WEIGHTED AVERAGE OF PARTICULATE EMISSIONS SUMMARY

Fuel Letter	AKI, [-]	EtOH, [vol%]	PMI, [-]	PM, [mg/mi]	EC+OC, [mg/mi]	MSS, [mg/mi]	CPC 3025, [particles/mi]	CPC 3790, [particles/mi]
A	87.2	9.55	1.42	3.35	2.77	2.29	6.17E+12	5.22E+12
B	87.1	9.56	2.65	10.55	10.70	8.56	1.52E+13	1.41E+13
C	87.9	0.00	1.40	2.71	2.40	1.79	5.36E+12	4.59E+12
D	88.2	0.00	2.61	7.84	7.86	6.31	1.22E+13	1.11E+13
E	93.6	9.56	1.28	3.53	3.48	2.56	6.50E+12	5.75E+12
F	93.7	9.51	2.54	10.90	10.89	8.93	1.58E+13	1.49E+13
G	93.8	0.00	1.26	2.05	1.45	1.24	3.80E+12	3.19E+12
H	94.1	0.00	2.31	7.56	7.25	5.88	1.09E+13	1.01E+13

4.2.1 Particulate Mass Emissions

Figure 14 shows phase-level and average weighted LA92 PM emissions for the first vehicle tested (Vehicle A). The PM emission for the remaining vehicles can be found in Appendix E. The bars in the figures below represent the minimum and maximum values for the measured emission, with the colored bar representing the average value for tests conducted.

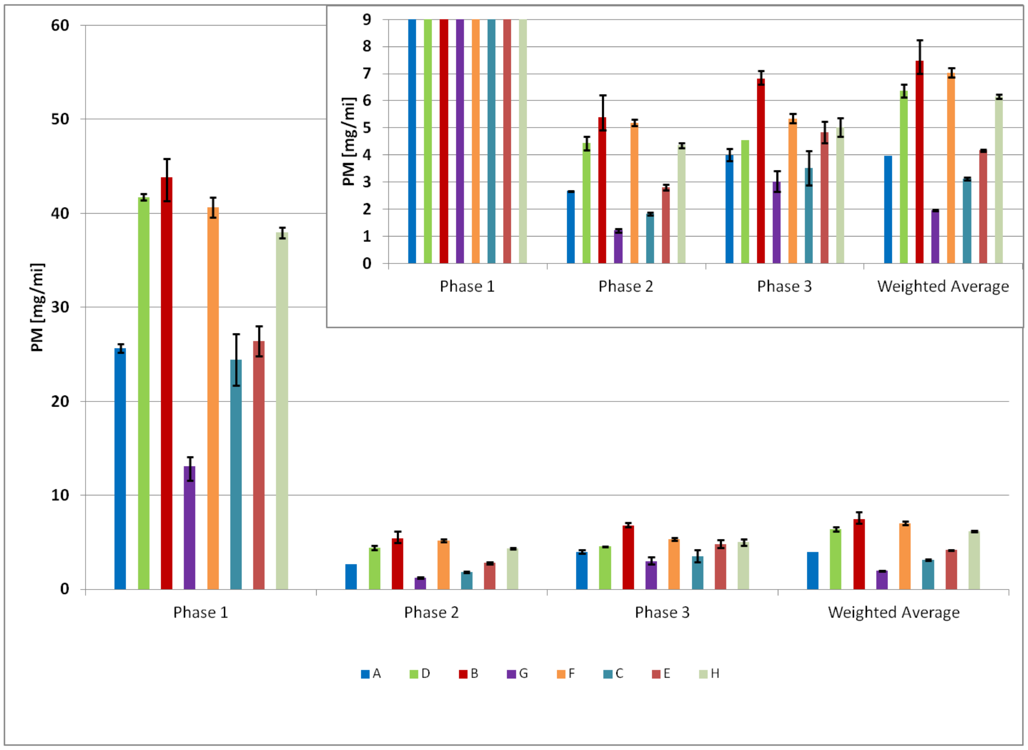


FIGURE 14. VEHICLE A PM EMISSIONS

Figure 15 shows PM emissions versus PMI for Vehicle A. PM emissions versus PMI for all other vehicles is located in Appendix F. Note that the PMI used for these plots is the PMI that was calculated based on Lab C's fuel measurements. In order to examine the effects of just PMI on PM emissions each symbol represents a constant AKI and ethanol content with only PMI being changed.

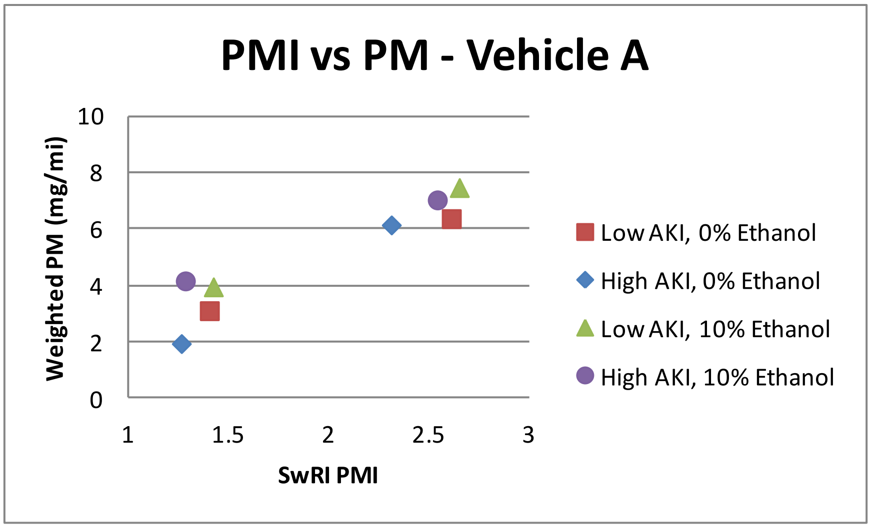


FIGURE 15. VEHICLE A PM EMISSIONS VERSUS PMI

Table 35 shows the percent difference in PM emissions between a high PMI fuel and a low PMI fuel (holding octane, and ethanol content constant).

$$\% \, Difference = \left(\frac{PM_{High\ PMI} - PM_{Low\ PMI}}{PM_{Low\ PMI}}\right) \times 100\%$$

TABLE 35. DIFFERENCE IN PM EMISSIONS BETWEEN HIGH PMI AND LOW PMI FUELS FOR VEHICLES A THROUGH L

Vehicle	Low AKI, 0% Ethanol	High AKI, 0% Ethanol	Low AKI, 10% Ethanol	High AKI, 10% Ethanol	Average PM Difference
A	105%	215%	89%	69%	119%
B	104%	88%	98%	40%	82%
C	107%	57%	111%	88%	91%
D	109%	130%	139%	91%	117%
E	106%	37%	116%	54%	78%
F	109%	67%	177%	48%	100%
G	2%	-5%	66%	43%	26%
H	198%	117%	160%	86%	140%
I	116%	80%	66%	36%	75%
J	89%	81%	64%	54%	72%
K	204%	101%	116%	66%	122%
L	190%	270%	216%	208%	221%

Figure 16 shows PM emissions versus octane (AKI) for Vehicle A. PM emissions versus octane for all other vehicles is located in Appendix F. Note that the AKI used for these plots is the AKI that was determined from Lab A's fuel measurements.

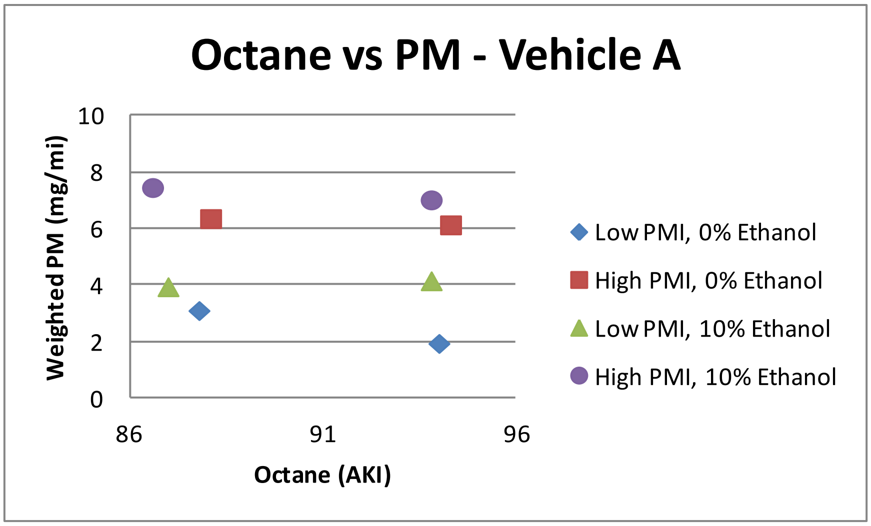


FIGURE 16. VEHICLE A PM EMISSIONS VERSUS OCTANE (AKI)

Table 36 shows the percent difference in PM emissions between a high octane fuels and a low octane fuels (holding PMI, and ethanol content constant). Vehicle G was an extremely low PM emitter, and some of the differences between low and high octane fuels may be within the measurement variability.

$$\%\ Difference = \left(\frac{PM_{High\ AKI} - PM_{Low\ AKI}}{PM_{Low\ AKI}}\right) \times 100\%$$

TABLE 36. DIFFERENCE IN PM EMISSIONS BETWEEN HIGH OCTANE AND LOW OCTANE FUEL FOR VEHICLES A THROUGH L

Vehicle	Low PMI, 0% Ethanol	High PMI, 0% Ethanol	Low PMI, 10% Ethanol	High PMI, 10% Ethanol	Average PM Difference
A	-37%	-4%	5%	-6%	-10%
B	-6%	-13%	8%	-24%	-9%
C	1%	-24%	-3%	-13%	-10%
D	-24%	-16%	-2%	-22%	-16%
E	19%	-21%	-2%	-30%	-9%
F	-13%	-31%	14%	-39%	-17%
G	21%	13%	21%	4%	15%
H	9%	-21%	12%	-20%	-5%
I	-20%	-33%	-4%	-21%	-20%
J	-5%	-9%	1%	-6%	-5%
K	9%	-28%	11%	-14%	-6%
L	-25%	-4%	6%	3%	-5%

Figure 17 shows PM emissions versus ethanol content for Vehicles A. Note that the ethanol content used for these plots is the ethanol content that was determined from Lab A's fuel measurements.

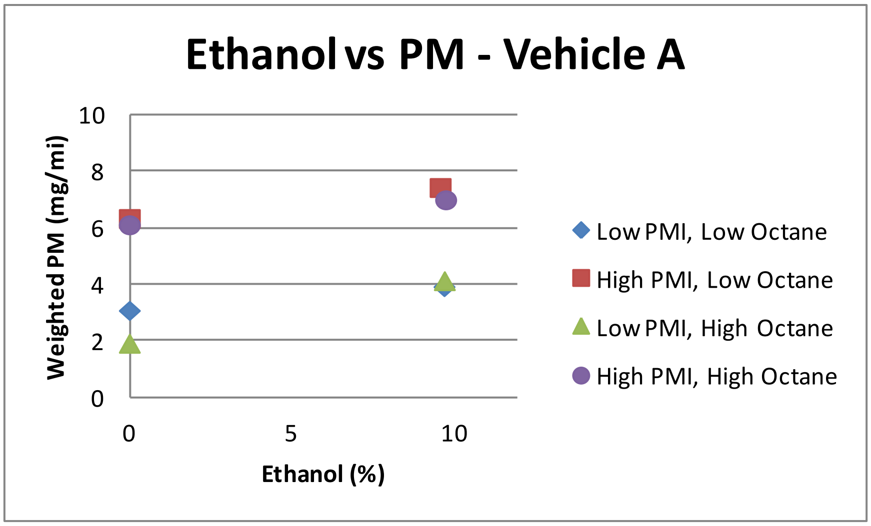


FIGURE 17. VEHICLE A PM EMISSIONS VERSUS ETHANOL CONTENT

Table 37 illustrates the percent change in weighted average PM emissions when moving from a 0% ethanol content fuel to a 10% ethanol content fuel and holding octane and PMI constant. Vehicle G was an extremely low PM emitter, and some of the differences between low and high ethanol fuels may be within the measurement variability.

$$\%\ Difference = \left(\frac{PM_{E10} - PM_{E0}}{PM_{E0}}\right) \times 100\%$$

TABLE 37. DIFFERENCE IN PM EMISSIONS BETWEEN 0% AND 10% ETHANOL CONTENT FUEL FOR VEHICLES A THROUGH L

Vehicle	Low PMI, Low AKI	High PMI, Low AKI	Low PMI, High AKI	High PMI, High AKI	Average PM Difference
A	27%	17%	114%	14%	43%
B	31%	27%	50%	11%	30%
C	14%	15%	10%	31%	18%
D	10%	26%	40%	17%	23%
E	52%	59%	25%	40%	44%
F	11%	47%	46%	29%	33%
G	-34%	9%	-33%	0%	-15%
H	42%	24%	45%	24%	34%
I	37%	6%	65%	25%	33%
J	35%	17%	43%	21%	29%
K	56%	10%	59%	31%	39%
L	24%	35%	73%	44%	44%

4.2.2 Soot Mass Emissions

In addition to PM mass emissions (solid + volatile emissions), soot (black carbon) mass emissions were measured using AVL's micro-soot sensor (MSS). Phase-level and weighted average LA92 MSS results are shown in Appendix E for all the vehicles.

Results show that soot mass correlates strongly with total PM emissions. Figure 18 shows the correlation between MSS and PM for all vehicles for all test phases.

The correlation between MSS and PM is strongly linear with a coefficient of determination of 0.9928. All data collected from the outliers shown above (emissions and OBD data) were investigated to try and determine the causes for the abnormalities. The origin for these outliers was not found. However, based on the other correlations between EC+OC and PM it suggests that the outliers are related to the PM measurement.

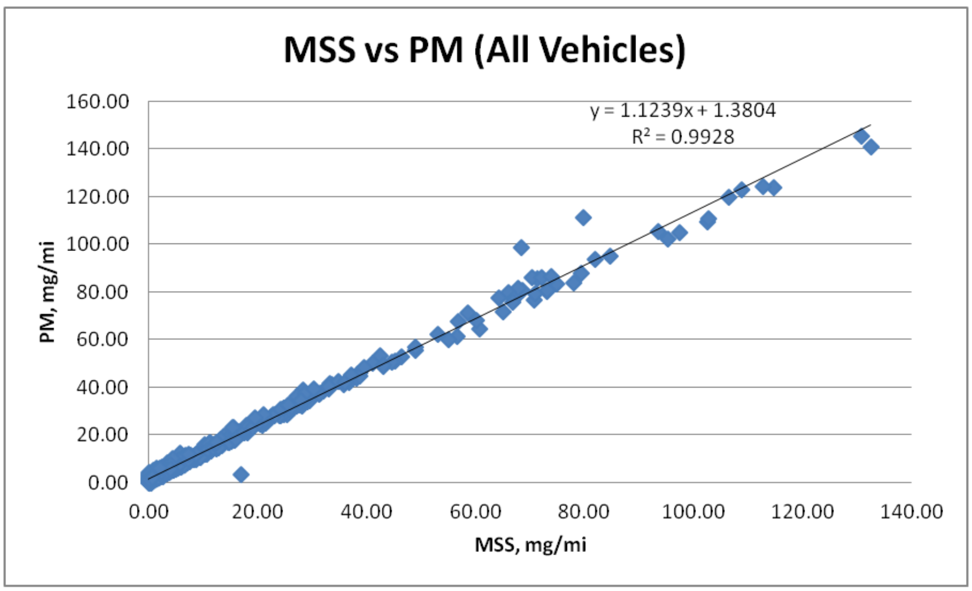


FIGURE 18. MSS VERSUS PM CORRELATION FOR ALL VEHICLES (VEHICLES A THROUGH L) AND PHASES

4.2.3 Elemental Carbon/Organic Carbon Analyses (EC/OC)

EC/OC analyses were performed using Sunset Laboratories Inc Lab thermal/optical carbon aerosol analyzer. Results from the primary filters were corrected for the gas–phase organic artifact. Overall, total carbon obtained from the analyses (sum of elemental and organic carbon) correlated with total particulate obtained from the PM mass measurements.

The majority of the PM consisted of elemental carbon. Figure 19 shows phase-level and weighted LA92 elemental carbon emissions for vehicle A, with the remaining vehicles being located in Appendix E. Trends for elemental carbon match those observed from the PM mass and soot mass measurements. The bars in the figures below represent the minimum and maximum values for the measured emissions for each fuel tested. The colored bar represents the average value of the measured emission from the tests conducted.

Organic fraction carbon (OC) was much lower than EC for most of the tests phases, and displayed higher variability between tests. Correction for the VOC artifact, as described in Section 3.3.3.6, practically eliminated any measured OC from several of the Phase 2 and Phase 3 samples. Figure 20 shows phase-level and weighted average LA92 OC emissions for vehicle A, with the remaining vehicles being located in Appendix E.

There was a strong correlation between PM and total carbon (both elemental and organic) (Figure 21). The correlation is strongly linear, with a coefficient of determination of 0.9896.

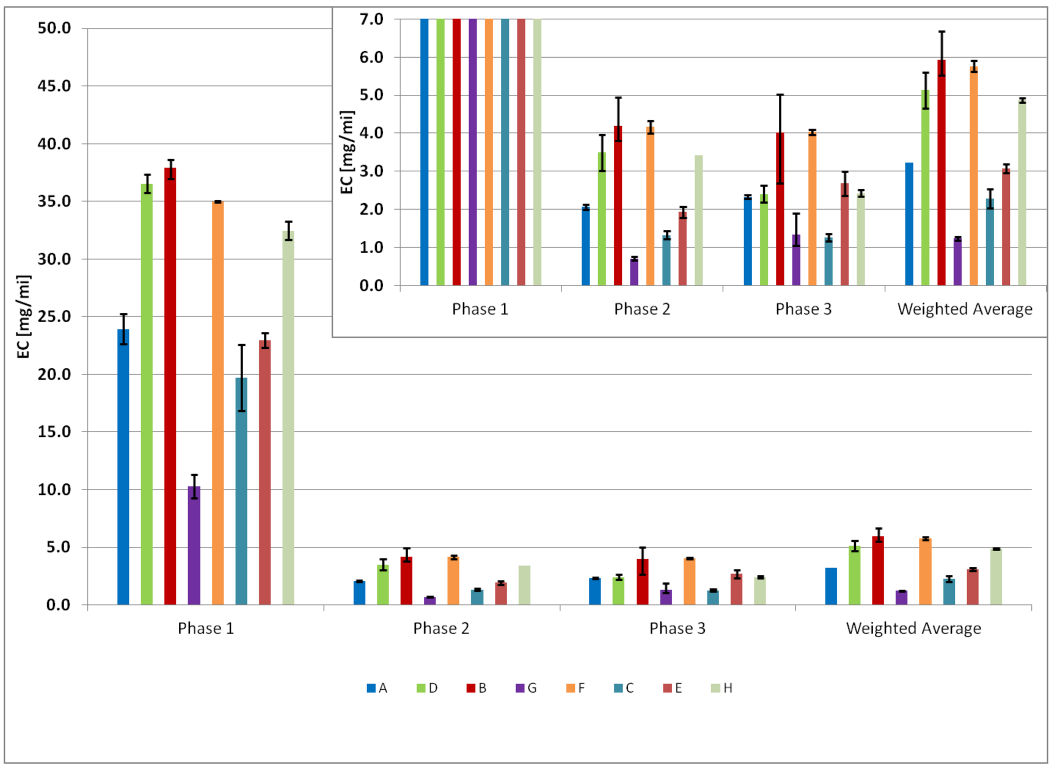


FIGURE 19. EC EMISSIONS FOR VEHICLE A

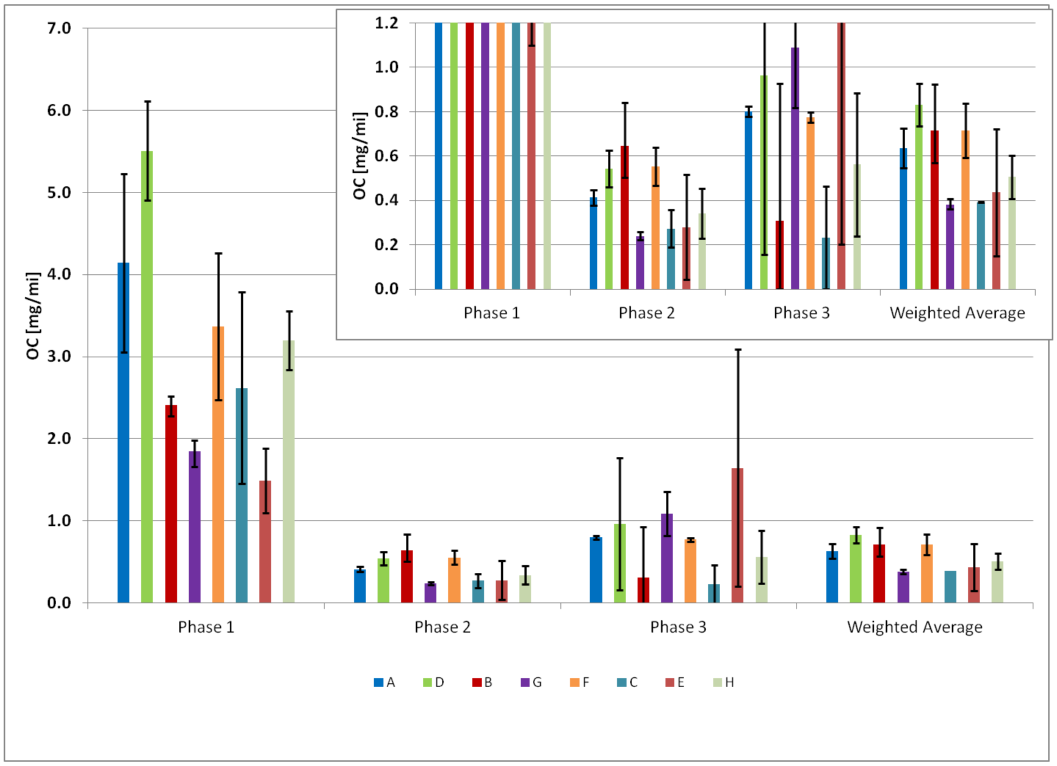


FIGURE 20. OC EMISSIONS FOR VEHICLE A

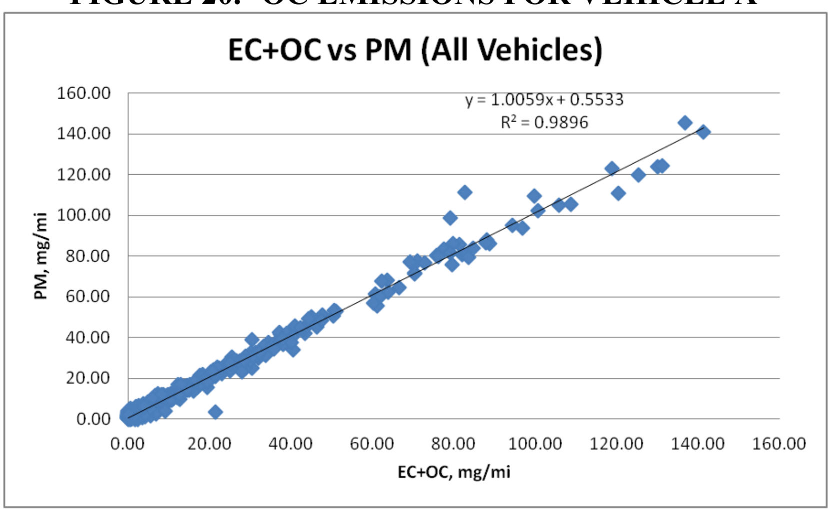


FIGURE 21. EC+OC VERSUS PM CORRELATION FOR ALL VEHICLES (VEHICLES A THROUGH L)

4.2.4 Particle Number (PN) Emissions

Particle number emissions measured with the CPC 3790 and CPC 3025 tracked each other well throughout the program in terms of trending on a phase-wise basis. Phase-level and weighted average LA92 emissions for CPC 3790 and CPC 3025 particle count for all of the vehicles can be found in Appendix E.

The average $\frac{\text{CPC 3025}}{\text{CPC 3790}}$ ratio was calculated for each phase for each vehicle (Table 38); a ratio greater than 1 indicates the presence of solid particles in the 3 nm to 23 nm size bin. Table 38 gives a sense of the amount of total particles that are in this smallest size bin. Phase-wise particle size distributions provide further insight into these ratios. Particle size distributions are discussed in the next section, Section 4.3.5. Additionally, the trends observed in the PN measurements correlated well with soot mass observations (micro-soot sensor). PN emissions for vehicle A for CPC 3025 and CPC 3790 are shown in Figure 22 and Figure 23, respectively. PN emissions for the remaining vehicles are shown in Appendix E.

TABLE 38. $\frac{CPC3025}{CPC3790}$ RATIO

	Phase 1	Phase 2	Phase 3
Vehicle A	1.151	1.310	1.290
Vehicle B	1.060	1.198	1.334
Vehicle C	1.083	1.201	1.169
Vehicle D	1.064	1.558	1.627
Vehicle E	0.981	1.103	1.311
Vehicle F	1.116	1.474	1.489
Vehicle G	1.312	1.725	1.862
Vehicle H	1.064	1.206	1.263
Vehicle I	1.156	1.506	1.615
Vehicle J	1.070	1.057	1.125
Vehicle K	0.964	1.134	1.431
Vehicle L	1.043	1.157	1.170

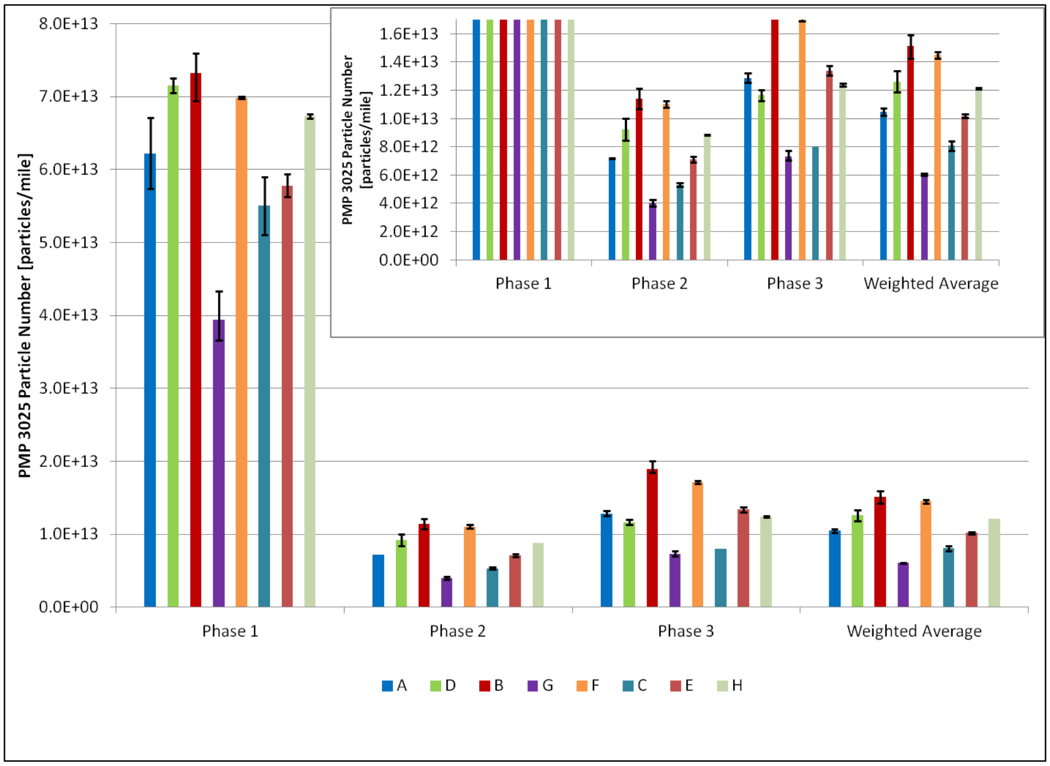


FIGURE 22. CPC 3025 EMISSIONS FOR VEHICLE A

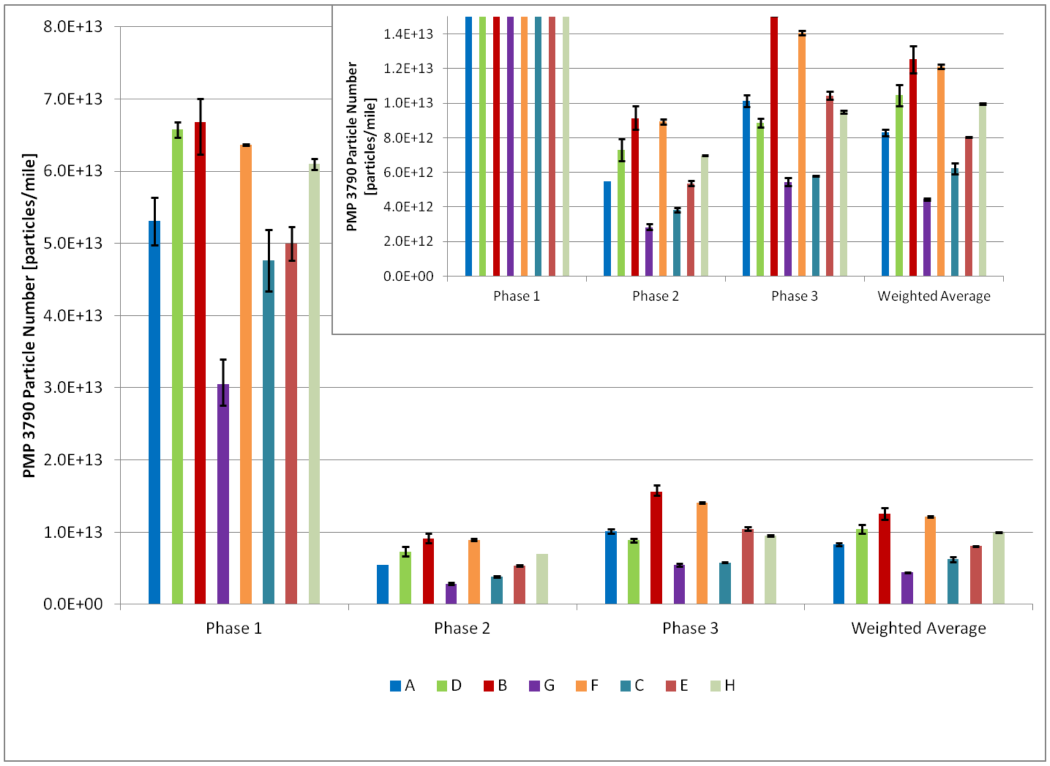


FIGURE 23. CPC 3790 EMISSIONS FOR VEHICLE A

4.2.5 Particle Size Distribution

TSI's model 3790 Engine Exhaust Particle Sizer (EEPS) was used to measure real-time particle size distribution. The EEPS was used in conjunction with the Solid Particle Sampling System (SPSS) as described in Section 3.3.3. Typical size distributions observed for the three test phases for Vehicle A are shown in Figure 24. The peak of the size distribution for phase 1 was ~ 70 nm, phase 2 was ~ 52 nm and phase 3 was ~ 60 nm. Typical size distributions for the remaining vehicles are presented in Appendix G.

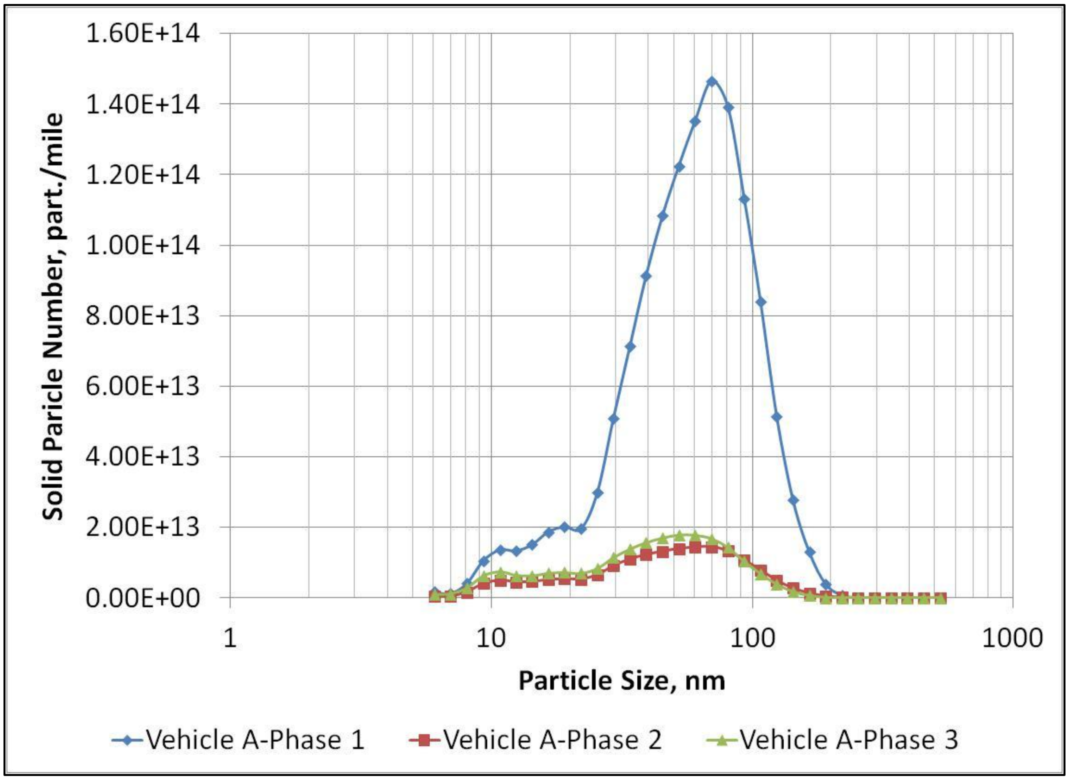


FIGURE 24. TYPICAL PARTICLE SIZE DISTRIBUTION FOR VEHICLE A

4.2.6 Real-time Particle Emissions

Figure 25 and Figure 26 show typical real-time continuous traces of soot mass and solid particle number emissions for all twelve vehicles for Fuel A. The vehicle speed trace is overlaid on these graphs. The graphs for the remaining fuels are presented in Appendix G. Typically, cold-start acceleration events in Phase 1 contribute significantly towards cumulative emissions. In the case of Vehicle J, a significant increase in both soot and number emissions profiles were observed in phase 2 of the LA 92 test cycle approximately 400 seconds into the cycle. This observation was made for all fuels and was unique to Vehicle J. During phase 3, typically, a very minimal increase in the emissions profile was observed for all vehicles. This observation was consistent for all fuels tested.

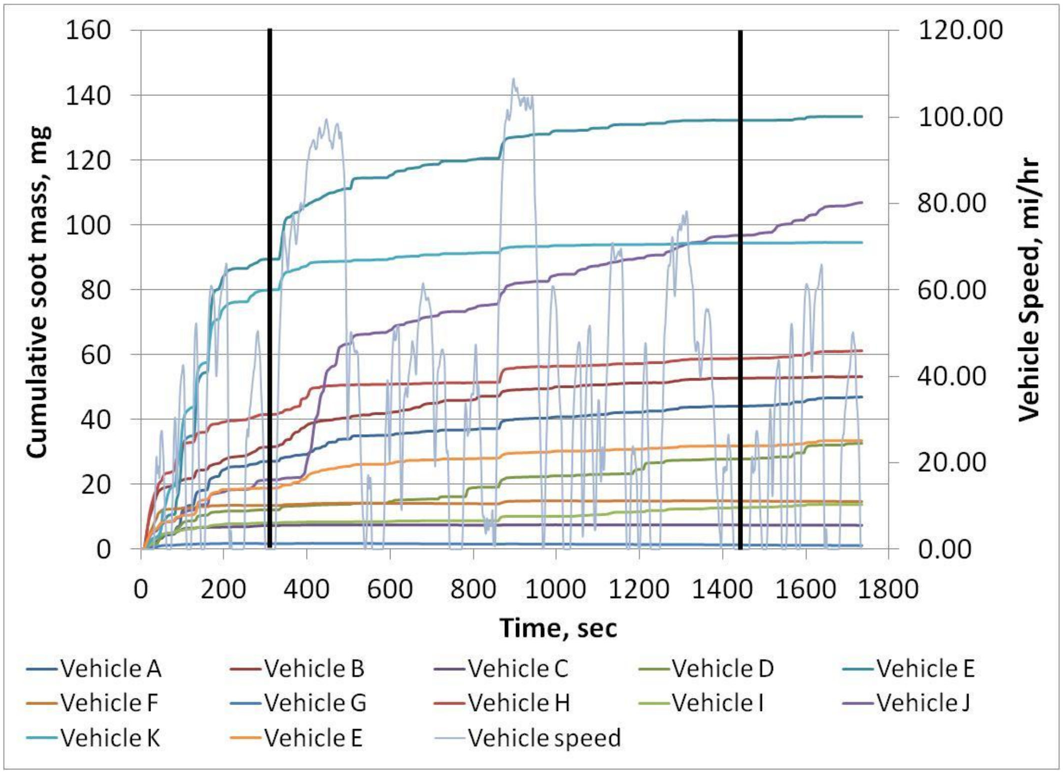


FIGURE 25. SOOT MASS EMISSIONS PROFILE FOR ALL VEHICLE FOR FUEL A

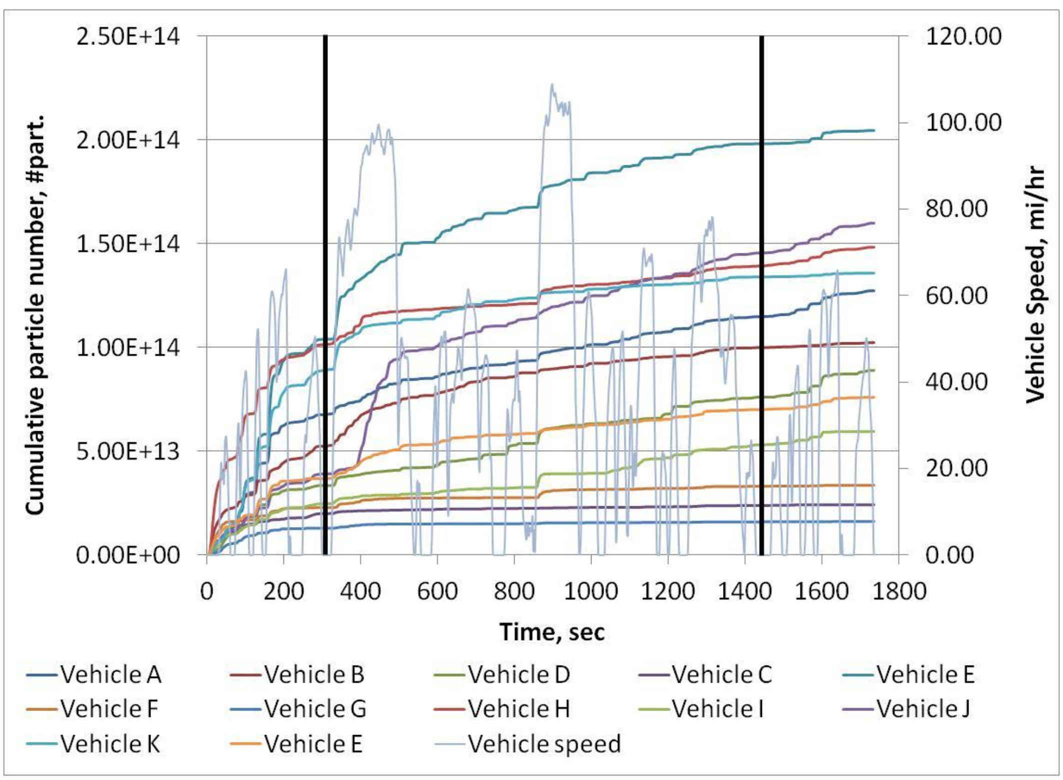


FIGURE 26. CPC 3790 SOLID PARTICLE NUMBER FOR EMISSIONS PROFILE (>23NM) FOR FUEL A

5.0 THE EFFECT OF FUELS ON VEHICLE EMISSIONS

5.1 Introduction

Following the completion of testing, a statistical analysis was conducted to understand the effect of fuels on the vehicular emissions of eight different pollutants (see Table 39). The analysis was structured to address the following questions of interest:

- Can the effects of AKI, PMI and EtOH be observed in each of the vehicles tested? If present, is sensitivity to these factors wide-spread in the test fleet or associated with only a few vehicles?
- What are the fuel effects of AKI, PMI, and EtOH on emissions of the entire test fleet?
- What are the effects on emissions for subsets of the data? For this purpose, the test vehicles were grouped: (1) by air induction type (NA versus turbocharged) for vehicles with 4-cylinder engines; and (2) into Low, Mid and High PM emitting vehicles (4- and 6-cylinder engines) based on their average PM emission level across the eight fuels.
- Can the fuel effects observed for the entire test fleet be seen in only those vehicles characterized as Low PM emitters, or are they too small to be detected at low PM levels?
- Are the results of the study influenced by any of the 22 additional fuel properties (other than AKI, PMI and EtOH) that were measured?

TABLE 39. POLLUTANTS EXAMINED IN THE ANALYSIS

Particulate Emissions	Gaseous Emission
LA92 PN	LA92 THC
LA92 PM	LA92 CO
Phase 1 PM	LA92 NO_X
LA92 EC	LA92 CO_2

This chapter is organized as follows. The methodology used in the statistical analysis is reviewed first. The experimental fuels and the emissions data used in the analysis are described as is the organization of the analysis. The repeatability of emissions measurement in back-to-back test runs is discussed as it is important to the question of whether fuel effects can be observed in Low PM vehicles. Finally, the formulation of the statistical models used in the analysis is documented and described.

After this, the results of the analysis for the effect of fuels on vehicle emissions are presented for each of the four particulate emission variables. The effect of fuels on particulate emissions overall is then summarized. Finally, the results of the analysis for gaseous emissions are presented and discussed briefly. More detailed information on the technical results of the analysis can be found in Appendix H.

5.2 Statistical Methodology

5.2.1 Experimental Fuels

As described in Section 3.1, eight experimental fuels were match-blended to meet PMI, EtOH and AKI targets in a 2 x 2 x 2 = 8 fuel design and to meet specifications for other characteristics. Reid Vapor Pressure (RVP) and mid-range distillation temperature (T50) were matched across the fuels, but other properties (e.g., olefins, aromatics and sulfur content) were allowed to vary within given ranges. Table 40 organizes the eight fuels into a matrix using nominal values for AKI, PMI and EtOH to refer to the levels. These values are employed when using the result of the statistical analysis to predict the emission levels of low and high AKI fuels, low and high PMI fuels, and E0 and E10 fuels. The actual measured values for AKI, PMI, and EtOH are used as independent variables in the analysis. Note that the high AKI fuel level (94) exceeds the octane level of premium grade gasoline in the market and that the E10 level has an ethanol content of 9.5 vol % rather than 10 vol %.

TABLE 40. FUEL DESIGN MATRIX

	Low PMI (1.3)	High PMI (2.5)
Low AKI (87)	E0 (0.0 vol %) E10 (9.5 vol %)	E0 (0.0 vol %) E10 (9.5 vol %)
High AKI (94)	E0 (0.0 vol %) E10 (9.5 vol %)	E0 (0.0 vol %) E10 (9.5 vol %)

One question posed to the statistical analysis is whether variation in fuel properties other than PMI, EtOH and AKI exerts an influence on vehicle emissions. Table 41 lists the other fuel properties of interest. Statistical tests were conducted in the analysis, as explained below, to determine whether such effects were present. <u>In no case, and for none of the dependent variables, was an emissions effect from the other fuel properties detected</u>.

TABLE 41. OTHER FUEL PROPERTIES OF INTEREST

RVP	T10	T90
Sulfur	T20	T95
C10 Aromatics	T30	FBP
Non-C10 Aromatics	T40	Drivability Index
Benzene	T50	Gums (Washed)
Olefins	T60	Density
IBP	T70	
T05	T80	

The match blending process used to create the fuels leads unavoidably to correlations between the design variables (PMI, EtOH and AKI) and other physical and chemical properties.

For example, to increase ethanol content from 0.0% to 9.5% (E10) while holding the AKI level fixed, a blend stock with lower base octane must be used to allow for the increase in octane caused by the added ethanol. Because different blend stocks are used, other fuel properties will vary between the E0 and E10 fuels along with the variation in the design variable EtOH. Variables that are related to each other in this way are termed *aliased*. When the association is so strong that the correlation coefficient r approaches the value 1.0, the variables are said to be *confounded*. Such associations arise with respect to PMI and AKI as well.

There are a number of instances of confounded variables in the fuels dataset. For example, sulfur content, olefins content and gums (washed) are confounded with AKI to the extent that $|r| > 0.95$. C10 aromatics, T90, T95 and FBP are confounded with PMI to the same extent, as are T30 and density with EtOH. Based on multiple linear correlation coefficients, RVP and benzene content have the smallest correlations with PMI, EtOH and AKI (|multiple r| < 0.05), followed by T05 and T60 (|multiple r| < 0.30). These four variables are the ones most likely to exert an independent effect on vehicle emissions.

For variables that are confounded, it is not possible to distinguish the emissions effect of one from the emissions effects of the others. For example, EtOH, T30 and density vary in near lock-step in the data. To the extent that T30 and density exert independent influences on emissions beyond that of EtOH itself, this analysis will ascribe the combined (net) effect of the variables EtOH, T30 and density to EtOH alone. <u>The emission effects ascribed in the analysis to the design variables AKI, PMI, and EtOH will include contributions from the confounded variables, to the extent they exert independent effects</u>.

A second caveat on the interpretation of results is related to the discrete fuel levels tested. The analysis conducted here has remained faithful to the experiment in that results are presented only for the eight discrete combinations of PMI, EtOH and AKI that were tested. The program obtained no emissions data for intermediate values and the analysis has avoided the temptation to estimate emissions by interpolation between the levels tested.

5.2.2 Emissions Data

The emissions testing data used in the analysis consist of 2 to 4 individual test runs for each vehicle/fuel combination. Each combination was tested twice with those exhibiting excess variability for one or more of the regulated pollutants being retested. Of the 96 vehicle/fuel combinations, 72 are represented by 2 test runs, 23 by 3 test runs, and one by 4 test runs, leading to a total of 217 test runs.

An initial step in the analysis was to screen the test run data for the presence of outliers. A statistical outlier is a data point that lies well away (either high or low) from most of the other values in a dataset such that it is an unlikely (but still possible) outcome of the experiment. Being an outlier in this sense does not automatically imply that the data point is invalid or should be excluded but, rather, that it requires additional scrutiny.

Appendix H.1 describes the process used to detect candidate outliers in the test run dataset and to exclude a small number from the analysis. In brief, two different statistical tests were applied to flag some test runs as candidate outliers:

- The Generalized ESD test[12] was used to compare the test runs overall using a method that determines how high or low (relative to the mean value) a data point is likely to fall merely by chance in a dataset of the given size.
- The Tukey test for outliers that underlies "box and whisker" plots[13] was applied to the residuals from a full-rank statistical model that related emissions to AKI, PMI and EtOH (see Eq. 1 in a Section 5.2.5.1). This approach recognized that some vehicle/fuel combinations will have higher or lower emissions than others and may tend to fall in the tails of the statistical distribution.

For those test runs flagged as candidate outliers, t values were determined for the variation of the test runs around the average for the vehicle/fuel combination. This was done only for cases where $N \geq 3$ test runs had been conducted.

Table 42 summarizes the result of this process and lists the number and identity of the test runs rejected for each pollutant. One test run (17169) was rejected for all dependent variables. It showed an anomalous Phase 1 PM result that was inconsistent with the other measures of particulate emissions and was also flagged as a candidate outlier for two of the four gaseous pollutants. In all other cases, a single test run for a given vehicle and fuel was rejected for an individual dependent variable.

TABLE 42. DETECTION AND REJECTION OF OUTLYING TEST RUNS

	Candidate Outliers [a/ b/]	Number Rejected	Vehicle (Fuel) Test Number
PN	1	1	
PM	4	2	D (A) 15953
Phase 1 PM	4	1	L (E) 17169 for all dependent variables
EC	3	2	F (D) 16390
THC	1	1	
CO	1	1	
NO_x	3	4	D (A) 15948; F (H) 16709; G (B) 16430
CO_2	3	3	D (A) 16146; I (F) 16999

[a/] Generalized ESD Test for Outliers applied to log(emissions) data. The assumption of a uniform standard deviation likely penalizes vehicles in the Low PM group due to their generally greater standard deviation in percent terms.
[b/] Tukey test for outliers (box/whisker plots) applied to residuals from a full-rank statistical model.

In a testing program that extends over several months, drift in the calibration of the instruments ("test cell drift") is a possibility. The first and best line of defense against drift was the attention that was given to instrument maintenance and calibration in the SwRI laboratory.

[12] See http://www.itl.nist.gov/div898/handbook/eda/section3/eda35h3.htm for a description.
[13] See http://www.itl.nist.gov/div898/handbook/eda/section3/boxplot.htm for a description.

Nevertheless, the data were examined for evidence of test cell drift as a precaution. As described in Appendix H.2, no such evidence was found.

Following removal of selected outliers, the dataset was reduced to averaged emissions values for each vehicle/fuel combination to produce a data set of N = 96 data points for each dependent variable (twelve vehicles times eight fuels). In about 3 of 4 cases, the averaged value is based on two test runs, while in the remainder it is based on three test runs. When a dataset varies in the amount of information underlying the data points, such as here, the points are often weighted in proportion to their precision so that points based on more information are given greater weight. Here, the data points based on 3 test runs are for vehicle/fuel combinations that displayed greater variability in testing. These require more information (more test runs) to achieve the same level of precision as the points based on 2 test runs. Thus, the 96 data points were given equal weight in the analysis.

5.2.3 Organization of the Analysis

The statistical analysis was designed to give a thorough evaluation of the effects of fuels on vehicle emissions by considering the dataset in a number of different ways. For each dependent variable, the analysis begins with the determination of fuel effects for the vehicles individually to determine whether sensitivity to PMI, EtOH and AKI is wide-spread in the test fleet or is associated with only a few vehicles. The analysis then continues to determine the effect of fuels for the entire test fleet and for subgroups of the vehicles. The subgroup analysis was done in two different ways.

First, the vehicles with 4-cylinder engines were subdivided by type of air induction system to permit comparison between NA and turbocharged vehicles; there are 5 vehicles in each subgroup. This comparison was restricted to 4-cylinder engine to provide close comparability between the subgroups, but it leaves out Vehicles G and H with 6-cylinder engines. Therefore, comparisons of effects between the entire test fleet and the air induction subgroups are influenced by the presence of two additional vehicles for the former. The NA versus turbocharged mix is otherwise the same (a 50:50 ratio) in the entire test fleet and in the subgroup of 10 test vehicles equipped with 4-cylinder engines.

Second, the test fleet was subdivided into three groups (of 4 vehicles each) based on their PM emission levels averaged across the 8 experimental fuels. This provides completeness in the analysis because all vehicles, including both 4- and 6-cylinder engines, are considered. It also supports the determination of whether fuel effects exist and can be detected across the full range of vehicle PM levels. However, the emissions responses of the subgroups are influenced by the fact that they have varying ratios of NA and turbocharged vehicles (from 3:1 to 1:3 NA:turbocharged). Thus, these subgroups are both smaller and more heterogeneous than the subgroups of 4-cylinder engines and their emission responses are more strongly influenced by technology differences and the performance of individual vehicles.

Table 43 summarizes the distribution of sample size and degrees of freedom (DF) among the several vehicle groupings in the analysis. For the individual vehicles, eight data points are available consisting of the average emissions on each fuel. In a dataset of this size, only a linear analysis is possible to relate emissions to the three variables PMI, EtOH, and AKI. A model in three terms has four degrees of freedom (DF) remaining in the error term after the mean value and coefficients for the linear terms are estimated. More DFs translate into improved precision and better ability to resolve effects that are present in the data. Having only 4 DFs in an analysis of 3 variables limits the precision that can be achieved in the determination of emissions for individual vehicles.

A larger number of DFs is available in the analysis of the vehicle subgroups. Twenty one DFs are available for the subgroups based on PM level, 28 are available in the subgroups of 4-cylinder engines and 77 are available for the analysis of the entire test fleet. The precision and ability to resolve effects in the data will vary by subgroup according to the available DFs.

TABLE 43. DISTRIBUTION OF SAMPLE SIZE AND DEGREES OF FREEDOM (DF)

Analysis Group	Number of Vehicles	Number of Test Runs [a/]	Number of Vehicle/Fuel Averages (N)	DF for Analysis of Vehicles Individually (3 fuel terms)	DF for Analysis of Vehicle Groups (7 fuel terms)
All Vehicles	12	217	96		77
4-Cyl NA	5	86	40		28
Vehicle B	1	18	8	4	
Vehicle D	1	19	8	4	
Vehicle E	1	16	8	4	
Vehicle I	1	17	8	4	
Vehicle K	1	17	8	4	
4-Cyl Turbocharged	5	93	40		28
Vehicle A	1	18	8	4	
Vehicle C	1	16	8	4	
Vehicle F	1	20	8	4	
Vehicle J	1	20	8	4	
Vehicle L	1	19	8	4	
Vehicle G (V6 NA)	1	19	8	4	
Vehicle H (V6 Turbo)	1	19	8	4	
Low PM Vehicles	4	75	32		21
Mid PM Vehicles	4	70	32		21
High PM Vehicles	4	72	32		21

[a/] In total, before exclusion of selected outlying test runs

5.2.4 Repeatability of Measurement

Repeatability of measurement is defined as the variability observed in repeated measurements of the same subject – here, in repeated test runs for the same vehicle and fuel. The degree of variability that is observed depends on both the measurement resolution of the instruments and the repeatability of vehicle performance; the repeatability of measurement will vary across vehicles and fuels depending on both factors.

Table 44 shows the estimated repeatability of measurement in back-to-back test runs as observed in the entire test fleet and in the subgroup of Low PM vehicles. These values have been calculated by computing the squared deviation of each test run from the corresponding average emission level for the vehicle/fuel combination and summing the deviations across the test runs to compute a pooled variance and standard deviation. The values given for Low PM vehicles are used in determining whether the fuel effects that are detected in these vehicles could be observed and reliably measured in back-to-back test runs given the low PM levels that such vehicles display.

TABLE 44. REPEATABILITY OF MEASUREMENT

	Standard Deviation of Repeated Test Runs [a/]	
Dependent Variable	Test Fleet	Low PM Vehicles
LA92 PM	13.7 %	19.4 %
Phase 1 PM	10.5 %	10.6 %
LA92 EC	12.8 %	16.2 %
LA92 PN (CPC 3790)	9.3 %	11.8 %
LA92 THC	17.1 %	10.1 %
LA92 CO	18.5 %	18.5 %
LA92 NO_x	31.1 %	43.1 %
LA92 CO_2	0.8 %	1.0 %

[a/] After exclusion of selected outlying test runs.

5.2.4 Grouping of Vehicles by PM Level

Vehicles were grouped by PM level as shown in Figure 27. Vehicles were ranked from lowest to highest based on their LA92 PM emissions averaged across the 8 fuels and then divided into three groups of 4 vehicles each. The Low PM group has three NA vehicles and one turbocharged vehicle. The Mid PM group has one NA and three turbocharged vehicles, all with 4-cylinder engines. The High PM group has two NA and two turbocharged vehicles. The Low and High PM groups each have one vehicle with a V6 engine.

As noted, the subgroups by vehicle PM level are the smallest subgroups examined and are more heterogeneous in terms of engine and air induction technologies than the subgroups of 4-cylinder engines. As a result, their emission responses will be more strongly influenced by differences in technology and the performance of the individual vehicles than for the subgroups of 4-cylinder vehicles.

	Naturally Aspirated	Turbocharged
Low PM Vehicles	D, G, I	F
Mid PM Vehicles	B	C, A, L
High PM Vehicles	E, K	H, J

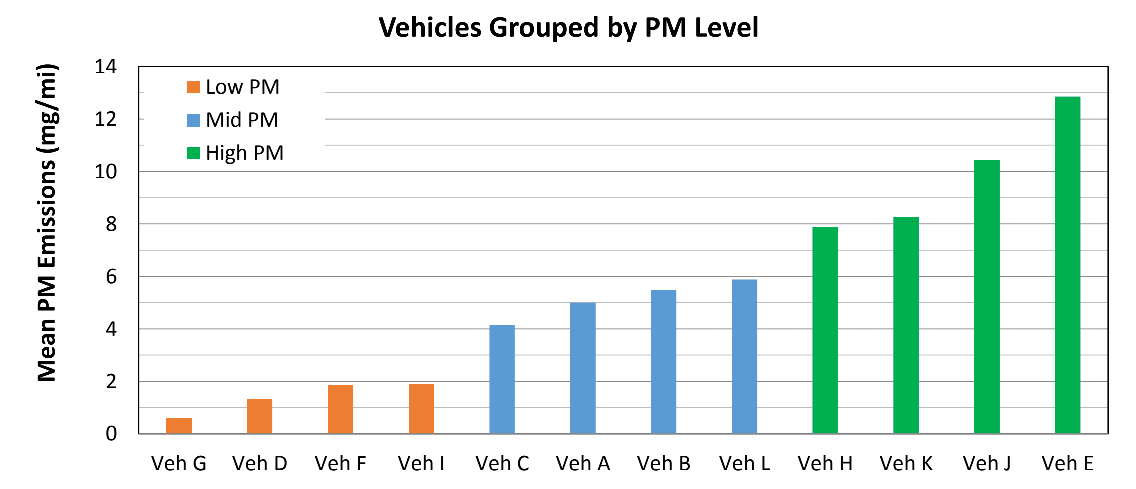


FIGURE 27. GROUPING OF VEHICLES BY PM LEVEL

5.2.5 Formulation of Statistical Models

The analysis used multiple linear regressions to relate emission variables to the design variables AKI, PMI and EtOH. Given that eight fuels were tested for each vehicle according to a 2 x 2 x 2 = 8 fuel design, a 3rd-order polynomial in the design variables is the highest order equation needed to describe the variation in emissions. Such an equation (the full-rank model) consists of the three linear terms for AKI, PMI and EtOH, the three 2-way interactions that can be formed from the variables and the one 3-way interaction. While additional terms are unnecessary, it is also true that fewer terms may be sufficient to describe the fuel effects that exist in the data. The process of identifying the simplest model required to describe the data is termed model development.

The dependent variable in the regression analysis is the natural logarithm of emissions. This choice, rather than the measured emissions value itself, is commonly used in the analysis of vehicle emissions, as it recognizes that the variability in emissions tends to increase with the absolute level of emissions. Use of the dependent variable expressed as a natural logarithm will offset this general trend and help to stabilize the variance in the data. Its use also leads to a mathematical form in which the emissions response to fuel variables is treated as constant in *percentage terms*. In fact, early exploratory analysis demonstrated that the effects of AKI, PMI and EtOH are approximately proportional to the vehicle PM level, which is to say approximately constant in percentage terms. The approximate constancy of emissions response in percentage terms can be judged by the plots of individual vehicle performance seen in Figure 29 for LA92 PN emissions and in later, comparable figures for other pollutants. The emissions response to a design variable may vary by air induction type or for some vehicles, but no consistent trend can be observed with respect to the average PM level of the vehicles.

5.2.5.1 Analysis for Vehicle Groups

The mathematical form of the full-rank model is given by Equation 1 below. The nomenclature assigns subscripts h, i, j, and k to represent the levels of AKI, PMI and EtOH and the sequential indices of the twelve vehicles. There is an overall mean emissions level μ for the average vehicle. Vehicles, each with their own average emission level $\mu + v_k$, are considered as being drawn at random from the overall SIDI population having standard deviation σ_v. The error term representing the random variation of emissions unrelated to vehicles and fuels is treated as having a mean of zero and a standard deviation of σ.

$$
\begin{aligned}
Y_{hijk} = {} & \mu + v_k + AKI_h + PMI_i + EtOH_j \\
& + AKI_h\,PMI_i + AKI_h\,EtOH_j + PMI_i\,EtOH_j \\
& + AKI_h\,PMI_i\,EtOH_j + \varepsilon_{hijk}
\end{aligned}
\qquad \text{(Eq. 1)}
$$

where:

μ = mean emissions for the average vehicle

$h = 1, 2$	AKI_h	
$i = 1, 2$	PMI_i	
$j = 1, 2$	$EtOH_j$	
$k = 1, \ldots, 12$	v_k: vehicles	$v_k \sim N(0,\sigma_v)$
		$\varepsilon_{hijk} \sim N(0,\sigma)$

The model development process seeks to remove terms in Eq. 1 to yield the simplest form required to describe the data. In this study, AKI was found to be the weakest predictor of emissions. Terms in AKI were sequentially removed from the full-rank model based on statistical significance, beginning with the third-order interaction, proceeding to the two second-order interactions involving AKI and, finally, to the linear term in AKI. The conventional p=0.05 level for statistical significance was used for this purpose. All of the AKI terms were pruned from the full-rank model for the 4 dependent variables measuring particulate emissions, where no emissions effect related to AKI can be found.

The terms involving PMI and EtOH were then evaluated and simplified to give a parsimonious representation of the variation that is both seen in the data and can be supported at the usual level of statistical significance (p=0.05 or better).

Based on such observations, hypotheses for the effects of PMI and EtOH can be expressed in mathematical terms and then tested against the data for statistical significance. For example, Eq. 2 gives a form that can be used to test whether the effect of EtOH differs for the AKI 94 Low PMI and AKI 94 High PMI fuels compared to an average EtOH effect for all fuels.

$$Y_{hijk} = \mu + v_k + PMI_i + EtOH_j + EtOH_j{*}d94Lo + EtOH_j{*}d94Hi + \varepsilon_{hij} \qquad \text{(Eq. 2)}$$

When decisions are reached on the pattern of EtOH effects present in the data, further tests can be made for whether the PMI effects are consistent across the fuels or differ for some fuels. Throughout the analysis, the emissions effect of PMI was found to be uniform across the AKI and EtOH levels.

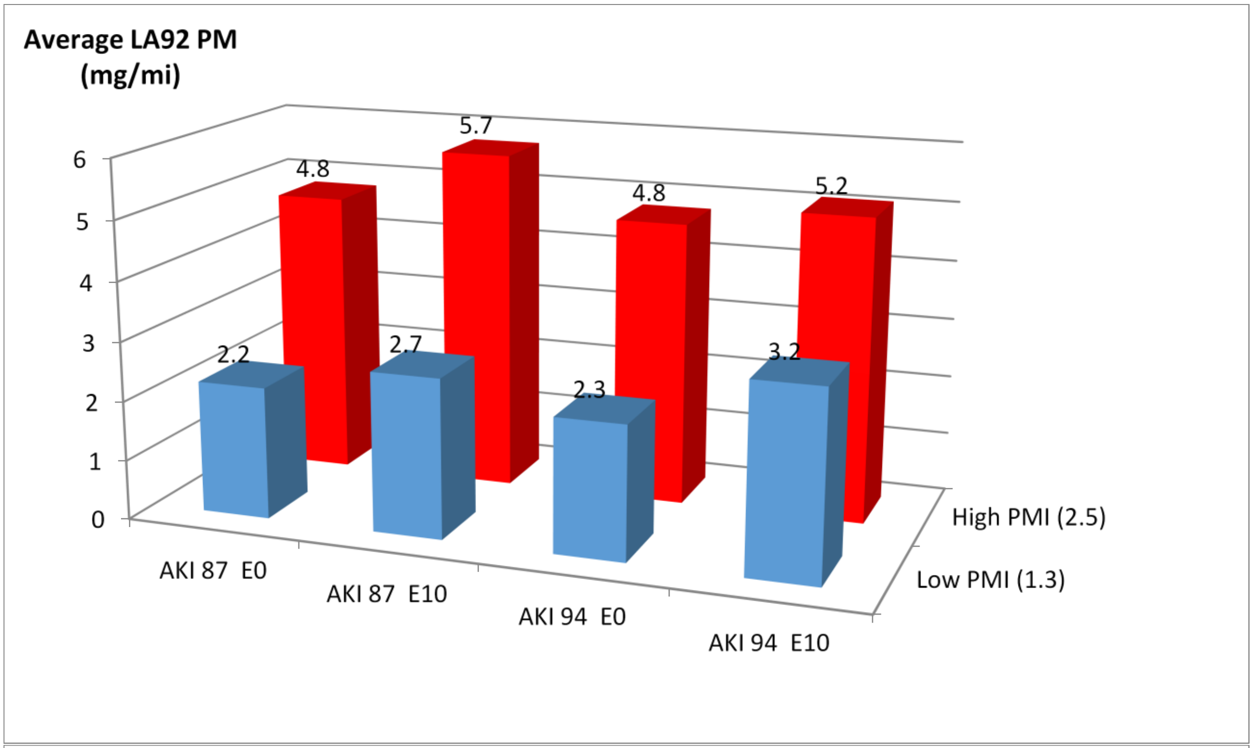
Once a provisional model was identified, the residuals from the model were tested against a range of fuel effects to confirm that no statistically-significant information remained behind. One such form involved testing for remaining differences among fuels for the effects of PMI, EtOH and AKI. The mathematical terms involved in these tests were of the following form:

$$\begin{aligned} &PMI \; {*} \; \{ d87E0, d87E10, d94E0, d94E10 \} && \text{(Eq. 3)} \\ &EtOH \; {*} \; \{ d87E0, d87E10, d94E0, d94E10 \} \\ &AKI \; {*} \; \{ d87E0, d87E10, d94E0, d94E10 \} \end{aligned}$$

Here, a dummy variable such as d87E0 has the value 1 for AKI 87 E0 fuels (both Low and High PMI) and the value 0 for all other fuels. If the model development process has identified the simplest form that fully describes the data, then none of the terms itemized in Eq. 3 will be found statistically significant.

Figure 28 illustrates the starting and ending points of the model development process using the predictions of LA92 PM emissions based on the full rank model (upper part) and on the final statistical model (lower part). The columns in the figure represent the predicted level of emissions for each fuel on average for the test fleet, which is also termed "the average vehicle." When all possible AKI, PMI and EtOH effects are taken into account (by the full rank model), the comparison of emissions from the fuels indicates that PMI strongly influences emissions for all four levels of AKI and EtOH. EtOH influences emissions for at least three levels of AKI and PMI (but possibly not for AKI 94 High PMI fuels). AKI appears to have little influence on PM emissions, particularly for the AKI 87 and 94 E0 fuels of both Low and High PMI.

As the complete set of fuel terms in the full rank model is evaluated and pruned based on the statistical significance of observed emission differences, the model development process leads ultimately to the emission patterns shown in the lower part of the figure (the final statistical model). PMI is found to have the strongest effect, increasing PM emissions by an estimated +114% between Low and High PMI fuels for all four AKI / EtOH levels. That is, the emissions of 2.3 mg/mi for the AKI 87 E0 Low PMI fuel are predicted to increase to 4.9 mg/mi (+114%) for the AKI 87 E0 High PMI fuel. The same percentage change is predicted for the AKI 87 E10 fuels when varied from Low to High PMI, for the AKI 94 E0 fuels from Low to High PMI, and for the AKI 94 E10 fuels from Low to High PMI. An increase in EtOH content from E0 to E10 (9.5 vol %) is found to have the same percentage effect in the AKI 87 fuels (both Low and High PMI), a larger effect in the AKI 94 Low PMI fuels, and no effect in the AKI 94 High PMI fuel. Because AKI was found to have no statistically significant effect on emissions, the emissions for AKI 87 and 94 E0 fuels are predicted to be the same for the Low and High PMI levels. Emissions for the AKI 87 and 94 E10 fuels differ, but this is attributed by the analysis to differences in the emissions response to EtOH.



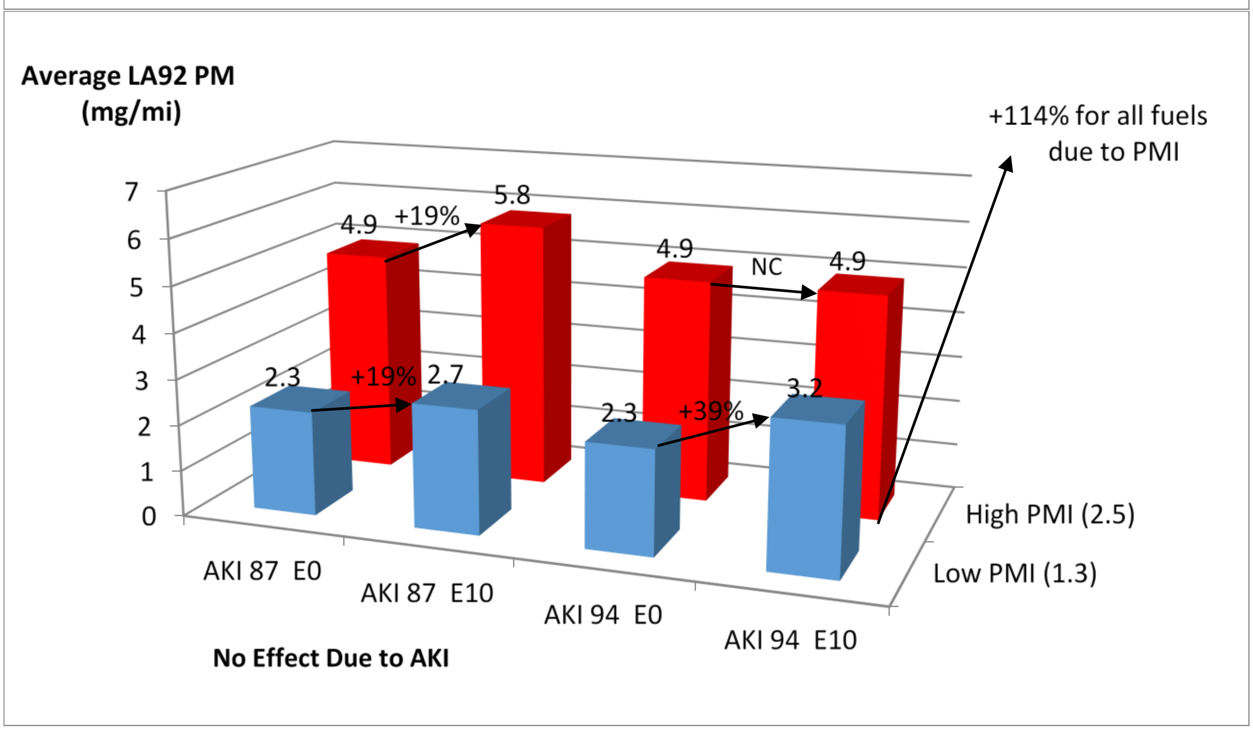


FIGURE 28. PREDICTED LA92 PM EMISSIONS BASED ON THE FULL RANK (TOP) AND FINAL (BOTTOM) STATISTICAL MODELS

5.2.5.2 Analysis of Residuals for Other Fuel Effects

Once a final statistical model is identified, the model is used to predict emissions of the average vehicle on each fuel and to estimate the effect of PMI and EtOH on emissions. The estimate for the average vehicle is obtained by setting the v_k terms in Eq. 1 to zero, permitting the predictions for each fuel to be graphed in a form similar to Figure 28.

Predictions for the effects of PMI and EtOH on emissions are obtained by having the statistical software evaluate specified changes in independent variables, leading to an estimate of the emissions change (and its uncertainty) for each case. As many as twelve fuel changes are possible as PMI, EtOH and AKI each go from low to high in the four fuels described by the other two properties. However, only those representing fuel effects in the final model are of interest.

The method of evaluation is one of computing differences between the emissions of specified starting and ending fuels. The percent change in emissions is equal to $\exp(\Delta Y_{hijk}) - 1$, where Y is a natural logarithm of emissions, and is given by Equation 4:

$$\Delta Y_{A\text{-}B} = Y_{A[hij]} - Y_{B[hij]} \text{ where A and B are two fuels} \qquad \text{(Eq. 4)}$$

$$\begin{aligned}\Delta Y_{A\text{-}B} = {} & c_h \cdot \Delta AKI_h + c_i \cdot \Delta PMI_i + c_j \cdot \Delta EtOH_j + c_{hi} \cdot \Delta AKI_h \, \Delta PMI_i \\ & + c_{hj} \cdot \Delta AKI_h \, \Delta EtOH_j + c_{ij} \cdot \Delta PMI_i \, \Delta EtOH_j \\ & + c_{hij} \cdot \Delta AKI_h \, \Delta PMI_i \, \Delta EtOH_j\end{aligned}$$

where:

$h = 1, 2$ AKI_h

$i = 1, 2$ PMI_i

$j = 1, 2$ $EtOH_j$

the coefficients c are estimated in fitting each model.

The vehicle intercepts play no role in this calculation, as they are constants present for both fuels A and B. There is uncertainty in the level of average emissions for each vehicle because of the finite number of fuels on which they were tested. In fact, accounting for vehicle-specific differences in average emission levels is the largest contributor to the explanatory power of the models as measured by the R^2 statistic. Uncertainty in the average emission level of each vehicle is also the largest contributor to the overall uncertainty (larger than that related to fuels) when predicting the absolute level of emissions for each fuel. However, the vehicle-specific emission levels drop out of the predictions for the relative effects of fuels on emissions. Because of this, the statistical analysis across multiple vehicles is able to achieve better precision and to resolve smaller fuel effects than would be possible from simple comparisons of average emissions on each fuel.

5.2.5.3 Analysis for Individual Vehicles

The analysis conducted for individual vehicles used a linear model form given by Eq. 5. Here, the term v_k is simply an intercept term; the notation is carried forward from Eq. 1 to indicate that it represents a vehicle-specific emissions level.

$$Y_{hijk} = v_k + AKI_h + PMI_i + EtOH_j + \varepsilon_{hij} \qquad \text{(Eq. 5)}$$

where: v_k = mean emissions for vehicle "k"

h = 1, 2 AKI_h

i = 1, 2 PMI_i

j = 1, 2 $EtOH_j$

$\varepsilon_{hij} \sim N(0,\sigma)$

5.2.5.4 Analysis of Residuals for Other Fuel Effects

Once a final statistical model was obtained, additional tests of residuals were conducted to determine whether any of the other fuel properties of interest (see Table 40) contribute to the variation in the emissions data. These tests were formulated as given in Eq. 6:

$$\text{residual}\ (Y_{hijk}) = \mu + FuelParm_{hijk,m=1} + \ldots + FuelParm_{hijk,m=n} + \varepsilon_{hijk} \qquad \text{(Eq. 6)}$$

where:

μ = mean value for emission residuals

m = 1, …, n Other Fuel Parameters (FuelParm, one to several)

h = 1, 2 AKI_j

i = 1, 2 PMI_h

j = 1, 2 $EtOH_i$

k = 1, …, 12 Vehicles

A total of 22 different fuel properties were considered in this process, which raises the problem of determining statistical significance when multiple comparisons are made. The conventional level for statistical significance is p = 0.05, which means that the result observed has a 5% chance of arising merely by chance (a false positive). If twenty comparisons are made at the p = 0.05 level, then one should expect that one false positive will be encountered on average. The solution to this problem when N comparisons are being made is to test each comparison at the $\alpha = 0.05 / N$ level. Then, the overall risk of a false positive is limited to only 5%. Here, the level for multiple comparisons is $\alpha = 0.05 / 22 \sim 0.002$.

In the residuals testing, fuel properties other than AKI, PMI and EtOH were occasionally found to be statistically significant at the p = 0.05 level, but in no case at the $p \leq 0.002$ level. Such cases are reported in the Appendix H tables of analytical results. <u>Because none of the other</u>

fuel properties reach the adjusted significance level for multiple comparisons, there is no evidence to conclude that they exert an actual effect on vehicle emissions.

5.3 The Effect of Fuels on Particulate Emissions

In the following, the report presents *results* of the statistical analysis for the emission differences due to fuels that were found to be real, meaning those that one can conclude with a high degree of reliability are actually present in the data and not caused merely by random variation in the emissions data. Where emission levels are shown graphically, the values being plotted are the expected level of emissions by fuel for the average vehicle in the test fleet (or in a subset of the test fleet). These values are not averages of the emissions data, which are *inputs* to the statistical analysis, but are *predictions* derived from the final statistical models developed for each pollutant.

The particulate emissions examined were the LA92 weighted-average emissions for PN, PM and EC, and the LA92 Phase 1 emissions for PM. Because the total mass of particulate emitted from a vehicle is the result of both the number of particles and the average mass of the particles, the presentation considers first the effects of fuels on LA92 PN emissions, followed by the effects on LA92 PM, Phase 1 PM, and LA92 EC.

5.3.1 LA92 PN Emissions

Particle number emissions were determined by the CPC 3790 instrument that counts the number of solid particles emitted that are greater than 23 nm in diameter. Emissions are reported in units of 10^{12} particles/mi.

5.3.1.1 Emissions Response of the Test Vehicles

As noted in the methodology discussion, a linear analysis was conducted in which emissions of each vehicle were related to PMI, EtOH and AKI. The results of this analysis are tabulated in Appendix H. Figure 29 shows the overall result for the test vehicles by displaying the predicted changes in PN emissions over the range of variation in PMI, EtOH and AKI in the fuels. The vertical axis gives the emissions response. The error bars give the uncertainty in emissions response corresponding to one standard deviation (1σ) as calculated by the statistical software for the indicated fuel change. The top of the chart indicates the division of vehicles into Low, Mid, and High PM groups, while the horizontal axis gives the average PM level of the vehicles in mg/mi terms. Circles indicate NA vehicles (both 4- and 6-cylinder) and squares indicate turbocharged vehicles (both 4- and 6-cylinder).

Taken overall, the results demonstrate that the emissions response, when measured on a percentage basis, is approximately constant over a wide range of vehicle PM levels. This implies that the emissions change in absolute terms (here, particles/mile) will be greater for a vehicle with a higher average PN level than for one with a lower average PN level. The homogeneity in response on a percentage basis is typical of vehicular emissions and is a chief rationale for use of the log(Emissions) model form.

The upper portion of the graph shows the predicted emission change when moving from a Low PMI fuel (1.3) to a High PMI fuel (2.5). PN emissions increase by amounts that range from +50% to as much as +170% depending on the vehicle. In general, the turbocharged vehicles (squares) have larger responses than the NA vehicles (circles), but there is also substantial vehicle-to-vehicle variation in response both generally and within each air induction type. Vehicles C and L have the largest responses to PMI and stand out above the others. It is useful to compare the emission response to fuels among generic subgroups of the data – including air induction type and PM level – but it should be remembered that vehicle-specific differences exist within the subgroups and that the response of some vehicles can differ substantially from the rest.

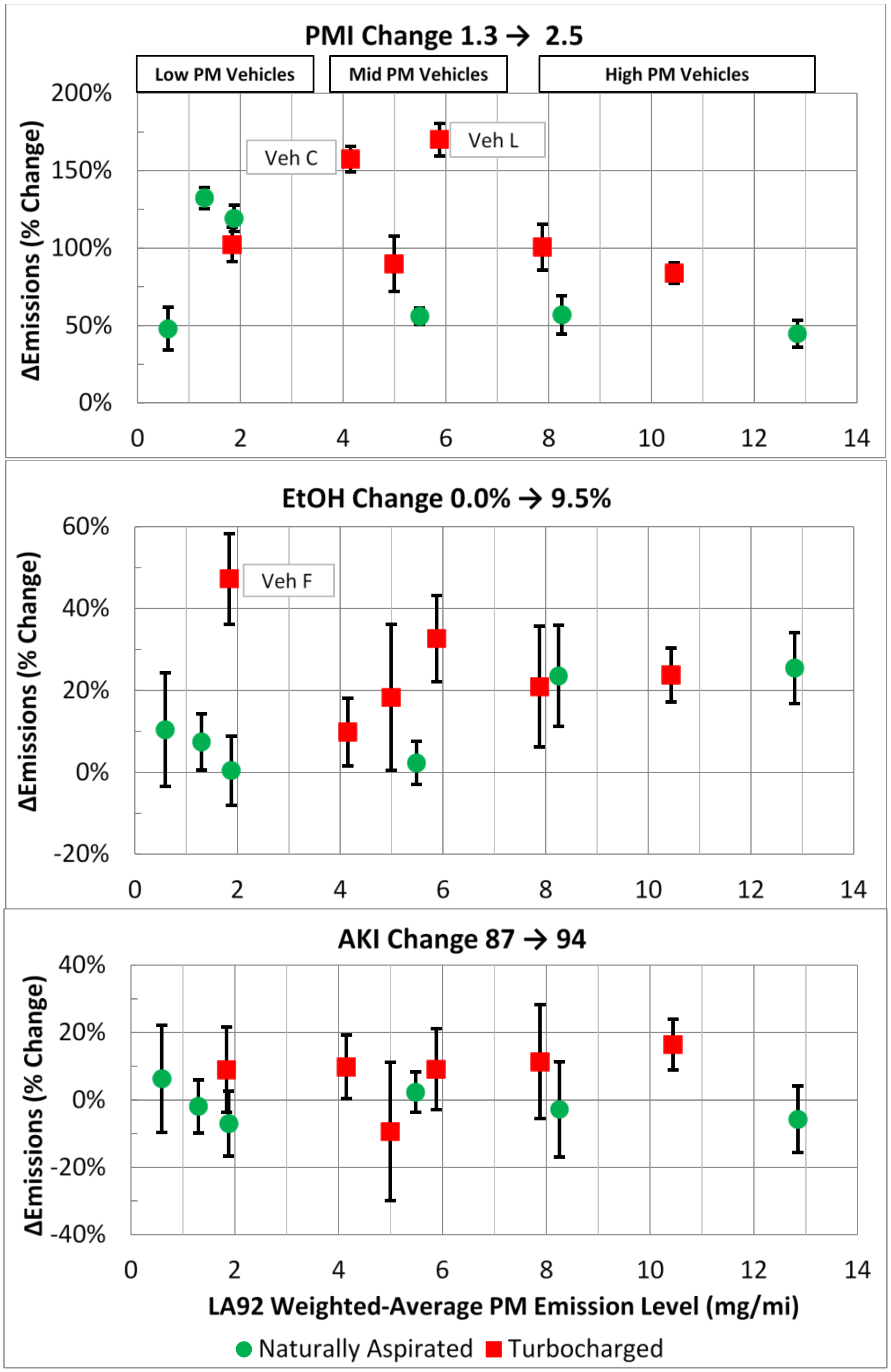


FIGURE 28 RESPONSE OF LA92 PN EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE (ERROR BARS SHOW 1 σ RANGE)

The middle portion of the graph shows the predicted emissions change when moving from an E0 fuel to an E10 fuel (9.5 vol %). The magnitude of the emissions response is smaller than for PMI, ranging from values near zero for four vehicles to nearly +50% for Vehicle F (a Low PM vehicle). In general, the turbocharged vehicles have larger responses to EtOH than do the NA vehicles.

The lower portion of the graph demonstrates that a change in AKI from 87 to 94 does not lead to statistically significant changes in LA 92 PN emissions. PN emissions increase for some vehicles and decrease for others. In all cases, a 2σ error band (giving the 95 percent confidence interval) overlaps the horizontal axis (zero percent change). None of the predicted changes achieve an acceptable level of statistical significance here or for the other particulate emission variables examined.

5.3.1.2 Emissions Response of the Entire Test Fleet

A full statistical analysis was conducted for the entire test fleet and for its subgroups. Beginning with a full-rank model (containing linear plus second- and third-order terms), it was reduced based on the statistical significance of terms to create a model that most concisely described the effect of fuels.

Figure 30 shows the result of this process for the test fleet of twelve vehicles. A change from Low PMI (1.3) to High PMI (2.5) fuel is predicted to increase PN emissions by +105% on average (for the entire test fleet) irrespective of fuel octane or EtOH level. This means that a uniform +105% change due to PMI connects the fuels in the front and back row of the figure, such that the emissions of 3.5×10^{12} particles per mile for the AKI 87 E0 Low PMI fuel are predicted to become 7.1×10^{12} particles per mile for an AKI87 E0 High PMI fuel. The same, uniform +105% change connects the AKI 87 E10 fuels of Low and High PMI, the AKI 94 E0 fuels of Low and High PMI, and the AKI 94 E10 fuels of Low and High PMI..

For EtOH, the emissions change in going from E0 to E10 (9.5 vol %) is found to depend on the PMI level of the fuel. Going from E0 to E10 increases predicted PN emissions by +37% in the Low PMI fuels (both AKI 87 and AKI94), but by a lesser +14% in the High PMI fuels (both AKI 87 and AKI 94). No effect of AKI on emissions was found; because of this, the predicted emission levels are the same at AKI 87 and AKI 94 levels for E0 and E10 fuels of both Low and High PMI.

The emissions responses to PMI and EtOH have strong statistical significance, as summarized in Table 45. The emissions response to PMI is determined to within an uncertainty of ± 4% (or 1 part in 26). An effect of this size has less than 1 chance in 10,000 of arising solely by chance. The responses to EtOH are smaller in size and have no more than 1 chance in 100 of arising by chance.

TABLE 45. EFFECT OF FUELS ON LA92 PN EMISSIONS

Fuel Change	Fuel	ΔLA 92 PN	Statistical Significance
PMI 1.3 → 2.5	All Fuels	+ 105% ± 4%	$p < 0.0001$
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 37% ± 4%	$p = 0.0001$
	AKI 87 High PMI	+ 14% ± 4%	$p = 0.001$
	AKI 94 Low PMI	+ 37% ± 4%	$p = 0.0001$
	AKI 94 High PMI	+ 14% ± 4%	$p = 0.001$
AKI 87 → 94	All Fuels	–	–

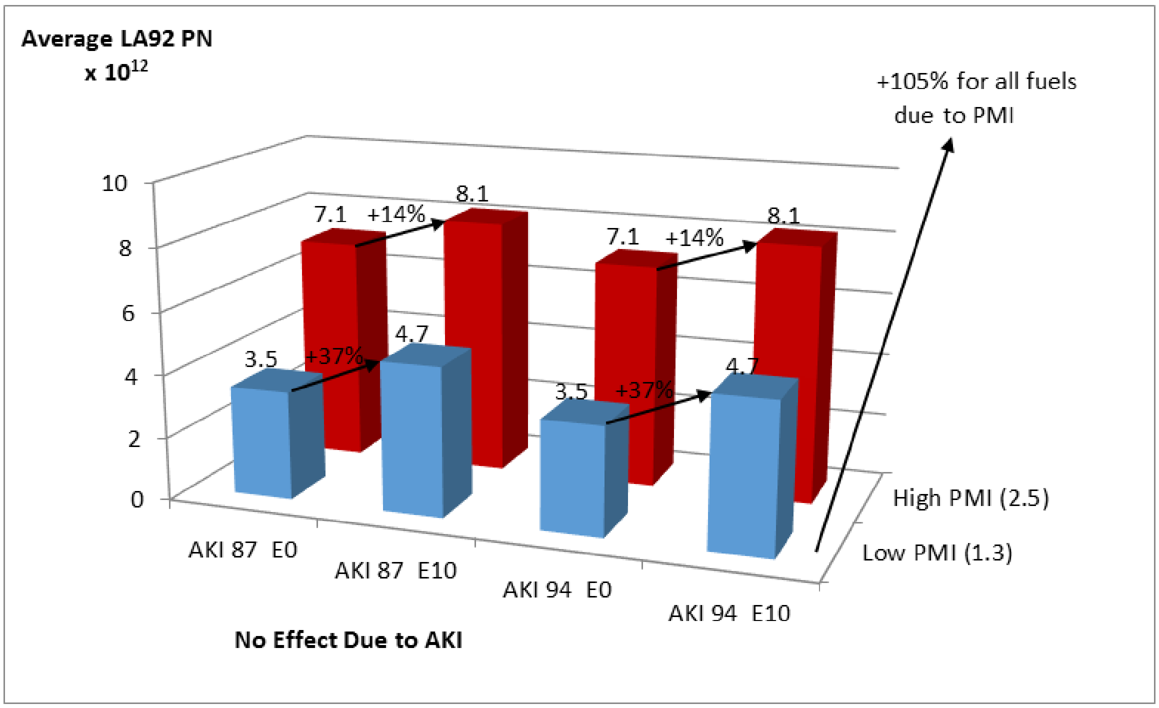


FIGURE 29. RESPONSE OF LA92 PN EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI.

5.3.1.3 Emissions Response by Air Induction Type for 4-cylinder Vehicles

The emissions response to fuels observed in the entire test fleet is also observed in the subgroups of 4-cylinder vehicles by air induction type as shown in Table 46. A PMI change from 1.3 to 2.5 is estimated to increase PN emissions by +117% in 4-cylinder NA vehicles and by 89% in the 4-cylinder turbocharged vehicles. The emissions response in the test fleet, with its 50:50 mix of NA and turbocharged vehicles (including one V-6 engine of each type), is an intermediate +105%.

TABLE 46. EFFECT OF FUELS ON LA92 PN EMISSIONS BY AIR INDUCTION TYPE

Fuel Change	Fuel	Test Fleet	4-Cyl NA	4-Cyl Turbo
NA : Turbo Mix		6 : 6	5 : 0	0 : 5
PMI 1.3 → 2.5	All Fuels	↑ 105%	↑ 117%	↑ 89%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 37%	↑ 39%	↑ 24%
	AKI 87 High PMI	↑ 14%	↑ 14%	↑ 24%
	AKI 94 Low PMI	↑ 37%	↑ 39%	↑ 34%
	AKI 94 High PMI	↑ 14%	–	↑ 18%
AKI 87 → 94	All Fuels	–	–	–

For EtOH, a change from E0 to E10 (9.5 vol %) is estimated to increase the PN emissions of 4-cylinder NA vehicles by 14 to 39%, although the analysis fails to detect an increase for the AKI 94 High PMI fuel. In 4-cylinder turbocharged vehicles, EtOH is estimated to increase emissions in all fuels by amounts ranging from 18 to 34%. These changes are generally similar in size to those for the entire test fleet. No effect due to AKI can be detected.

5.3.1.4 Emissions Response by PM Groups

When vehicles are classified as Low, Mid and High PM vehicles, PMI and EtOH effects are detected in all three groups. As Table 47 shows, a PMI change from 1.3 to 2.5 is estimated to increase PN emissions by +84% in the Low PM group and by similar amounts in the other groups. The corresponding emissions response in the test fleet is +105%, a similar but numerically larger value resulting from the independent analysis of all twelve test vehicles as a group[14]. The smaller response to PMI in Low PM vehicles is the net result of the disparate responses of the individual vehicles. Three of the four vehicles in the group have a relatively large response to PMI, while one has a relatively small response compared to other vehicles (see Figure 29), leading to a smaller response in the Low PM group compared to the other groups and the entire test fleet.

A relatively large EtOH effect is detected in the Low PM group, as one of the four vehicles has the largest response in the test fleet (see Figure 29). In the other groups, a change from E0 to E10 (9.5 vol %) is estimated to increase PN emissions by amounts that are generally comparable to that observed for the entire test fleet. No difference could be detected among the fuels in the emissions response to EtOH. As elsewhere, no effect due to AKI was detected.

[14] The emissions changes cited for the test fleet in Table 5-9 and similar tables are derived from independent analysis of the data for all twelve vehicles and is not an average or composite value created by combining the subgroup results. The percentage values cited in the tables reflect emission changes measured in percent terms with respect to differing base emission values for the test fleet and each of the subgroups. When converted to mg/mi terms, the emissions changes predicted for the test fleet will be intermediate to those predicted for the subgroups individually even when the numerical percentage changes are not.

TABLE 47. EFFECT OF FUELS ON LA92 PN EMISSIONS BY PM GROUP

Fuel Change	Fuel	Test Fleet	Low PM	Mid PM	High PM
NA : Turbo Mix		6 : 6	3 : 1	1 : 3	2 : 2
PMI 1.3 → 2.5	All Fuels	↑ 105%	↑ 84%	↑ 93%	↑ 73%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 37%	↑ 39%	↑ 24%	↑ 23%
	AKI 87 High PMI	↑ 14%	↑ 39%	↑ 24%	↑ 23%
	AKI 94 Low PMI	↑ 37%	↑ 39%	↑ 24%	↑ 23%
	AKI 94 High PMI	↑ 14%	↑ 39%	↑ 24%	↑ 23%
AKI 87 → 94	All Fuels	—	—	—	—

The PMI effect that is present in the Low PM vehicles is large enough to observe and reliably measure in back-to-back test runs using Low and High PMI fuels. The repeatability of PN test-run measurements is observed to be ± 12% in Low PM vehicles. The size of the PMI effect (+84% for PMI 1.3 → 2.5) amounts to 7σ in terms of measurement repeatability, meaning that the emissions difference between Low and High PMI fuels is seven times the repeatability of the emission measurements. One can conclude that an observed difference is meaningful when it amounts to two or more times the measurement repeatability, as is the case here. The size of the EtOH effect (+39% for E0 → E10) amounts to 3σ in terms of measurement repeatability.

5.3.1.5 Summary for LA92 PN Emissions

Fuel PMI and ethanol content exert clear effects on LA92 PN emissions:

- PMI substantially increases PN emissions across the board – in all fuels, all vehicles and across all subgroups examined. The effect is large, amounting to a near doubling, or more than doubling, for a PMI change from 1.3 to 2.5.
- EtOH also increases PN emissions by amounts that range up to 39% depending on fuel and subgroup. The analysis generally does not detect an EtOH effect for the AKI 94 High PMI fuel.
- The PMI and EtOH fuel effects are large enough to be observed and reliably measured in the subgroup of Low PM vehicles.

Fuel octane number (AKI) does not influence PN emissions.

5.3.2 LA92 PM Emissions

PM emissions were determined by gravimetric method that determines the particle mass emitted over the LA92 cycle in units of mg/mi.

5.3.2.1 Emissions Response of the Test Vehicles

Figure 31 shows the predicted change in PM emissions due to PMI, EtOH, and AKI for the individual vehicles. The top of the chart indicates the division of vehicles into Low, Mid, and High PM groups, while the horizontal axis gives the average PM level of the vehicles in mg/mi terms. Circles indicate NA vehicles (both 4- and 6-cylinder) and squares indicate turbocharged vehicles (both 4- and 6-cylinder) in the graphs.

As was seen for PN, the results demonstrate that the emissions response is nearly constant on a percentage basis over the range of vehicle PM levels. There is general homogeneity by vehicle in response to all three fuel parameters, but Vehicles G and L display substantially different responses compared to the others.

The upper portion of the graph shows the predicted emission change when moving from a Low PMI (1.3) to a High PMI (2.5) fuel. PM emissions are shown to increase by amounts ranging from as little as +30% to more than +200% depending on the vehicle. Except for two vehicles, there is little difference in the response between NA (circles) and turbocharged vehicles (squares). Vehicle L has the largest response to PMI, while Vehicle G has the smallest. As for PN, vehicle-specific differences exist within the subgroups and the response of some vehicles can differ substantially from the rest.

The middle portion of the graph shows the predicted emissions change when moving from an E0 to an E10 fuel (9.5 vol %). The emissions response is smaller than for PMI and, with one exception, ranges from +15% to +40% with little difference between NA and turbocharged

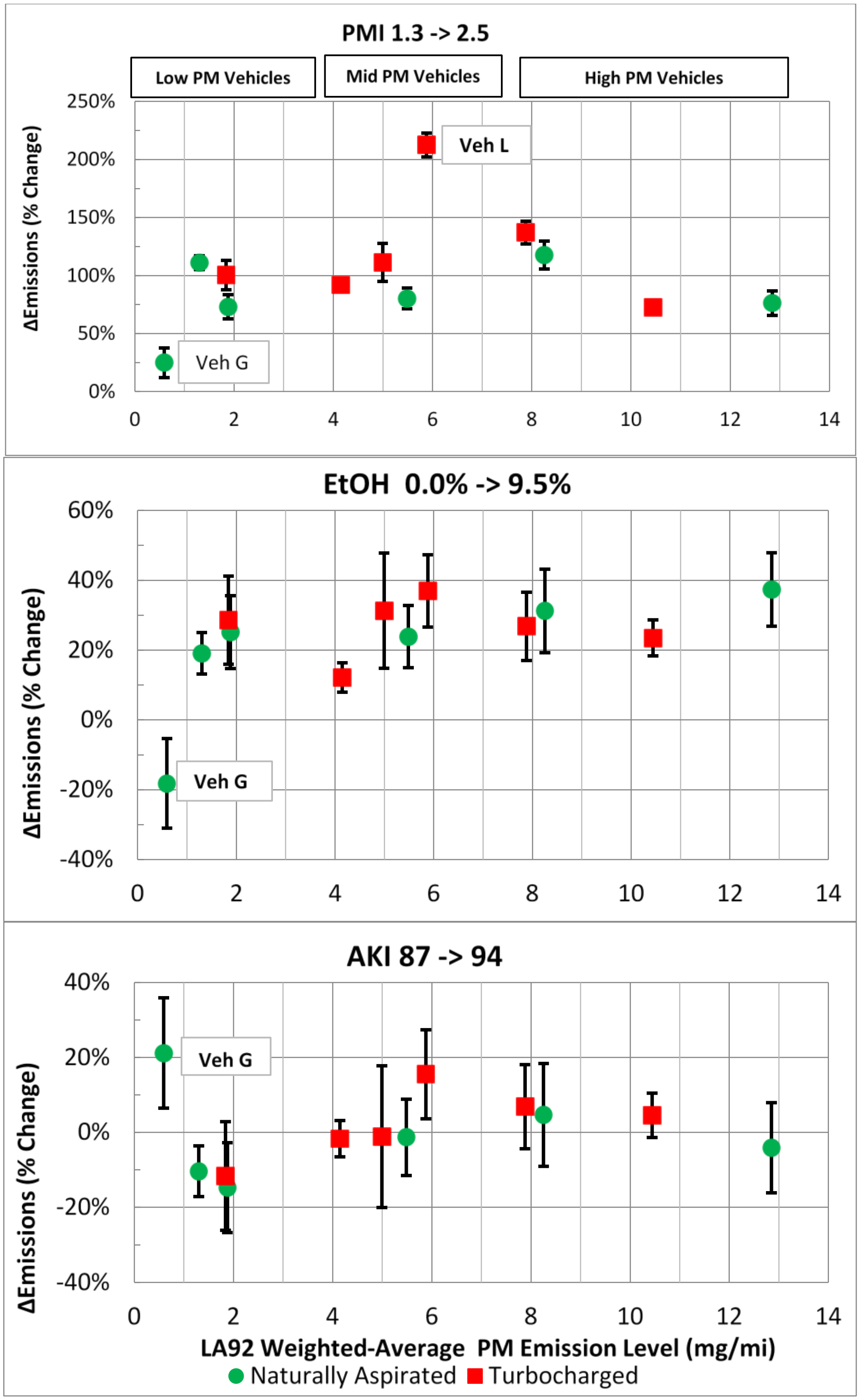


FIGURE 30. RESPONSE OF LA92 PM EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE (ERROR BARS SHOW 1 σ RANGE)

vehicles. Here, Vehicle G displays a contrary emissions response in which its PM emissions *decrease* on E10 fuels.

The lower portion of the graph demonstrates that a change in AKI from 87 to 94 does not lead to statistically significant changes in LA 92 PM emissions. PM emissions increase for some vehicles and decrease for others. Vehicle G shows a larger response to AKI than the entire test fleet. In all cases, a 2σ error band (giving the 95 percent confidence interval) overlaps the horizontal axis (zero percent change). None of the predicted changes achieve an acceptable level of statistical significance here or for the other particulate emission variables examined.

5.3.2.2 Emissions Response of the Entire Test Fleet

Figure 32 shows the result for PM emissions of the entire test fleet. A change from Low PMI (1.3) to High PMI (2.5) fuel causes PM emissions to increase by +114% in all fuels. Compared to the +105% increase observed for LA92 PN, this result means that the average particle mass (LA92 PM mg/mi divided by LA92 PN particles/mi) is increased by only 9% between Low and High PMI fuels. The effect of PMI does not depend on the ethanol content or octane number of the fuels.

For EtOH, the emissions impact associated with a change from E0 to E10 (9.5 vol %) is found to depend on the PMI level of the fuel. Here, PM emissions are increased by +19% in the AKI 87 Low and High PMI fuels, but by +39% in the AKI 94 Low PMI fuel. No effect of ethanol on emissions was found in the AKI 94 High PMI fuel. The emissions responses to PMI and EtOH have strong statistical significance, as summarized in Table 48, having in all cases less than 1 chance in 10,000 of arising by chance.

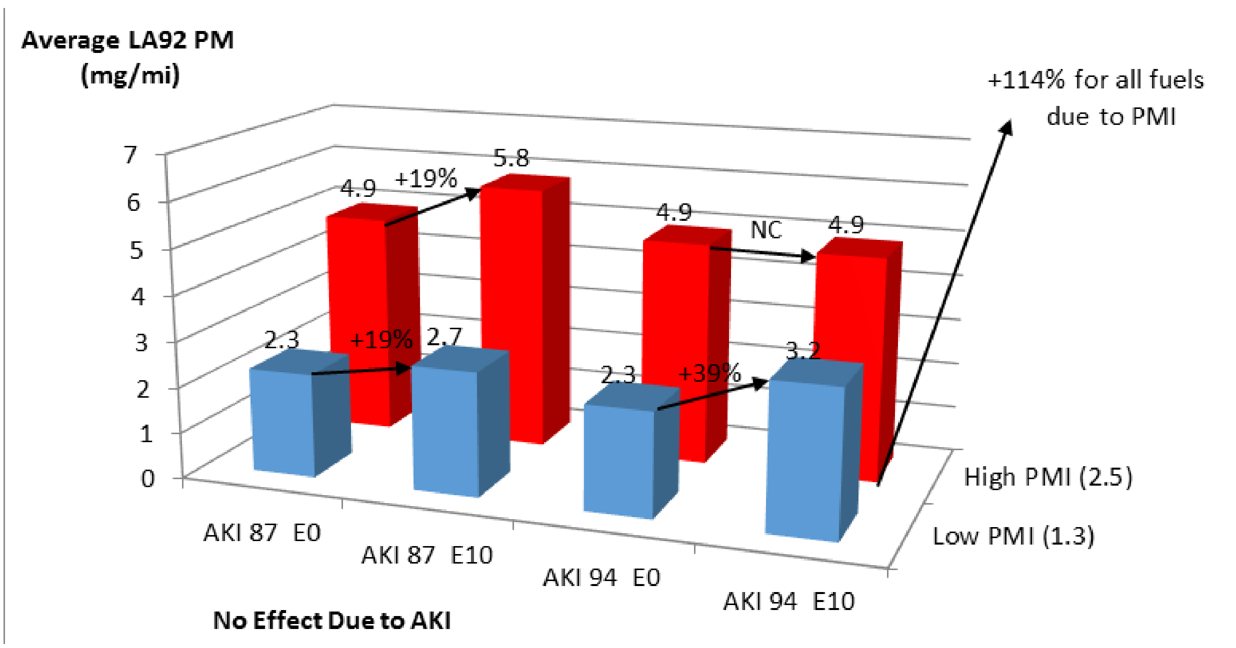


FIGURE 31. RESPONSE OF LA92 PM EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

TABLE 48. EFFECT OF FUELS ON LA92 PM EMISSIONS

Fuel Change	Fuel	ΔLA 92 PN	Statistical Significance
PMI 1.3 → 2.5	All Fuels	+ 114% ± 4%	$p < 0.0001$
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 19% ± 4%	$p < 0.0001$
	AKI 87 High PMI	+ 19% ± 4%	$p < 0.0001$
	AKI 94 Low PMI	+ 39% ± 6%	$p < 0.0001$
	AKI 94 High PMI	—	—
AKI 87 → 94	All Fuels	—	—

5.3.2.3 Emissions Response by Air Induction Type for 4-cylinder Vehicles

A comparable emissions response to fuels is seen in the subgroups of 4-cylinder vehicles by air induction type as shown in Table 49. A PMI change from 1.3 to 2.5 is estimated to increase PM emissions by +106% in the 4-cylinder NA vehicles and by 136% in the 4-cylinder turbocharged vehicles. The emissions response in the entire test fleet, with its 50:50 mix of NA and turbocharged vehicles (including one V-6 engine of each type), is an intermediate +114%.

For EtOH, a change from E0 to E10 (9.5 vol %) is estimated to increase PM emissions by amounts similar to the entire test fleet, although the sizes and pattern among the fuels differs somewhat between the 4-cylinder NA and turbocharged vehicles. The analysis failed to detect an EtOH response in the AKI 94 High PMI fuel. An increase, if present, fails to reach the conventional level of statistical significance ($p \leq 0.05$). No effect due to AKI was detected.

TABLE 49. EFFECT OF FUELS ON LA92 PM EMISSIONS BY AIR INDUCTION TYPE

Fuel Change	Fuel	Test Fleet	4-Cyl NA	4-Cyl Turbo
NA : Turbo Mix		6 : 6	5 : 0	0 : 5
PMI 1.3 → 2.5	All Fuels	↑ 114%	↑ 106%	↑ 136%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 19%	↑ 33%	↑ 20%
	AKI 87 High PMI	↑ 19%	↑ 33%	↑ 20%
	AKI 94 Low PMI	↑ 39%	↑ 33%	↑ 46%
	AKI 94 High PMI	—	—	—
AKI 87 → 94	All Fuels	—	—	—

5.3.2.4 Emissions Response by PM Groups

When vehicles are grouped by their average PM level, a PMI effect is detected in Low PM vehicles and PMI and EtOH effects are detected in the Mid and High PM groups (see Table 50). A PMI change from 1.3 to 2.5 is estimated to increase PM emissions by +76% in the Low PM group and by larger amounts in the other groups. This result parallels the findings for PN emissions and can be traced to the smaller response to PMI for one of the four vehicles in the Low PM group. PMI effects in the Mid and High PM groups are larger and are comparable to the findings for PN emissions.

No EtOH effect can be detected with acceptable statistical significance ($p \leq 0.05$) in the Low PM group. The disparate performance of Vehicle G, for which emissions decrease as EtOH increases, reduces the net effect of EtOH to below the threshold of detection. In the other PM groups, a change from E0 to E10 (9.5 vol %) is estimated to increase PM emissions by amounts that are similar in size to the entire test fleet. The analysis again fails to detect an EtOH effect in the AKI 94 High PMI fuel. As elsewhere in the analysis, no effect due to AKI can be detected.

TABLE 50. EFFECT OF FUELS ON LA92 PM EMISSIONS BY PM GROUP

Fuel Change	Fuel	Test Fleet	Low PM	Mid PM	High PM
NA : Turbo Mix		6 : 6	3 : 1	1 : 3	2 : 2
PMI 1.3 → 2.5	All Fuels	↑ 114%	↑ 76%	↑ 142%	↑ 110%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 19%	–	↑ 18%	↑ 22%
	AKI 87 High PMI	↑ 19%	–	↑ 18%	↑ 22%
	AKI 94 Low PMI	↑ 39%	–	↑ 46%	↑ 41%
	AKI 94 High PMI	–	–	–	–
AKI 87 → 94	All Fuels	–	–	–	–

The PMI effect that is present in the Low PM vehicles is large enough to observe and reliably measure in back-to-back test runs on Low and High PMI fuels. The repeatability of PM measurements is observed to be ± 19% in Low PM vehicles. The size of the PMI effect (+76% for PMI 1.3 → 2.5) amounts to 4σ in terms of measurement repeatability.

5.3.2.5 Summary for LA92 PM Emissions

As for PM emissions, PMI and EtOH exert clear effects on LA92 PM emissions:

- PMI substantially increases PM emissions across the board – in all fuels, all vehicles and across all subgroups examined. With the exception of Vehicle G, the effect is large, amounting to a near doubling, or more than doubling, for a PMI change from 1.3 to 2.5.

- EtOH also increases PM emissions by amounts up to 46% depending on fuel and subgroup. The analysis does not detect an EtOH effect in the AKI 94 High PMI fuel.
- The PMI fuel effect is large enough to be observed and measured in the subgroup of Low PM vehicles. An EtOH effect is not detected at these low PM levels due to the disparate response of one vehicle.

Fuel octane number (AKI) does not influence PM emissions.

5.3.3 Phase 1 PM Emissions

Phase 1 PM emissions constitute the first part of the LA92 drive cycle in which the beginning of a cold-start start trip is simulated. Although only 1.2 miles are traveled, the Phase 1 PM emissions account for 40% of the total particulate mass emitted over the course of the two simulated trips (each 9.8 miles long with a 43/57 percent weighting of cold- and hot-starts).

5.3.3.1 Emissions Response of the Test Vehicles

Figure 33 shows the emission responses of the individual vehicles, with the division of vehicles into Low, Mid, and High PM groups given at the top and using circles for NA vehicles (both 4- and 6-cylinder) and squares for turbocharged vehicles (both 4- and 6-cylinder). The results continue to demonstrate a general homogeneity in the emissions response to all three fuel parameters, although vehicle-specific differences do occur. Here, Vehicles C and F display different emissions responses compared to the entire test fleet.

At the top of the graph, Phase 1 PM emissions are shown to increase by amounts ranging from +50% to +150%, depending on the vehicle, for a change from Low to High PMI fuel. There is a difference in the response by air induction type, with the NA vehicles generally having a smaller response to PMI than the turbocharged vehicles. Vehicle C has the largest response to PMI. Four NA vehicles have relatively low responses to PMI.

The middle portion of the graph shows the predicted emissions change when moving from an E0 to an E10 fuel (9.5 vol %). The size of the emissions response is smaller than for PMI, ranging from nearly zero up to +25%. Vehicle F, one of four vehicles in the Low PM group, has the largest response of all.

The lower portion of the graph demonstrates that changes in AKI from 87 to 94 do not lead to statistically significant changes in LA 92 PM emissions. Phase 1 PM emissions increase for some vehicles and decrease for others with the 2σ error band (95 percent confidence interval) overlapping the horizontal axis (zero percent change) in all cases.

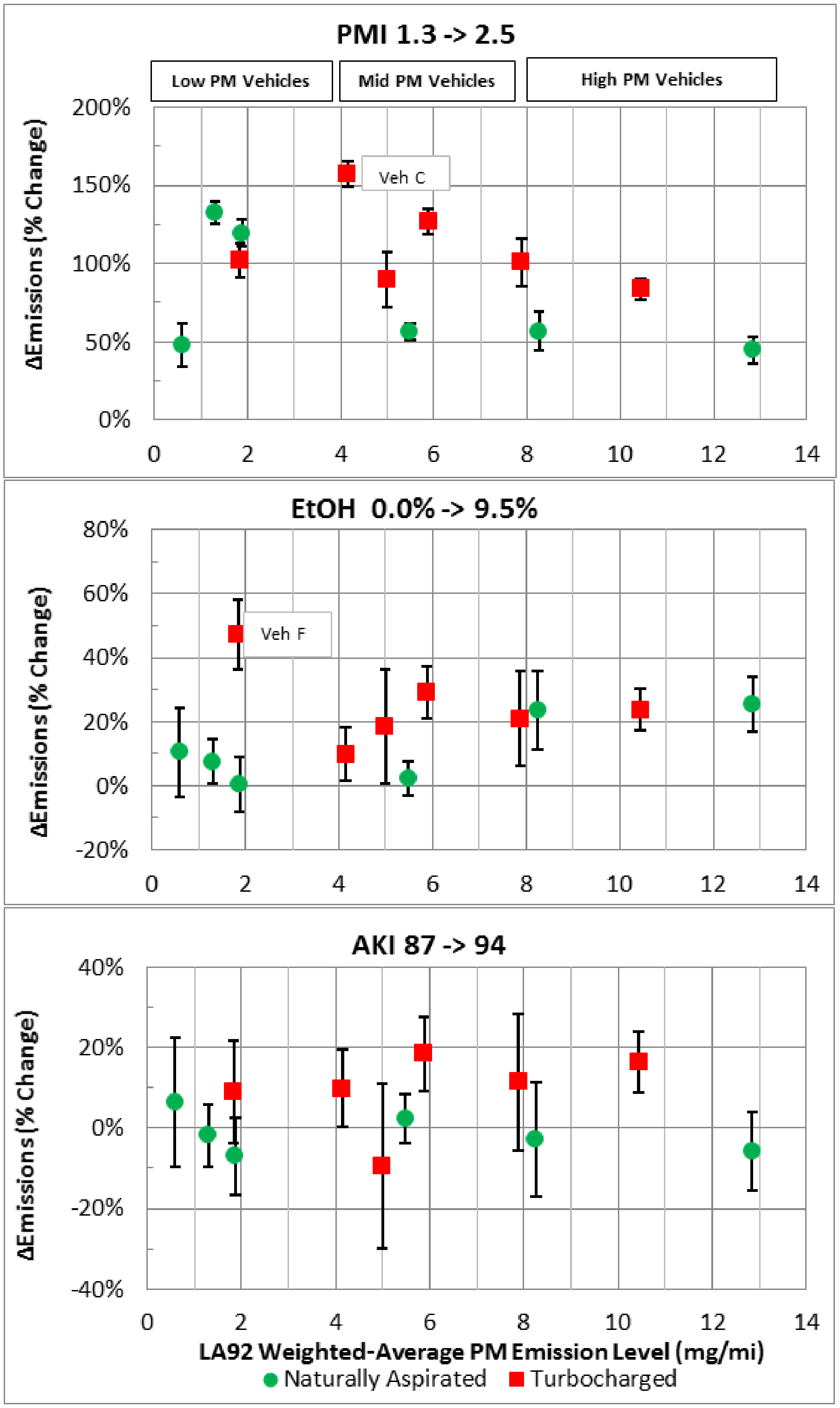


FIGURE 32. RESPONSE OF PHASE 1 PM EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE (ERROR BARS SHOW 1 σ RANGE)

5.3.3.2 Emissions Response of the Entire Test Fleet

Figure 34 shows the Phase 1 PM emissions for the entire test fleet of twelve vehicles. A change from Low to High PMI fuel increases Phase 1 PM emissions by +106% in all of the fuels (compared to +114% for LA92 PM). As for the particulate measures already examined, the effect of PMI does not depend on the ethanol content or the octane number of the fuels.

For EtOH, the emissions change in going from E0 to E10 (9.5 vol %) is found to depend on the PMI level of the fuel. Here, Phase 1 PM emissions are increased by +12% in the AKI 87 Low and High PMI fuels and by +37% in the AKI 94 Low PMI fuel. These changes are similar in size to those found for the LA92 PM emissions (+19% and +39%, respectively). The emissions responses to PMI and EtOH have strong statistical significance, as summarized in Table 51. No effect of AKI on emissions was found.

Overall, these findings for Phase 1 PM emissions mirror the findings for LA92 PM.

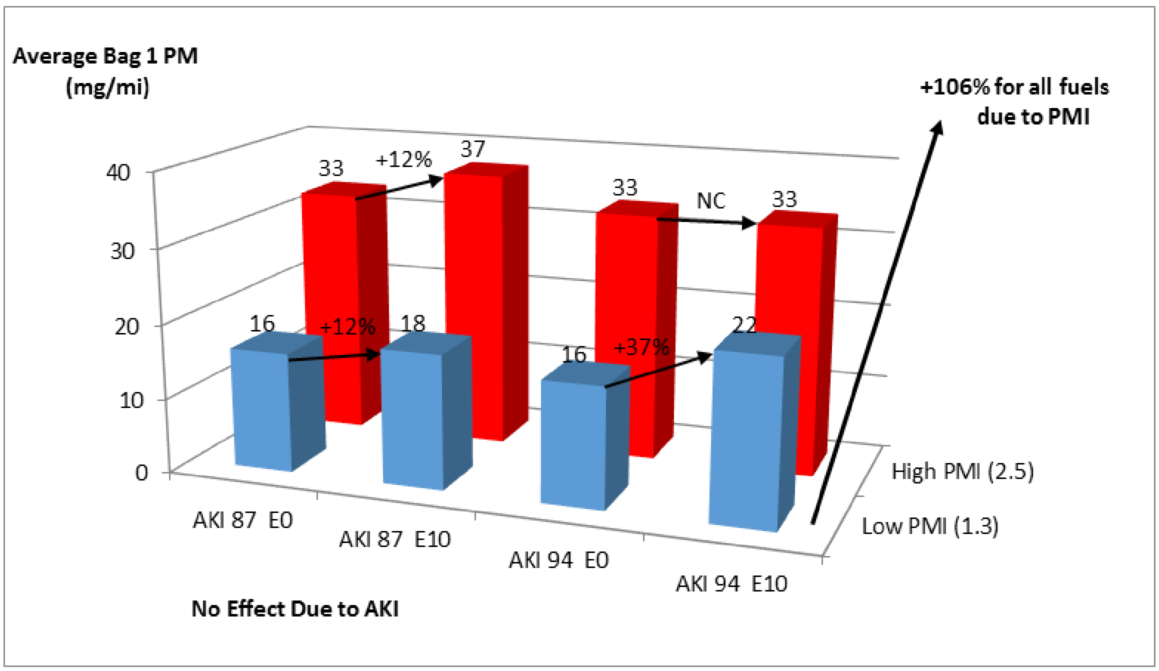


FIGURE 33. RESPONSE OF PHASE 1 PM EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

5.3.3.3 Emissions Response by Air Induction Type for 4-cylinder Vehicles

In the subgroups by air induction type, a PMI change from 1.3 to 2.5 is estimated to increase Phase 1 PM emissions by +89% in 4-cylinder NA vehicles and by +150% in the 4-cylinder turbocharged vehicles (see Table 52). The emissions response in the test fleet, with its 50:50 mix of NA and turbocharged vehicles (including one V-6 engine of each type), is an intermediate +106%.

TABLE 51. EFFECTS OF FUELS ON PHASE 1 PM EMISSIONS

Fuel Change	Fuel	ΔLA 92 PN	Statistical Significance
PMI 1.3 → 2.5	All Fuels	+ 106% ± 3%	$p < 0.0001$
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 12% ± 4%	$p < 0.0001$
	AKI 87 High PMI	+ 12% ± 4%	$p < 0.0001$
	AKI 94 Low PMI	+ 37% ± 5%	$p < 0.0001$
	AKI 94 High PMI	—	—
AKI 87 → 94	All Fuels	—	—

For EtOH, a change from E0 to E10 (9.5 vol %) is estimated to increase the emissions of 4-cylinder NA vehicles by amounts that are very similar to the entire test fleet in the AKI 87 fuels, but with a smaller response in the AKI 94 Low PMI fuel. The 4-cylinder turbocharged vehicles show a different pattern of response among the fuels and larger responses in both cases where an EtOH effect can be detected. As before, the analysis fails to detect a response to EtOH in the AKI 94 High PMI fuel. No effect due to AKI can be detected.

TABLE 52. EFFECT OF FUELS ON PHASE 1 PM EMISSIONS BY AIR INDUCTION TYPE

Fuel Change	Fuel	Test Fleet	4-Cyl NA	4-Cyl Turbo
NA : Turbo Mix		6 : 6	5 : 0	0 : 5
PMI 1.3 → 2.5	All Fuels	↑ 106%	↑ 89%	↑ 150%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 12%	↑ 14%	↑ 23%
	AKI 87 High PMI	↑ 12%	↑ 14%	—
	AKI 94 Low PMI	↑ 37%	↑ 23%	↑ 57%
	AKI 94 High PMI	—	—	—
AKI 87 → 94	All Fuels	—	—	—

5.3.3.4 Emissions Response by PM Groups

PMI and EtOH effects were detected in the Low, Mid and High PM groups. A PMI change from 1.3 to 2.5 is estimated to increase PM emissions by +97% in the Low PM group, by +122% in the Mid PM group and by +62% in the High PM groups (see Table 53). The effects in each subgroup vary around the test fleet average in response to the varying air induction mix and vehicle-specific behavior in each group.

EtOH effects can be detected in all of the subgroups, but not necessarily for all of the fuels. A change from E0 to E10 (9.5 vol %) is estimated to increase PM emissions by +15% and

+17% in all fuels for the Low and High groups, respectively, but by +35% in only one fuel for the Mid PM group. As elsewhere, no effect due to AKI can be detected.

TABLE 53. EFFECT OF FUELS ON PHASE 1 PM EMISSIONS BY PM GROUP

Fuel Change	Fuel	Test Fleet	Low PM	Mid PM	High PM
NA : Turbo Mix		6 : 6	3 : 1	1 : 3	2 : 2
PMI 1.3 → 2.5	All Fuels	↑ 106%	↑ 97%	↑ 122%	↑ 62%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 12%	↑ 15%	–	↑ 17%
	AKI 87 High PMI	↑ 12%	↑ 15%	–	↑ 17%
	AKI 94 Low PMI	↑ 37%	↑ 15%	↑ 35%	↑ 17%
	AKI 94 High PMI	–	↑ 15%	–	↑ 17%
AKI 87 → 94	All Fuels	–	–	–	–

The PMI effect that is present in the Low PM vehicles is large enough to observe and reliably measure in back-to-back test runs using Low and High PMI fuels. The repeatability of Phase 1 PM measurements is observed to be ± 11% in Low PM vehicles. The size of the PMI effect (+106% for PMI 1.3 → 2.5) amounts to 9σ in terms of measurement repeatability. An EtOH effect (+15% for E0 → E10) was detected in the statistical analysis, but at 1σ in size it is too small to detect in back-to-back test runs using E0 and E10.

5.3.3.5 Summary for Phase 1 PM Emissions

As for LA92 PM emissions, fuel PMI and ethanol content exert clear effects on Phase 1 PM emissions:

- PMI substantially increases PM emissions across the board – in all fuels, all vehicles and across all subgroups examined. The effect is large, amounting to a near doubling, or more than doubling, for a PMI change from 1.3 to 2.5.
- EtOH also increases PM emissions by amounts that range up to 37% depending on fuel and subgroup. The analysis does not detect an EtOH effect in the AKI 94 High PMI fuel.
- The PMI fuel effect is large enough to be observed and measured in the subgroup of Low PM vehicles in back-to-back test runs. While an EtOH effect is present, it cannot be reliably measured in back-to-back test runs.

Fuel octane number (AKI) does not influence Phase 1 PM emissions.

5.3.4 LA92 EC Emissions

EC emissions are the largest component of total PM, accounting for 80% of total PM emissions on average for the 8 fuels, and were determined in the testing by a thermo-optical method that determines the particle mass emitted over the LA92 cycle in units of mg/mi.

5.3.4.1 Emissions Response of the Test Vehicles

Figure 35 shows the emission responses of the test vehicles to PMI, EtOH, and AKI. As has been seen throughout, there is a general homogeneity among the vehicles in the emissions response to the three fuel parameters, but also vehicle-specific differences. Here, Vehicles L and F display substantially different responses to PMI and EtOH, respectively, than the remainder of the test fleet.

As shown in the upper portion of the graph, EC emissions increase by +50% to +150%, depending upon vehicle, when moving from a Low to High PMI fuel. Vehicle L has a much larger response than the other vehicles; its EC emissions increase by +300% in response to the same PMI change. Overall, the turbocharged vehicles are seen to have a generally larger response to PMI than the NA vehicles.

The middle portion of the graph shows the predicted emissions change when moving from an E0 to an E10 fuel (9.5 vol %). The magnitude of the emissions response is once again smaller than for PMI, ranging from a low of nearly zero to as much as +50%. Vehicle F displays the largest response to EtOH of the test fleet.

The lower portion of the graph demonstrates that changes in octane from AKI 87 to 94 do not lead to statistically significant changes in LA92 EC emissions. None of the predicted changes achieve an acceptable level of statistical significance here or for the other particulate emissions variables examined.

5.3.4.2 Emissions Response of the Entire Test Fleet

Figure 36 shows the response of LA92 EC emissions to fuels for the entire test fleet. A change from Low PMI (1.3) to High PMI (2.5) fuel causes EC emissions to increase by +167% in all of the fuels. For LA92 PM, the emissions increase was +114%, implying that the EC share of the total PM mass increases as one moves from Low to High PMI fuels. The effect of PMI does not depend on the ethanol content or the octane number of the fuels.

For EtOH, the emissions change in going from E0 to E10 (9.5 vol %) is found to depend on the PMI level of the fuel. Here, EC emissions are increased by +47% in the AKI 87 and 94 Low PMI fuels, and by +21% in the AKI 87 High PMI fuel. No effect of AKI on emissions was found. The emissions responses to PMI and EtOH have strong statistical significance, as summarized in Table 54.

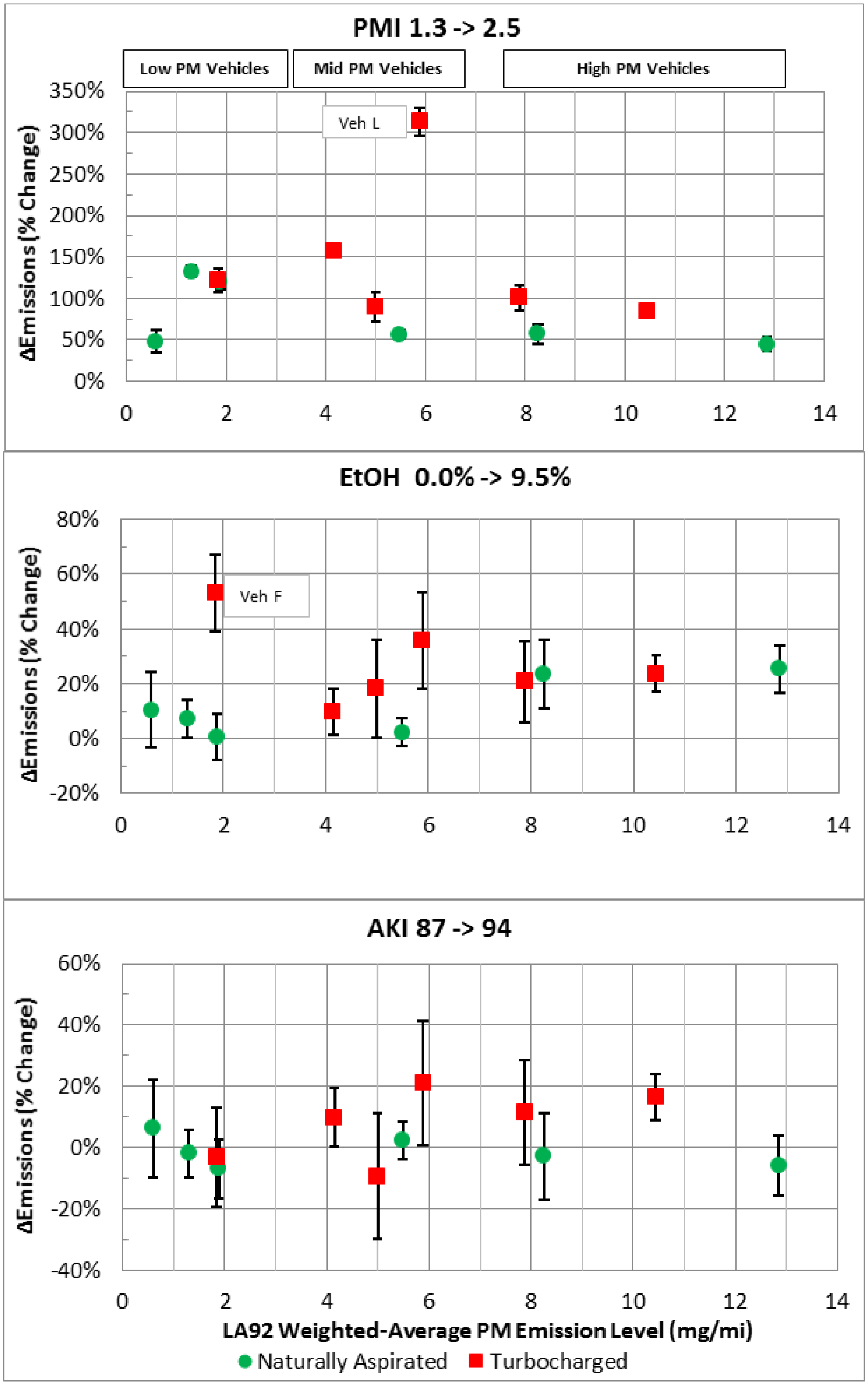


FIGURE 34. RESPONSE OF LA92 EC EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE(ERROR BARS SHOW 1σ RANGE)

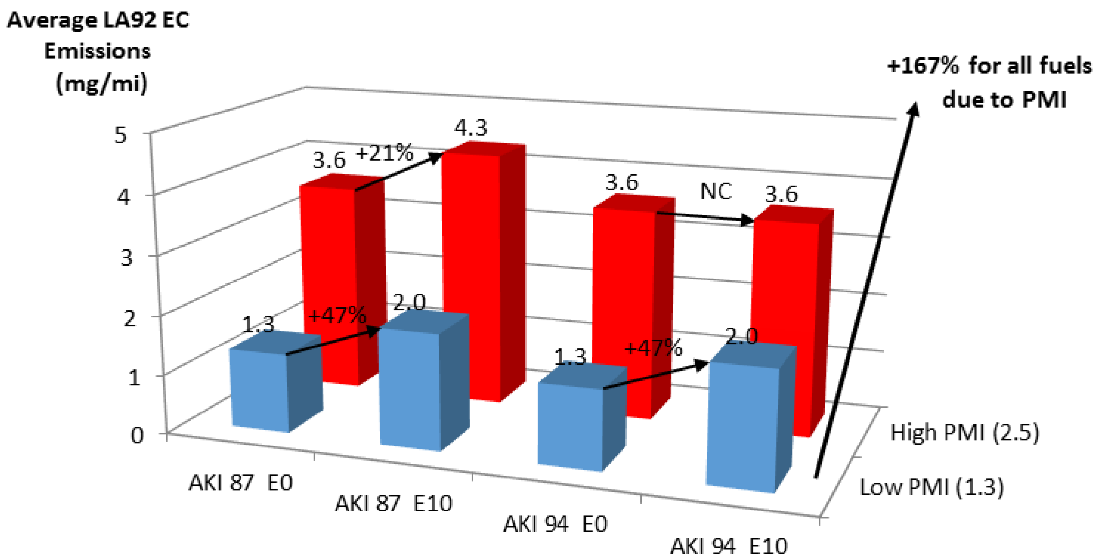


FIGURE 35. RESPONSE OF LA92 EC EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI.

TABLE 54. EFFECT OF FUELS ON LA92 EC EMISSIONS

Fuel Change	Fuel	ΔLA 92 PN	Statistical Significance
PMI 1.3 → 2.5	All Fuels	+ 167% ± 5%	$p < 0.0001$
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 47% ± 6%	$p < 0.0001$
	AKI 87 High PMI	+ 21% ± 7%	$p = 0.005$
	AKI 94 Low PMI	+ 47% ± 6%	$p < 0.0001$
	AKI 94 High PMI	—	—
AKI 87 → 94	All Fuels	—	—

5.3.4.3 Emissions Response by Air Induction Type for 4-cylinder Vehicles

A comparable emissions response to fuels is seen in the subgroups of 4-cylinder vehicles by air induction type (see Table 55). A PMI change from 1.3 to 2.5 is estimated to increase EC emissions by +173% in 4-cylinder NA vehicles and by +168% in the 4-cylinder turbocharged vehicles compared to a response of +167% in the entire test fleet.

For EtOH, a change from E0 to E10 (9.5 vol %) is estimated to increase the emissions of 4-cylinder NA vehicles by amounts that are closely comparable to the entire test fleet, but by often smaller amounts, with a different pattern among the fuels, for the 4-cylinder turbocharged vehicles. The analysis fails to detect a response to EtOH in the AKI 94 High PMI fuel. No effect due to AKI can be detected.

TABLE 55. EFFECT OF FUELS ON LA92 EC EMISSIONS BY AIR INDUCTION TYPE

Fuel Change	Fuel	Test Fleet	4-Cyl NA	4-Cyl Turbo
NA : Turbo Mix		6 : 6	5 : 0	0 : 5
PMI 1.3 → 2.5	All Fuels	↑ 167%	↑ 173%	↑ 168%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 47%	↑ 50%	↑ 23%
	AKI 87 High PMI	↑ 21%	↑ 19%	↑ 23%
	AKI 94 Low PMI	↑ 47%	↑ 50%	↑ 55%
	AKI 94 High PMI	–	–	–
AKI 87 → 94	All Fuels	–	–	–

5.3.4.4 Emissions Response by PM Groups

PMI and EtOH effects were detected in all of the subgroups based on PM level. As Table 56 shows, a PMI change from 1.3 to 2.5 is estimated to increase EC emissions by +165% in the Low PM group and by smaller amounts in the other groups. This difference among the subgroups can be traced to the large emissions response of Vehicle L in the Low PM group.

EC emissions are estimated to increase in all subgroups due to the change from E0 to E10 (9.5 vol %) fuels. The effect is largest (+47%) in the Low PM group, which contains Vehicle F with the largest EtOH response of the test fleet. An intermediate effect (+30%) is found in the Mid PM group, and generally smaller effects (+18 to +45%) in the High PM group. As elsewhere, no effect due to AKI can be detected.

TABLE 56. EFFECT OF FUELS ON LA92 EC EMISSIONS BY PM GROUP

Fuel Change	Fuel	Test Fleet	Low PM	Mid PM	High PM
NA : Turbo Mix		6 : 6	3 : 1	1 : 3	2 : 2
PMI 1.3 → 2.5	All Fuels	↑ 167%	↑ 165%	↑ 144%	↑ 114%
EtOH 0% → 9.5%	AKI 87 Low PMI	↑ 47%	↑ 47%	↑ 30%	↑ 18%
	AKI 87 High PMI	↑ 21%	↑ 47%	↑ 30%	↑ 18%
	AKI 94 Low PMI	↑ 47%	↑ 47%	↑ 30%	↑ 45%
	AKI 94 High PMI	–	–	↑ 30%	↑ 18%
AKI 87 → 94	All Fuels	–	–	–	–

The PMI effect that is present in the Low PM vehicles is large enough to observe and reliably measure in back-to-back test runs using Low and High PMI fuels. The repeatability of EC measurements is observed to be ± 16% in Low PM vehicles. The size of the PMI effect (+165% for PMI 1.3 → 2.5) amounts to 10σ in terms of measurement repeatability. The EtOH effect (+47% for E0 → E10) amounts to 3σ.

5.3.4.5 Summary for LA92 EC Emissions

As has been seen for all of the particulate emission measures, fuel PMI and ethanol content exert clear effects on LA92 EC emissions:

- PMI substantially increases EC emissions across the board – in all fuels, all vehicles and across all subgroups examined. The effect is large, more than doubling EC emissions of the entire test fleet for a PMI change from 1.3 to 2.5.
- EtOH also increases EC emissions by amounts that range up to 50% depending on fuel and subgroup. The analysis generally does not detect an EtOH effect in the AKI 94 High PMI fuel.
- The PMI fuel effect is large enough to be observed and measured in the subgroup of Low PM vehicles.

Fuel octane number (AKI) does not influence EC emissions.

5.4 Summary of Fuel Effects on Particulate Emissions

Throughout the analysis, PMI has shown the strongest effect on particulate emissions, whether measured as LA9 PN, LA92 PM, Phase 1 PM, or LA92 EC (see Table 57). Increasing PMI from low (1.3) to high (2.5) was found to nearly double, or more than double, LA92 PM and other particulate emissions. The addition of ethanol was also found to increase particulate emissions by amounts ranging up to 57 percent at the E10 level (9.5 vol %) depending on the pollutant and subgroup. The EtOH effect was clearly observed in three of the four pairs of fuels with matched AKI and PMI, but was generally not seen in the AKI 94 High PMI fuel. Conversely, fuel octane number (AKI) was found to have no effect on particulate emissions in the entire test fleet or in any of its subgroups.

The fuel effects due to PMI and EtOH are seen not only in the entire test fleet, but also in the individual vehicles and in the subgroups by air induction type (naturally aspirated and turbocharged 4-cylinder engines only) and vehicle PM level (low, medium, and high emitting for all vehicles). The PMI effects were found to differ by air induction type in the subgroups of 4-cylinder vehicles, being larger for LA92 PN and LA92 PM, but smaller for Phase 1 PM, in 4-cylinder naturally aspirated vehicles. The PMI effect on LA92 emissions was similar by air induction type. PMI and EtOH are seen to influence particulate emissions in all test vehicles, although the responsiveness of emissions to fuels can vary based on individual vehicle performance. PMI and EtOH effects are also observed in low PM emitting vehicles, where the emission increases associated with use of high PMI fuels are large enough to be easily measured in all cases.

TABLE 57. EFFECT OF FUELS ON PARTICULATE EMISSIONS

Fuel Change	LA92 PN	LA92 PM	Phase 1 PM	LA92 EC
PMI 1.3 → 2.5	↑ PN by 73-117% in all fuels Larger effect in 4-cyl naturally aspirated vehicles	↑ PM by 106-142% in all fuels Larger effect in 4-cyl naturally aspirated vehicles	↑ Phase 1 PM by 62-150% in all fuels Smaller effect in 4-cyl naturally aspirated vehicles	↑ EC by 114-173% in all fuels Similar effects in 4-cyl vehicles by air induction type
EtOH 0% → 9.5%	↑ PN by 14-39% in all fuels	↑ PM by 18-46% (except AKI 94 High PMI)	↑ Phase 1 PM by 12-57% (except AKI 94 High PMI)	↑ EC by 12-57% (except AKI 94 High PMI)
AKI 87 → 94	No Effect	No Effect	No Effect	No Effect

Note: The ranges cited for the percentage changes caused by fuels refer to the lowest and highest percentage effects found for the test fleet overall or in any of the subgroups examined (by air induction type for 4-cylinder engines and by average PM level for all vehicles).

5.5 Effect of Fuels on Gaseous Emissions

The gaseous emissions examined in the analysis were the weighted-average LA92 THC, LA92 CO, LA92 NO_X and LA92 CO_2. Table 58 summarizes the findings for the effects of PMI, EtOH and AKI on gaseous emissions. More detailed results for the test fleets and its subgroups can be found in Appendix H.

With respect to these pollutants, no effect related to PMI was detected, except for THC emissions in one subset of vehicles that could be traced to the performance of an individual vehicle. Ethanol content at E10 was found to *decrease* CO emissions in the 4-cylinder NA vehicles, while having no effect in 4-cylinder turbocharged vehicles. Increasing EtOH leads to *increased* CO_2 emissions by small amounts (0.5-0.8%) in the 4-cylinder NA vehicles, but not in the 4-cylinder turbocharged vehicles.

Conversely, increasing AKI from 87 to 94 was found to *decrease* the THC emissions of the 4-cylinder NA vehicles and two other subgroups made up largely of NA vehicles. A similar effect was not seen in the 4-cylinder turbocharged vehicles. This is the only instance in which a general effect of AKI on vehicle emissions was detected in the analysis. AKI was found to decrease NO_X emissions in one subgroup, but the effect was traced to the performance of an individual vehicle.

TABLE 58. EFFECT OF FULES ON GASEOUS EMISSIONS

Fuel Change	LA92 THC	LA92 CO	LA92 NO_X	LA92 CO_2
PMI 1.3 → 2.5	↑ THC by +21% (one subgroup, vehicle-specific)	No Effect	No Effect	No Effect
EtOH 0% → 9.5%	No Effect	↓ CO by -14% in 4-cylinder NA vehicles	No Effect	↑ CO_2 by 0.5-0.8%
AKI 87 → 94	↓ THC by -15% in 4-cylinder NA vehicles	No Effect	↓ NO_X by -27% (one subgroup, vehicle-specific)	No Effect

Figures 37 through 40 illustrate these results for the entire test fleet. In addition to the effects described above, the analysis found that THC emissions for one fuel (AKI 94 Low PMI E0) were 15% lower than the other fuels. CO_2 emissions for E10 fuels were found to be 0.8% higher on a g/mi basis compared to the E0 baseline. These results have modest statistical significance (p values between 0.01 and 0.05). They may indicate a systematic difference in emissions associated with the composition of the one fuel, but they also may arise simply by chance (probability > 1%). The interpretation of these differences remains uncertain.

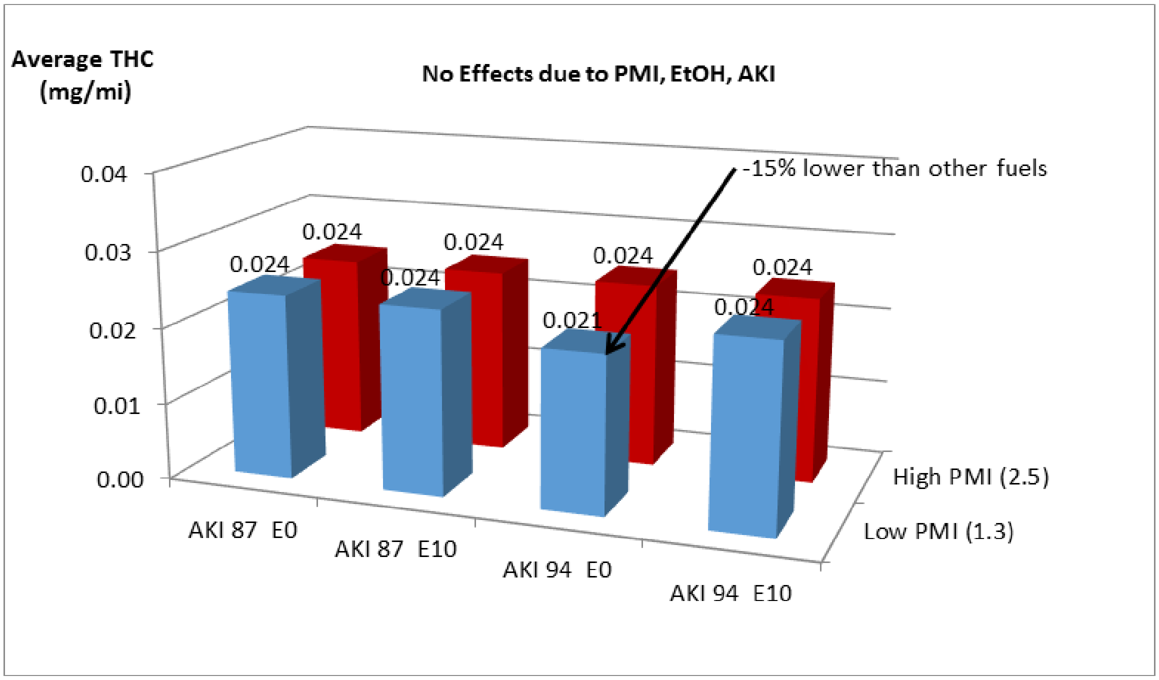


FIGURE 37. RESPONSE OF LA92 THC EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

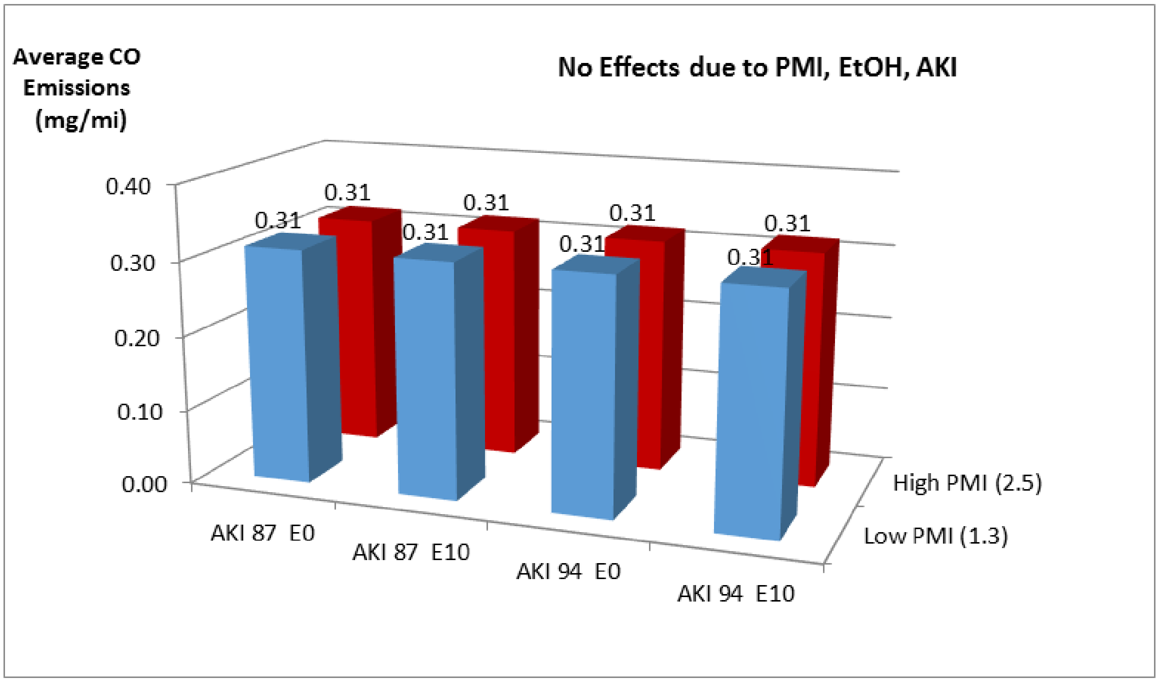


FIGURE 38. RESPONSE OF LA92 CO EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

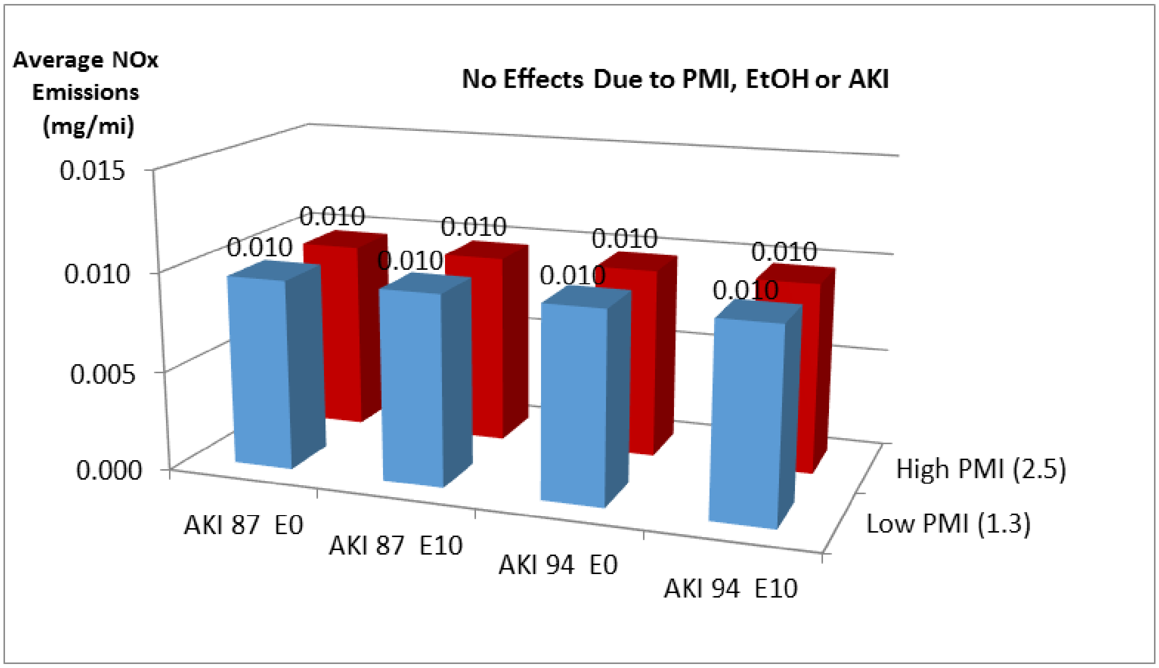


FIGURE 39. RESPONSE OF LA92 NO_X EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

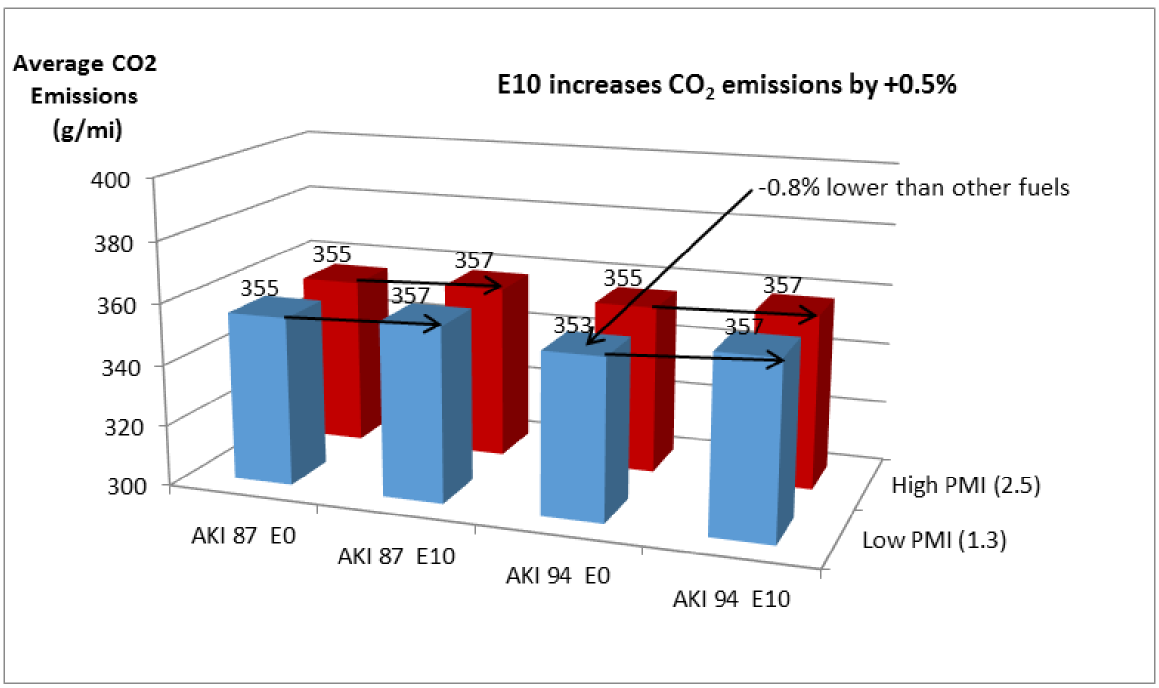


FIGURE 40. RESPONSE OF LA92 CO_2 EMISSIONS FOR THE TEST FLEET TO PMI, ETOH AND AKI

6.0 RECOMMENDATIONS FOR FUTURE WORK

Match blending was employed to create the eight fuels used in this study in order to minimize the variation in values of fuel properties other than that intended solely for the design variables AKI, PMI and EtOH. This approach is an accepted technique in automotive research to control the effects of other variables and thereby permit the experiment to better isolate the effect of the design variables. However, the fuels used in this program meet commercial specifications and could be sold as commercial fuels. The CRC undertook additional work to test whether the method of blending has a substantial effect on the emissions observed from vehicles. This additional program (CRC E-94-3) consisting of four splash-blended E10 fuels and four (of the twelve) test vehicles involved in this study. The four splash-blended E10 fuels can be compared to match-blended fuels of similar levels for AKI and PMI (low and high), but the values for AKI and PMI will differ from those of the match-blended fuels. CRC will conduct an analysis of the emissions observed in the new test program versus the emissions observed for the test vehicles in this study.

APPENDIX A

FUEL ANALYSIS AND PROPERTIES

TABLE A-1. FUEL A PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel A					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	90.5	91.4	--	91.8
MON	D2700	83.4	83.7	--	82.7
AKI	(R+M)/2	87.0	87.5	--	87.3
Sensitivity	R-M	7.1	7.7	--	9.1
Aromatic, vol%	D6729	27.0	33.3	27.2	--
PMI Honda Eq	PMI Tool	1.38	1.40	1.42	--
RVP @ 100˚F, psi	D5191	7.2	7.3	--	7.1
Ethanol, vol%	D4815	9.73	9.6	9.55	--
Sulfur, ppm w/w	D5453	8.8	9.2	8.8	--
Benzene, vol%	D6729	0.6	0.6	0.5	0.5
Olefins, vol%	D6729	5.4	--	5.8	5.7
Distillation, IBP °F	D86	112.1	99.7	--	102.7
Distillation, 5% °F	D86	130.5	128.7	--	133.8
Distillation, 10% °F	D86	136.9	136.4	--	139.5
Distillation, 20% °F	D86	146.3	145.2	--	147.8
Distillation, 30% °F	D86	153.1	151.7	--	153.8
Distillation, 40% °F	D86	174.0	170.4	--	182.2
Distillation, 50% °F	D86	220.1	216.1	--	219.1
Distillation, 60% °F	D86	237.9	235.6	--	236.5
Distillation, 70% °F	D86	255.0	253.0	--	254.2
Distillation, 80% °F	D86	276.1	273.9	--	275.2
Distillation, 90% °F	D86	307.8	304.3	--	305.1
Distillation, 95% °F	D86	335.3	330.6	--	332.1
Distillation, DP °F	D86	391.1	387.3	--	390.6
Recovery, vol %	D86	97.5	98.0	--	98.2
Residue, vol %	D86	1.1	1	--	1.0
Loss, vol%	D86	1.4	1	--	0.8
DI Index	D4814	1197	1180.2	--	1171.7
C10+ Aromatics, vol%	D6729	3.3	--	3.5	--
Existent Gums washed, mg/100 ml	D381	0.8	<0.5	--	1.0
Unwashed Gums, mg/100 ml	D381	9.4	--	--	13.0
Specific Gravity @ 60°F	D4052	0.7506	--	0.7506	--
Density @ 60°F, g/ml	D4052	0.7500	0.7497	0.7500	0.8000
API Gravtiy	D4052	57.0	57.1	57.0	56.3

TABLE A-2. FUEL B PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel B					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	90.7	91.1	--	92.0
MON	D2700	82.4	83.4	--	82.8
AKI	(R+M)/2	86.6	87.3	--	87.4
Sensitivity	R-M	8.3	7.66	--	8.3
Aromatic, vol%	D6729	26.9	34.8	26.6	--
PMI Honda Eq	PMI Tool	2.57	2.61	2.65	--
RVP @ 100˚F, psi	D5191	7.3	7.4	--	7.3
Ethanol, vol%	D4815	9.61	9.65	9.56	--
Sulfur, ppm w/w	D5453	9.3	9.2	9.3	--
Benzene, vol%	D6729	0.5	0.6	0.5	0.5
Olefins, vol%	D6729	4.9	--	5.5	5.3
Distillation, IBP °F	D86	110.1	106.9	--	102.0
Distillation, 5% °F	D86	128.5	127.0	--	130.6
Distillation, 10% °F	D86	134.4	133.5	--	136.5
Distillation, 20% °F	D86	143.6	143.8	--	144.5
Distillation, 30% °F	D86	150.4	151.0	--	151.4
Distillation, 40% °F	D86	164.1	165.9	--	167.0
Distillation, 50% °F	D86	222.4	220.6	--	219.1
Distillation, 60% °F	D86	250	248.2	--	247.2
Distillation, 70% °F	D86	278.8	277.2	--	276.8
Distillation, 80% °F	D86	308.8	309.0	--	307.9
Distillation, 90% °F	D86	342.7	341.8	--	341.3
Distillation, 95% °F	D86	371.1	364.3	--	369.1
Distillation, DP °F	D86	424.8	430.9	--	422.5
Recovery, vol %	D86	97.6	98.5	--	97.6
Residue, vol %	D86	1.4	0.30	--	1.1
Loss, vol%	D86	1.4	1.20	--	1.3
DI Index	D4814	1235	1227.0	--	1203.4
C10+ Aromatics, vol%	D6729	8.7	--	8.8	6.3
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	1.0
Unwashed Gums, mg/100 ml	D381	9.8	--	--	13.0
Specific Gravity @ 60°F	D4052	0.7535	--	0.7534	--
Density @ 60°F, g/ml	D4052	0.7530	0.75	0.7530	0.8
API Gravtiy	D4052	56.31	56.27	56.30	55.7

TABLE A-3. FUEL C PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel C					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	90.8	90.8	--	92.2
MON	D2700	84.8	84.7	--	84.1
AKI	(R+M)/2	87.8	87.8	--	88.2
Sensitivity	R-M	6.0	6.1	--	8.1
Aromatic, vol%	D6729	24.8	28.8	24.9	--
PMI Honda Eq	PMI Tool	1.37	1.4	1.4	--
RVP @ 100˚F, psi	D5191	7.4	7.6	--	6.9
Ethanol, vol%	D4815	0.00	0.00	0.00	--
Sulfur, ppm w/w	D5453	8.5	9.0	8.5	--
Benzene, vol%	D6729	0.6	0.6	0.6	0.5
Olefins, vol%	D6729	5.6	--	5.9	6.0
Distillation, IBP °F	D86	93.4	86.2	--	90.8
Distillation, 5% °F	D86	132.8	126.0	--	134.2
Distillation, 10% °F	D86	151.0	147.2	--	156.3
Distillation, 20% °F	D86	180.3	177.4	--	182.9
Distillation, 30% °F	D86	202.5	199.2	--	202.4
Distillation, 40% °F	D86	217.0	214.5	--	216.8
Distillation, 50% °F	D86	228.7	226.2	--	227.6
Distillation, 60% °F	D86	239.2	236.5	--	238.0
Distillation, 70% °F	D86	251.4	249.1	--	250.0
Distillation, 80% °F	D86	269.6	267.8	--	268.6
Distillation, 90% °F	D86	305.6	300.6	--	301.2
Distillation, 95% °F	D86	335.1	331.5	--	330.2
Distillation, DP °F	D86	384.3	385.2	--	389.8
Recovery, vol %	D86	97.6	97.7	--	97.7
Residue, vol %	D86	1.2	1.0	--	1.0
Loss, vol%	D86	1.2	1.3	--	1.3
DI Index	D4814	1218.0	1200.0	--	1218.5
C10+ Aromatics, vol%	D6729	3.5	--	3.5	2.5
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	1.0
Unwashed Gums, mg/100 ml	D381	9.0	--	--	12.0
Specific Gravity @ 60°F	D4052	0.7375	--	0.7377	--
Density @ 60°F, g/ml	D4052	0.7370	0.7	0.7370	0.7
API Gravtiy	D4052	60.4	60.3	60.3	59.3

TABLE A-4. FUEL D PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel D					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	91.6	91.7	--	92
MON	D2700	84.6	84.6	--	84.6
AKI	(R+M)/2	88.1	88.2	--	88.3
Sensitivity	R-M	7.0	7.1	--	7.4
Aromatic, vol%	D6729	25.8	31.6	25.6	--
PMI Honda Eq	PMI Tool	2.54	2.64	2.61	--
RVP @ 100˚F, psi	D5191	6.9	6.96	--	6.6
Ethanol, vol%	D4815	0.00	0.00	0.00	--
Sulfur, ppm w/w	D5453	9.4	10.3	9.4	--
Benzene, vol%	D6729	0.60	0.64	0.57	0.58
Olefins, vol%	D6729	5.2	--	5.3	6.8
Distillation, IBP °F	D86	100.4	99.7	--	92.2
Distillation, 5% °F	D86	133.3	133.7	--	129.3
Distillation, 10% °F	D86	146.1	146.3	--	145
Distillation, 20% °F	D86	166.5	167.0	--	165.5
Distillation, 30% °F	D86	186.1	186.4	--	184.9
Distillation, 40% °F	D86	204.4	204.4	--	202.7
Distillation, 50% °F	D86	221.9	221.5	--	219.8
Distillation, 60% °F	D86	240.1	239.5	--	237.3
Distillation, 70% °F	D86	262.6	261.5	--	260.1
Distillation, 80% °F	D86	300.0	301.1	--	297.7
Distillation, 90% °F	D86	345.7	345.9	--	345
Distillation, 95% °F	D86	371.7	375.3	--	373.4
Distillation, DP °F	D86	430.5	436.1	--	423.5
Recovery, vol %	D86	98.1	98.7	--	97.5
Residue, vol %	D86	1.1	0.8	--	1.1
Loss, vol%	D86	0.8	0.5	--	1.4
DI Index	D4814	1231.0	1229.9	--	1221.9
C10+ Aromatics, vol%	D6729	8.8	--	8.9	--
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	1
Unwashed Gums, mg/100 ml	D381	10.4	--	--	14
Specific Gravity @ 60°F	D4052	0.7380	--	0.7377	--
Density @ 60°F, g/ml	D4052	0.7370	0.74	0.7370	0.738
API Gravtiy	D4052	60.2	60.2	60.3	60.1

TABLE A-5. FUEL E PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel E					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	99.2	98.9	--	99.0
MON	D2700	88.4	88.7	--	87.1
AKI	(R+M)/2	93.8	93.8	--	93.1
Sensitivity	R-M	10.8	10.2	--	11.9
Aromatic, vol%	D6729	27.9	34.4	28.2	--
PMI Honda Eq	PMI Tool	1.28	1.30	1.28	--
RVP @ 100˚F, psi	D5191	6.9	7.1	--	--
Ethanol, vol%	D4815	9.74	9.6	9.56	--
Sulfur, ppm w/w	D5453	0.7	1.2	0.7	--
Benzene, vol%	D6729	0.6	0.6	0.6	0.5
Olefins, vol%	D6729	4.9[15]	--	1.0	5.7
Distillation, IBP °F	D86	102.3	97.3	--	100.1
Distillation, 5% °F	D86	131.4	129.0	--	131.4
Distillation, 10% °F	D86	137.6	136.4	--	137.6
Distillation, 20% °F	D86	146.7	146.1	--	147.1
Distillation, 30% °F	D86	155.0	154.0	--	155.4
Distillation, 40% °F	D86	190.5	187.7	--	190.9
Distillation, 50% °F	D86	230.4	228.2	--	228.2
Distillation, 60% °F	D86	243.3	241.5	--	239.5
Distillation, 70% °F	D86	257.1	255.7	--	257.1
Distillation, 80% °F	D86	278.0	277.3	--	278.1
Distillation, 90% °F	D86	311.3	310.8	--	311.0
Distillation, 95% °F	D86	331.8	333.3	--	332.3
Distillation, DP °F	D86	367.3	367.7	--	366.9
Recovery, vol %	D86	98.2	98.3	--	97.9
Residue, vol %	D86	1.0	1.0	--	1.0
Loss, vol%	D86	0.8	0.7	--	1.1
DI Index	D4814	1232	1222.9	--	1202.0
C10+ Aromatics, vol%	D6729	3.2	--	3.3	--
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	<0.5
Unwashed Gums, mg/100 ml	D381	9.2	--	--	11.0
Specific Gravity @ 60°F	D4052	0.7529	--	0.7526	--
Density @ 60°F, g/ml	D4052	0.7520	0.8	0.7520	0.8
API Gravtiy	D4052	56.4	56.4	56.5	56.0

[15] Using method D1319

TABLE A-6. FUEL F PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel F					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	99.1	98.8	--	99.1
MON	D2700	88.4	88.9	--	87.6
AKI	(R+M)/2	93.8	93.9	--	93.4
Sensitivity	R-M	10.7	9.9	--	11.5
Aromatic, vol%	D6729	28.2	36.0	30.3	--
PMI Honda Eq	PMI Tool	2.40	2.31	2.54	--
RVP @ 100˚F, psi	D5191	7.1	7.2	--	7.2
Ethanol, vol%	D4815	9.78	9.58	9.51	--
Sulfur, ppm w/w	D5453	1.0	1.1	1.0	--
Benzene, vol%	D6729	0.5	0.6	0.5	0.5
Olefins, vol%	D6729	5.1[16]	--	0.8	5.7
Distillation, IBP °F	D86	107.8	105.3	--	100.4
Distillation, 5% °F	D86	128.8	129	--	129.9
Distillation, 10% °F	D86	135.1	135.5	--	136.1
Distillation, 20% °F	D86	144.7	145.4	--	145.3
Distillation, 30% °F	D86	153.5	154.2	--	152.7
Distillation, 40% °F	D86	174.4	176.9	--	178.1
Distillation, 50% °F	D86	225.9	223.9	--	221.9
Distillation, 60% °F	D86	234.7	238.5	--	234.4
Distillation, 70% °F	D86	257.5	246.2	--	254.4
Distillation, 80% °F	D86	289.0	289.6	--	286.4
Distillation, 90% °F	D86	341.1	337.8	--	340.1
Distillation, 95% °F	D86	374.2	374.9	--	370.7
Distillation, DP °F	D86	432	432.7	--	424.9
Recovery, vol %	D86	97.8	98.2	--	97.7
Residue, vol %	D86	0.9	0.9	--	1.1
Loss, vol%	D86	1.3	0.9	--	1.2
DI Index	D4814	1245.0	1235.7	--	1210.0
C10+ Aromatics, vol%	D6729	8.9	--	9.2	--
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	<0.5
Unwashed Gums, mg/100 ml	D381	11.2	--	--	12.0
Specific Gravity @ 60°F	D4052	0.7525	--	0.7525	--
Density @ 60°F, g/ml	D4052	0.7520	0.7515	0.7520	0.8
API Gravtiy	D4052	56.6	56.6	56.5	56.3

[16] Using method D1319

TABLE A-7. FUEL G PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel G					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	98.5	98.1	--	98.7
MON	D2700	89.4	89.7	--	88.3
AKI	(R+M)/2	94.0	93.9	--	93.5
Sensitivity	R-M	9.1	8.4	--	10.4
Aromatic, vol%	D6729	25.7	29.9	26.4	--
PMI Honda Eq	PMI Tool	1.18	1.30	1.26	--
RVP @ 100˚F, psi	D5191	7.3	7.4	--	--
Ethanol, vol%	D4815	0.00	0.00	0.00	--
Sulfur, ppm w/w	D5453	1.0	1.6	1.0	--
Benzene, vol%	D6729	0.5	0.6	0.5	0.5
Olefins, vol%	D6729	5.1[17]	--	0.9	5.2
Distillation, IBP °F	D86	98.4	86.7	--	89.6
Distillation, 5% °F	D86	128.3	120.6	--	123.4
Distillation, 10% °F	D86	140.9	136.2	--	139.9
Distillation, 20% °F	D86	163.4	160.0	--	163.6
Distillation, 30% °F	D86	189.1	186.3	--	188.5
Distillation, 40% °F	D86	212.4	209.7	--	211.0
Distillation, 50% °F	D86	226.8	224.1	--	224.5
Distillation, 60% °F	D86	236.3	234.0	--	235.1
Distillation, 70% °F	D86	247.1	244.6	--	246.2
Distillation, 80% °F	D86	266.2	263.5	--	265.1
Distillation, 90% °F	D86	311.2	308.8	--	309.0
Distillation, 95% °F	D86	339.1	337.1	--	334.6
Distillation, DP °F	D86	380.5	376.3	--	376.9
Recovery, vol %	D86	98.1	98.2	--	97.7
Residue, vol %	D86	1.0	1.0	--	1.1
Loss, vol%	D86	0.9	0.8	--	1.2
DI Index	D4814	1203.0	1185.4	--	1192.4
C10+ Aromatics, vol%	D6729	2.9	--	3.5	--
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	<0.5
Unwashed Gums, mg/100 ml	D381	11.4	--	--	12.0
Specific Gravity @ 60°F	D4052	0.7346	--	0.7346	--
Density @ 60°F, g/ml	D4052	0.7340	0.7	0.7340	0.7
API Gravtiy	D4052	61.1	61.1	61.1	60.7

[17] Using method D1319

TABLE A-8. FUEL H PROPERTIES, AS MEASURED BY LABS A, B, C AND D

Fuel H					
	Methods	**Lab A**	**Lab B**	**Lab C**	**Lab D**
RON	D2699	98.7	98.5	--	99.1
MON	D2700	89.8	89.8	--	88.6
AKI	(R+M)/2	94.3	94.1	--	93.9
Sensitivity	R-M	8.9	8.7	--	10.5
Aromatic, vol%	D6729	26.9	32.0	26.8	--
PMI Honda Eq	PMI Tool	2.40	2.50	2.31	--
RVP @ 100˚F, psi	D5191	7.30	7.3	--	7.1
Ethanol, vol%	D4815	0.00	0.00	0.00	--
Sulfur, ppm w/w	D5453	1.2	1.1	1.2	--
Benzene, vol%	D6729	0.5	0.6	0.5	0.5
Olefins, vol%	D6729	4.3[18]	--	0.9	5.0
Distillation, IBP °F	D86	88.4	97.0	--	88.2
Distillation, 5% °F	D86	120.6	127.8	--	122.8
Distillation, 10% °F	D86	137.7	140.4	--	139.3
Distillation, 20% °F	D86	163.0	165.0	--	163.6
Distillation, 30% °F	D86	189.5	191.7	--	190.3
Distillation, 40% °F	D86	213.1	215.4	--	213.0
Distillation, 50% °F	D86	228.2	228.7	--	225.7
Distillation, 60% °F	D86	239.2	239.7	--	237.4
Distillation, 70% °F	D86	252.8	254.1	--	253.2
Distillation, 80% °F	D86	282.6	284.0	--	281.2
Distillation, 90% °F	D86	344.5	343.9	--	342.6
Distillation, 95% °F	D86	375.5	377.2	--	371.8
Distillation, DP °F	D86	434.4	434.3	--	426.2
Recovery, vol %	D86	97.8	98.3	--	97.8
Residue, vol %	D86	1.1	0.8	--	1.1
Loss, vol%	D86	1.1	0.9	--	1.1
DI Index	D4814	1236.0	1240.6	--	1228.7
C10+ Aromatics, vol%	D6729	8.9	--	8.9	--
Existent Gums washed, mg/100 ml	D381	<0.5	<0.5	--	<0.5
Unwashed Gums, mg/100 ml	D381	10.2	--	--	13.0
Specific Gravity @ 60°F	D4052	0.7408	--	0.7408	--
Density @ 60°F, g/ml	D4052	0.7400	0.7	0.7400	0.7
API Gravtiy	D4052	59.5	59.5	59.5	58.8

[18] Using method D1319

TABLE A-9. EEE CERTIFICATION FUEL PROPERTIES

EEE Certification Fuel		
	Methods	
RON	D2699	96.6
MON	D2700	88.5
AKI	(R+M)/2	92.6
Sensitivity	R-M	8.1
Aromatic, vol%	D1319	28.0
PMI Honda Eq	PMI Honda Eq	1.59
RVP @ 100˚F, psi	D5191	9.1
Ethanol, vol%	D4815	0.0
Sulfur, ppm w/w	D5453	--
Sulfur, wt. %	D5453	0.0035
Benzene, vol%	D6729	--
Olefins, vol%	D1319	1.0
Distillation, IBP °F	D86	88.0
Distillation, 5% °F	D86	112.0
Distillation, 10% °F	D86	125.0
Distillation, 20% °F	D86	146.0
Distillation, 30% °F	D86	169.0
Distillation, 40% °F	D86	198.0
Distillation, 50% °F	D86	220.0
Distillation, 60% °F	D86	230.0
Distillation, 70% °F	D86	240.0
Distillation, 80% °F	D86	258.0
Distillation, 90% °F	D86	313.0
Distillation, 95% °F	D86	336.0
Distillation, DP °F	D86	402.0
Recovery, vol %	D86	--
Residue, vol %	D86	--
Loss, vol%	D86	--
DI Index	D4814	--
C10+ Aromatics, vol%	D6729	--
Existent Gums washed, mg/100 ml	D381	--
Unwashed Gums, mg/100 ml	D381	--
Specific Gravity @ 60°F	D4052	--
Density @ 60°F, g/ml	D4052	--
API Gravity	D4052	59.3
Saturates, vol %	D1319	71.0

APPENDIX B

FUEL CHANGE, CONDITIONING, AND TEST PROCEDURE

FUEL CHANGE, CONDITIONING, AND TEST PROCEDURE

1. Drain vehicle fuel completely via fuel rail whenever possible.
2. Turn vehicle ignition to RUN position for 30 seconds to allow controls to allow fuel level reading to stabilize. Confirm the return of fuel gauge reading to zero.
3. Turn ignition off. Fill fuel tank to 30% with the next 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 C. Apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system.
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 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 30% with fuel. Fill-up fuel must be less than 50°F.
7. Drain fuel again and refill to 40% with fuel. Fill-up fuel must be less than 50°F.
8. Take a fuel sample from the vehicle's fuel rail to be tested for ethanol content and octane number.
9. Check vehicle for diagnostic trouble codes (DTC). If new codes are detected the CRC Program Manager will be contacted.
10. Soak vehicle for at least 12 hours to allow fuel temperature to stabilize to the test temperature.
11. Move vehicle to test area without starting engine.
12. Start vehicle and perform 2-phase (bags 1 and 2) LA92 cycle. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system.
13. Allow vehicle to idle in park for two minutes, then shut-down the engine for 2-5 minutes.
14. Start vehicle and perform the second 2-phase (bags 1 and 2) LA92 cycle. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system.
15. Allow vehicle to idle in park for two minutes, then shut-down the engine for 2-5 minutes.
16. Start vehicle and perform 2-phase (bags 1 and 2) LA92 cycles. During these prep cycles, apply side fan cooling to the fuel tank to alleviate the heating effect of the exhaust system.
17. Allow the vehicle to idle for two minutes, then shut down the engine in preparation for the soak.
18. Move vehicle to soak area without starting the engine.
19. Park vehicle in soak area at proper temperature (75 °F) for at least 8 hours and no more than 24 hours. During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device.
20. Move vehicle to test area without starting engine.
21. Perform LA92 cycle emissions test.
22. Move vehicle to soak area without starting the engine.

23. Park vehicle in soak area of proper temperature for 8-24 hours. During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device.
24. Move vehicle to test area without starting the engine.
25. Perform LA92 emissions test.
26. Move vehicle to soak area without starting the engine.
27. Determine whether third test is necessary, based on repeatability criteria (to be provided by CRC prior to start of test program).
28. If a third test is required, repeat steps 23 – 25.If third replicate is not required, return to step 1 and proceed with next fuel in test sequence.

APPENDIX C

CHECK-OUT EMISSIONS RESULTS FOR VEHICLES A THROUGH L

TABLE C-1. CHECKOUT EMISSIONS RESULTS FOR VEHICLE A

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.270	0.023		0.018	
Checkout Test Weighted Results On FTP-75	0.031	0.226	0.028	0.024	0.025	4.199
Checkout Test Results On FTP-75 Phase 1	0.140	1.020	0.053	0.115	0.119	11.109
Checkout Test Results On FTP-75 Phase 2	0.001	0.023	0.020	0.000	0.000	1.774
Checkout Test Results On FTP-75 Phase 3	0.004	0.008	0.025	0.000	0.000	3.542

TABLE C-2. CHECKOUT EMISSIONS RESULTS FOR VEHICLE B

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.440	0.015		0.019	
Checkout Test Weighted Results On FTP-75	0.020	0.570	0.018	0.015	0.016	4.484
Checkout Test Results On FTP-75 Phase 1	0.084	2.184	0.023	0.068	0.070	12.853
Checkout Test Results On FTP-75 Phase 2	0.001	0.157	0.019	0.000	0.000	2.674
Checkout Test Results On FTP-75 Phase 3	0.006	0.138	0.014	0.003	0.003	1.608

TABLE C-3. CHECKOUT EMISSIONS RESULTS FOR VEHICLE C

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.37	0.011		0.019	
Checkout Test Weighted Results On FTP-75	0.024	0.337	0.012	0.019	0.020	2.857
Checkout Test Results On FTP-75 Phase 1	0.319	3.017	0.127	0.271	0.282	15.216
Checkout Test Results On FTP-75 Phase 2	0.007	0.188	0.006	0.005	0.005	1.813
Checkout Test Results On FTP-75 Phase 3	0.013	0.229	0.000	0.007	0.007	6.931

TABLE C-4. CHECKOUT EMISSIONS RESULTS FOR VEHICLE D

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.200	0.010		0.010	
Checkout Test Weighted Results On FTP-75	0.017	0.125	0.016	0.011	0.012	1.410
Checkout Test Results On FTP-75 Phase 1	0.045	0.464	0.020	0.036	0.037	3.677
Checkout Test Results On FTP-75 Phase 2	0.002	0.014	0.020	0.000	0.000	0.637
Checkout Test Results On FTP-75 Phase 3	0.023	0.081	0.007	0.014	0.015	1.172

TABLE C-5. CHECKOUT EMISSIONS RESULTS FOR VEHICLE E

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.488	0.005		0.012	
Checkout Test Weighted Results On FTP-75	0.050	1.953	0.019	0.041	0.042	10.946
Checkout Test Results On FTP-75 Phase 1	0.335	7.356	0.016	0.280	0.291	91.148
Checkout Test Results On FTP-75 Phase 2	0.036	1.650	0.021	0.029	0.030	6.894
Checkout Test Results On FTP-75 Phase 3	0.022	1.740	0.003	0.013	0.013	1.954

TABLE C-6. CHECKOUT EMISSIONS RESULTS FOR VEHICLE F

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.200	0.020		0.014	
Checkout Test Weighted Results On FTP-75	0.024	0.182	0.009	0.018	0.019	1.401
Checkout Test Results On FTP-75 Phase 1	0.100	0.797	0.021	0.083	0.086	4.816
Checkout Test Results On FTP-75 Phase 2	0.001	0.006	0.005	0.000	0.000	0.395
Checkout Test Results On FTP-75 Phase 3	0.009	0.052	0.006	0.004	0.004	0.719

TABLE C-7. CHECKOUT EMISSIONS RESULTS FOR VEHICLE G

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results	0.021	0.383	0.006		0.016	
Checkout Test Weighted Results On FTP-75	0.048	0.471	0.014	0.040	0.042	0.400
Checkout Test Results On FTP-75 Phase 1	0.154	1.276	0.040	0.141	0.147	1.100
Checkout Test Results On FTP-75 Phase 2	0.015	0.173	0.001	0.010	0.010	0.100
Checkout Test Results On FTP-75 Phase 3	0.030	0.422	0.019	0.021	0.022	0.300

TABLE C-8. CHECKOUT EMISSIONS RESULTS FOR VEHICLE H

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.200	0.020		0.014	
Checkout Test Weighted Results On FTP-75	0.046	0.709	0.066	0.032	0.034	5.707
Checkout Test Results On FTP-75 Phase 1	0.337	2.734	0.102	0.275	0.286	34.591
Checkout Test Results On FTP-75 Phase 2	0.029	0.585	0.068	0.018	0.019	3.817
Checkout Test Results On FTP-75 Phase 3	0.047	0.774	0.015	0.026	0.027	8.179

TABLE C-9. CHECKOUT EMISSIONS RESULTS FOR VEHICLE I

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.200	0.020		0.017	
Checkout Test Weighted Results On FTP-75	0.020	0.147	0.027	0.013	0.013	1.285
Checkout Test Results On FTP-75 Phase 1	0.052	0.312	0.049	0.040	0.041	4.317
Checkout Test Results On FTP-75 Phase 2	0.008	0.029	0.025	0.001	0.001	0.454
Checkout Test Results On FTP-75 Phase 3	0.021	0.245	0.012	0.013	0.014	0.562

TABLE C-10. CHECKOUT EMISSIONS RESULTS FOR VEHICLE J

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		3.400	0.050		0.075	
Certification Results		0.300	0.020		0.024	
Checkout Test Weighted Results On FTP-75	0.060	0.532	0.026	0.041	0.043	11.400
Checkout Test Results On FTP-75 Phase 1	0.200	1.317	0.085	0.167	0.174	18.400
Checkout Test Results On FTP-75 Phase 2	0.013	0.102	0.011	0.000	0.000	10.100
Checkout Test Results On FTP-75 Phase 3	0.040	0.750	0.009	0.023	0.024	8.800

TABLE C-11. CHECKOUT EMISSIONS RESULTS FOR VEHICLE K

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		2.100	0.040		0.070	
Certification Results		0.200	0.010		0.005	
Checkout Test Weighted Results On FTP-75	0.014	0.478	0.012	0.008	0.008	3.504
Checkout Test Results On FTP-75 Phase 1	0.056	1.905	0.018	0.034	0.036	13.890
Checkout Test Results On FTP-75 Phase 2	0.002	0.113	0.013	0.001	0.001	0.712
Checkout Test Results On FTP-75 Phase 3	0.006	0.094	0.007	0.000	0.000	0.978

TABLE C-12. CHECKOUT EMISSIONS RESULTS FOR VEHICLE L

	THC, g/mi	CO, g/mi	NO_X, g/mi	NMHC, g/mi	NMOG, g/mi	PM, mg/mi
Certification Standard (50,000 Miles)		2.100	0.040		0.070	
Certification Results		1.200	0.020		0.036	
Checkout Test Weighted Results On FTP-75	0.028	0.594	0.011	0.015	0.016	4.122
Checkout Test Results On FTP-75 Phase 1	0.105	1.342	0.022	0.073	0.075	14.589
Checkout Test Results On FTP-75 Phase 2	0.004	0.374	0.004	0.000	0.000	1.170
Checkout Test Results On FTP-75 Phase 3	0.017	0.445	0.014	0.000	0.000	1.792

APPENDIX D

CATALYST SULFUR PURGE CYCLE

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. It is required to demonstrate that the catalyst inlet temperature must exceed 700°C during the wide open throttle (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).

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 for a minimum of 5 seconds, to achieve a speed in excess of 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 five (5) WOT excursions.
6. One sulfur removal cycle has been completed.
7. Repeat steps 1 to 5 for the second sulfur removal cycle.

APPENDIX E

COMPLETE EMISSIONS RESULTS

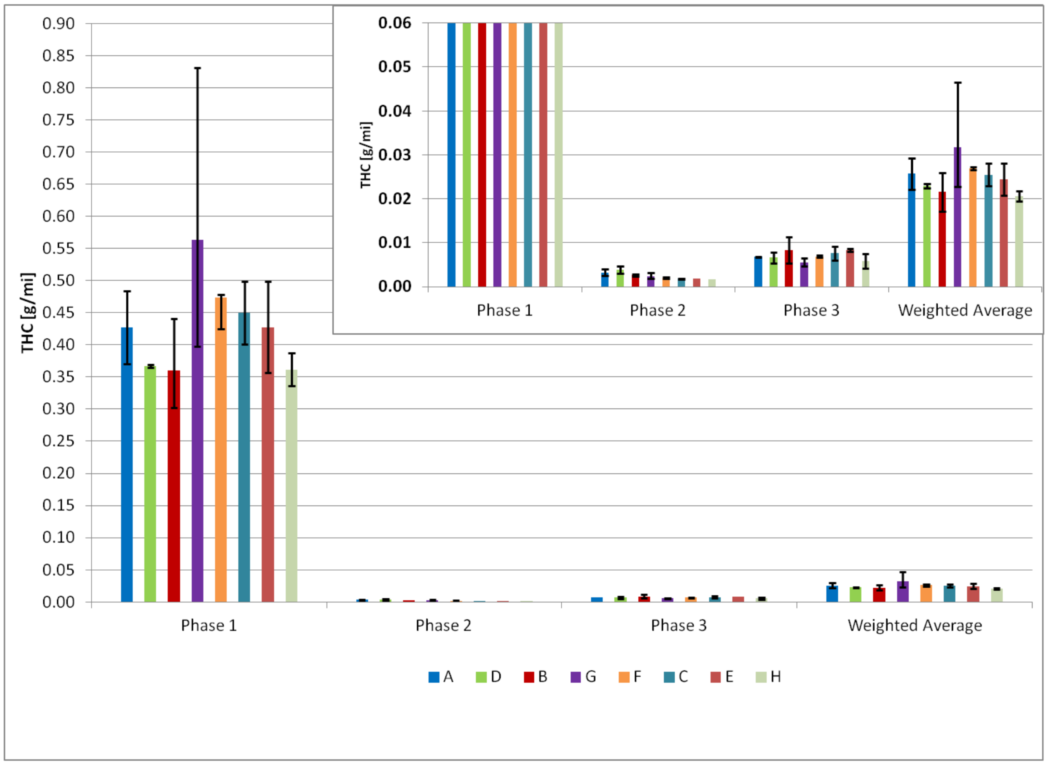


FIGURE E-1. THC EMISSIONS FOR VEHICLE A

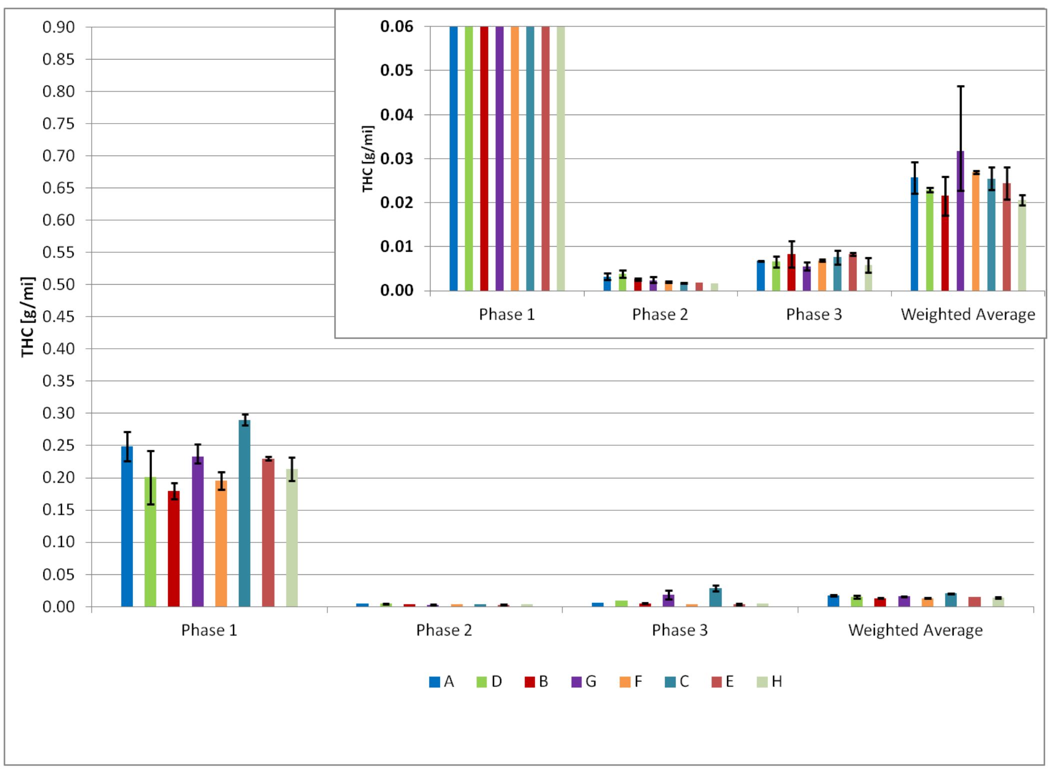


FIGURE E-2. THC EMISSIONS FOR VEHICLE B

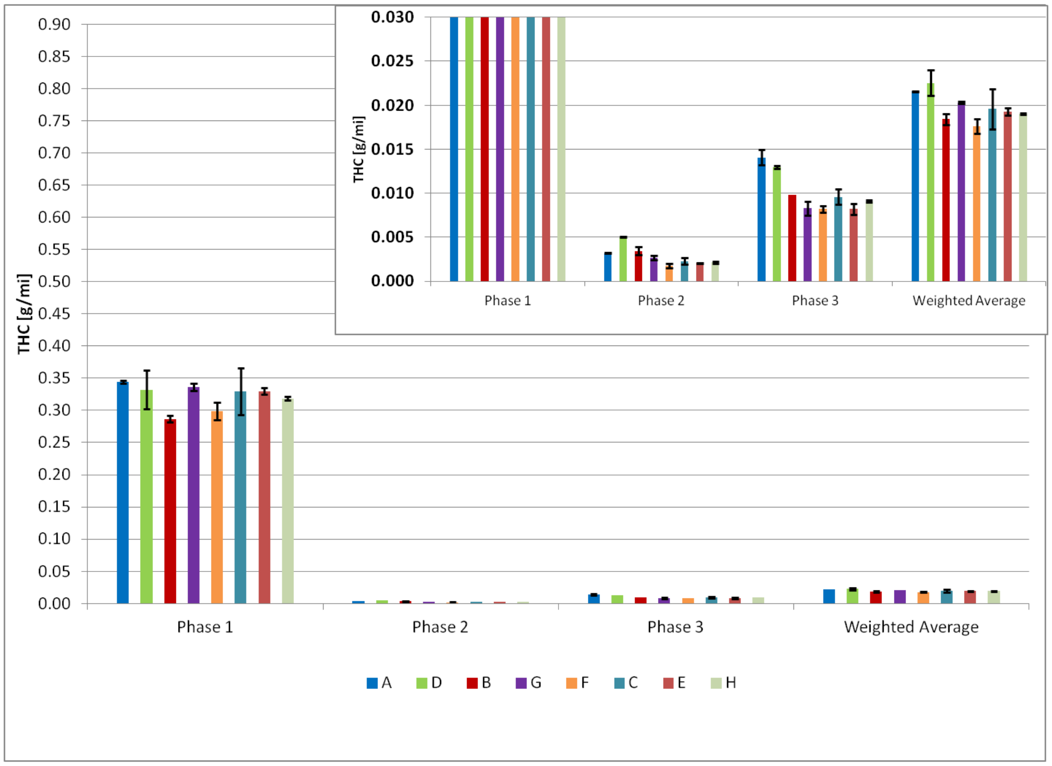


FIGURE E-3. THC EMISSIONS FOR VEHICLE C

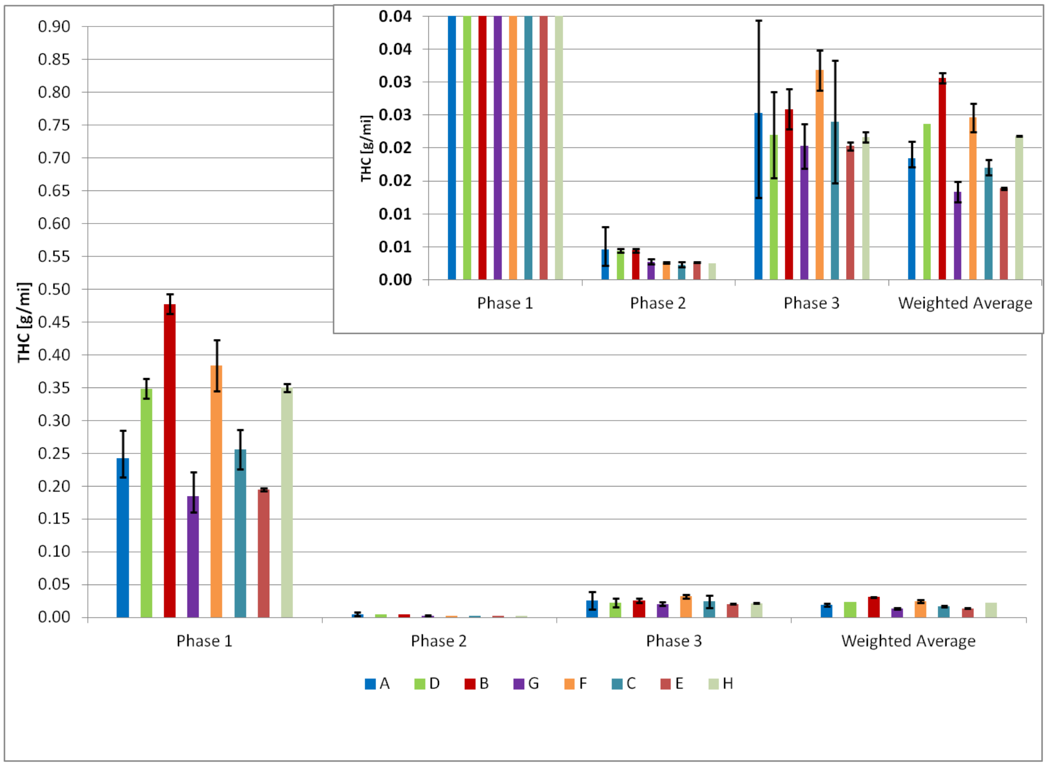


FIGURE E-4. THC EMISSIONS FOR VEHICLE D

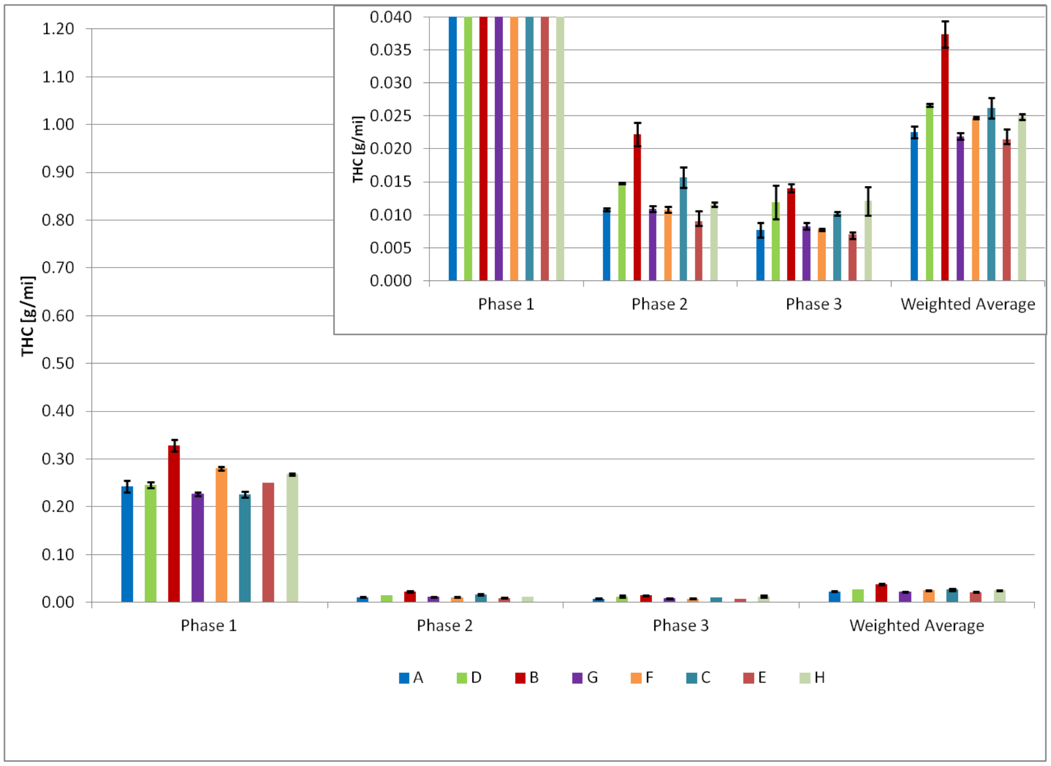


FIGURE E-5. THC EMISSIONS FOR VEHICLE E

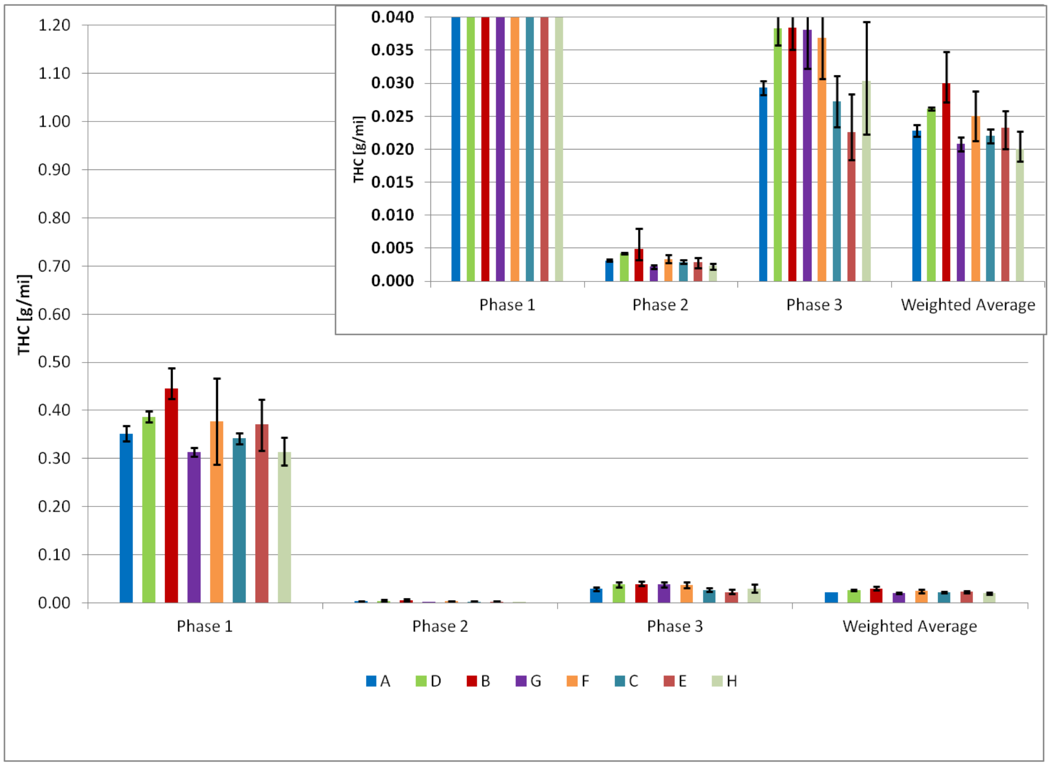


FIGURE E-6. THC EMISSIONS FOR VEHICLE F

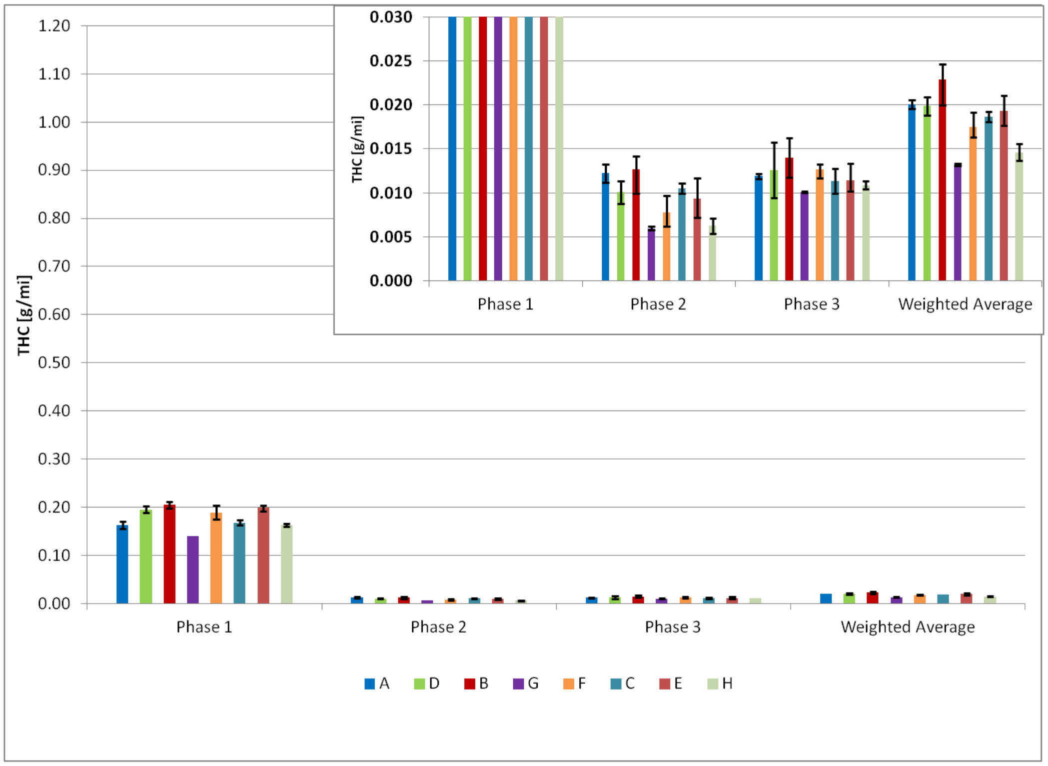


FIGURE E-7. THC EMISSIONS FOR VEHICLE G

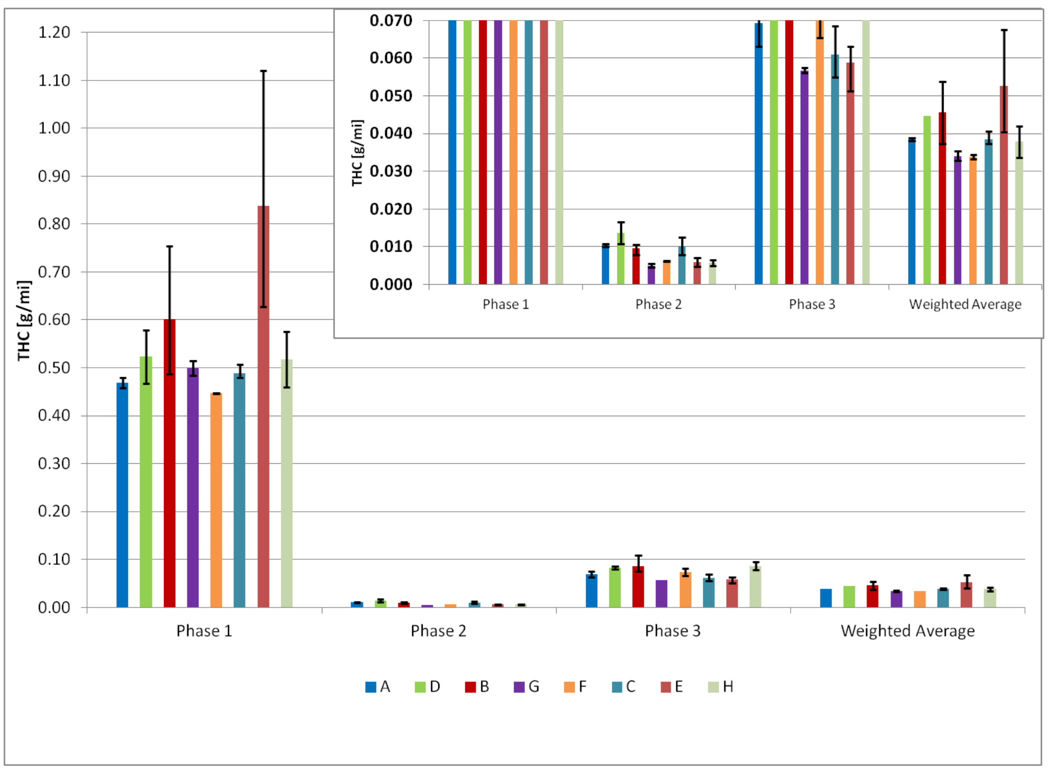


FIGURE E-8. THC EMISSIONS FOR VEHICLE H

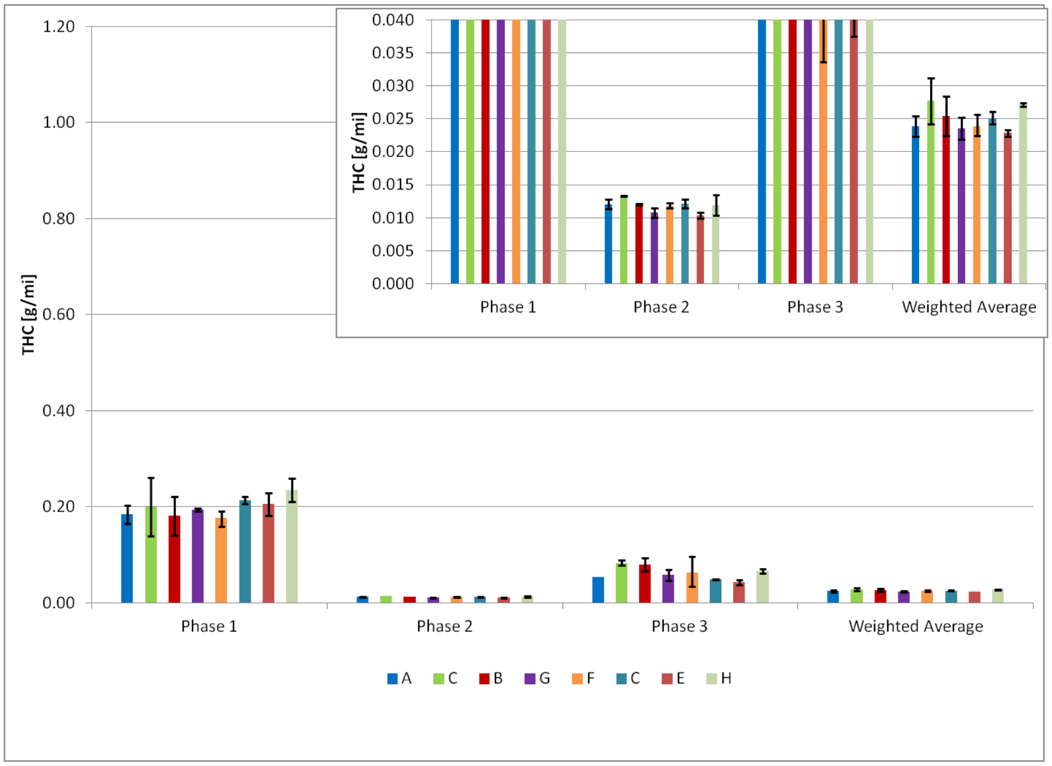


FIGURE E-9. THC EMISSIONS FOR VEHICLE I

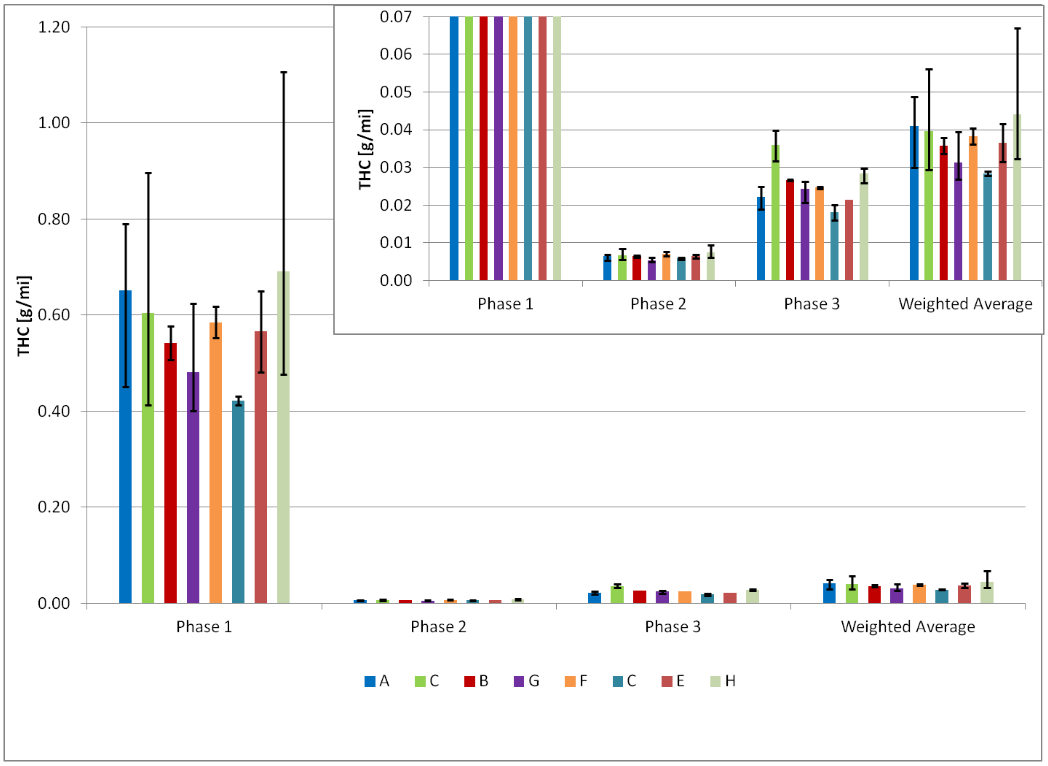


FIGURE E-10. THC EMISSIONS FOR VEHICLE J

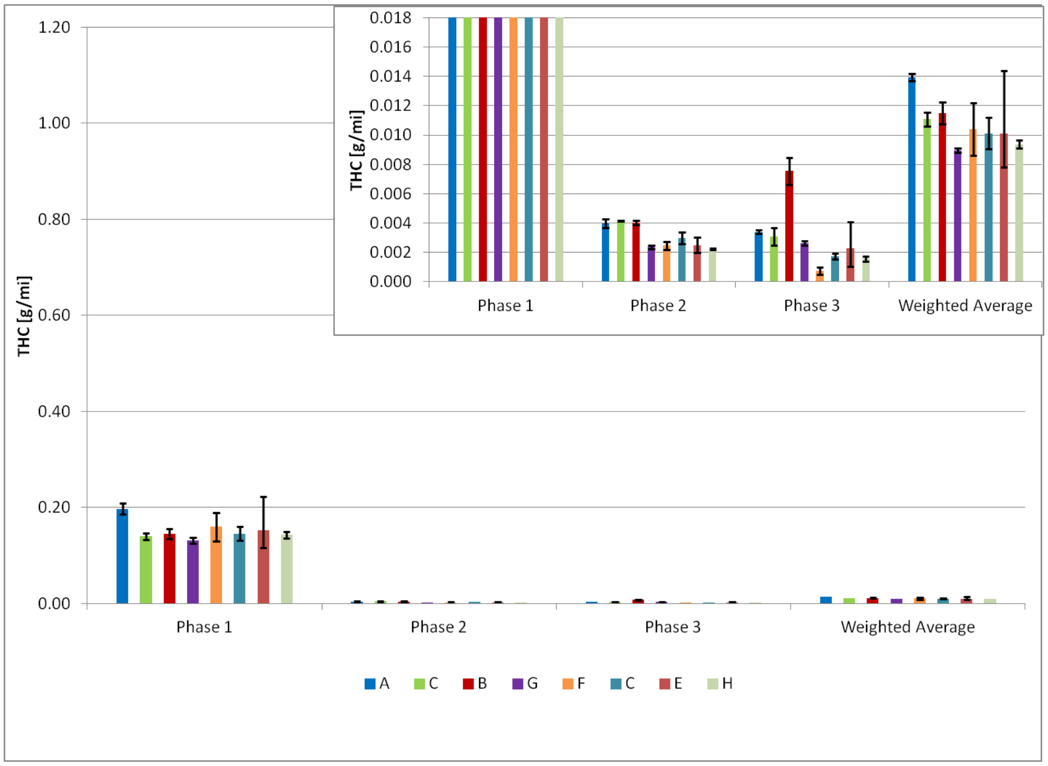


FIGURE E-11. THC EMISSIONS FOR VEHICLE K

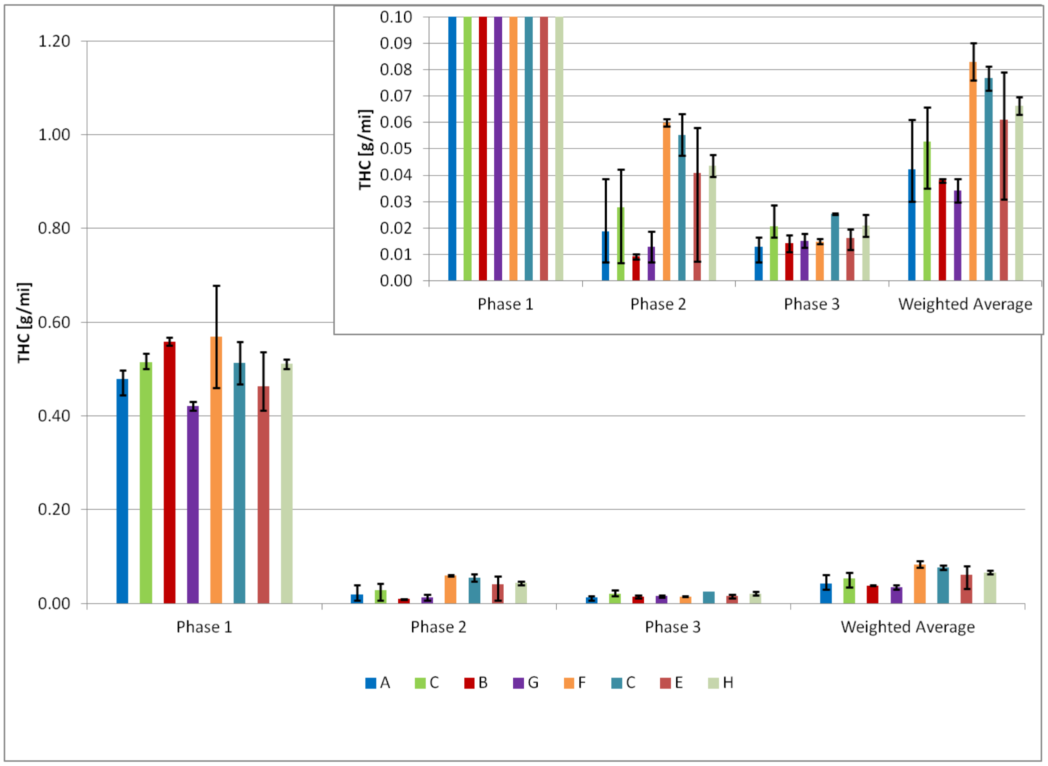


FIGURE E-12. THC EMISSIONS FOR VEHICLE L

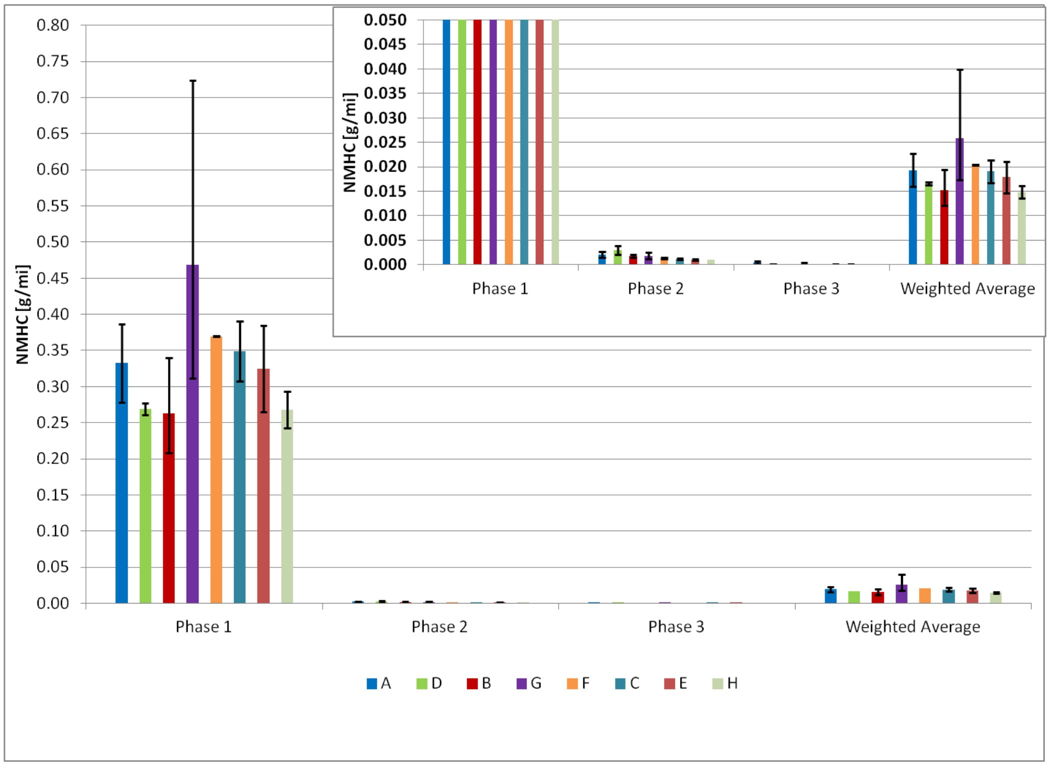


FIGURE E-13. NMHC EMISSIONS FOR VEHICLE A

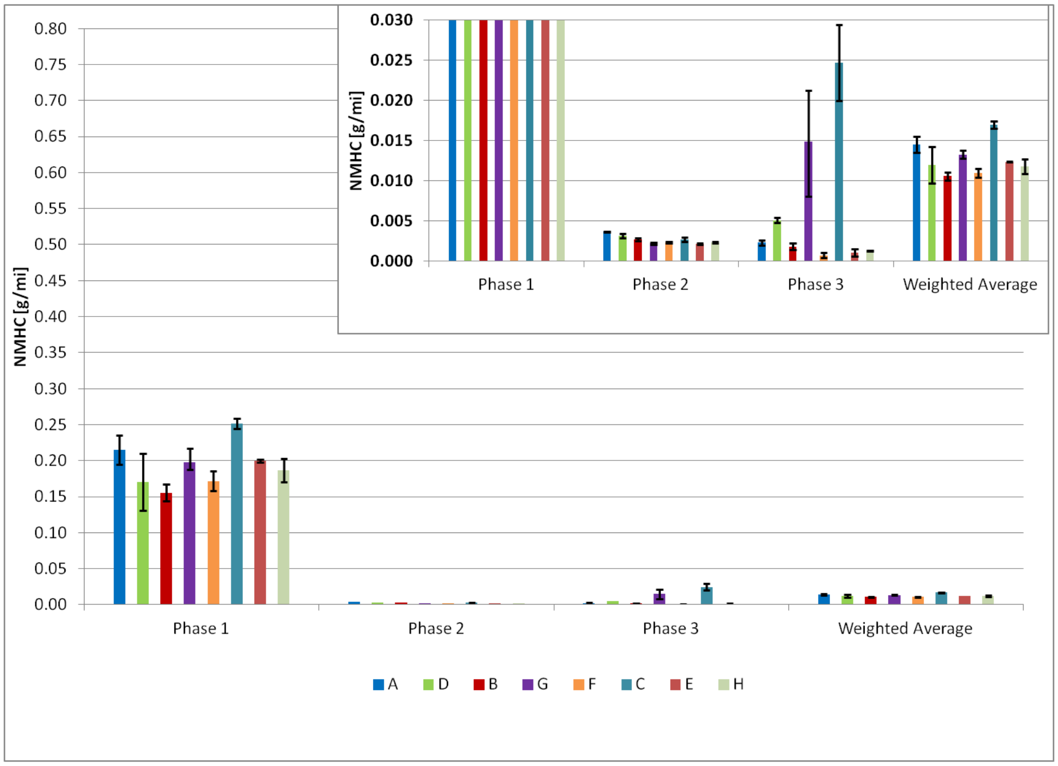


FIGURE E-14. NMHC EMISSIONS FOR VEHICLE B

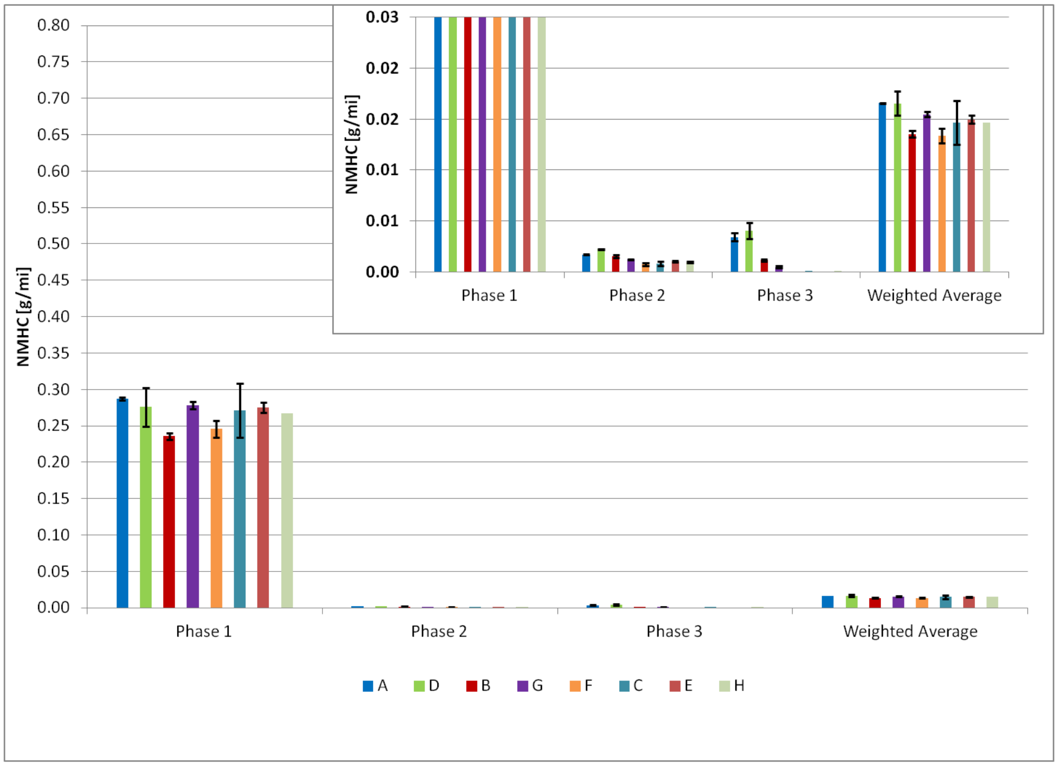


FIGURE E-15. NMHC EMISSIONS FOR VEHICLE C

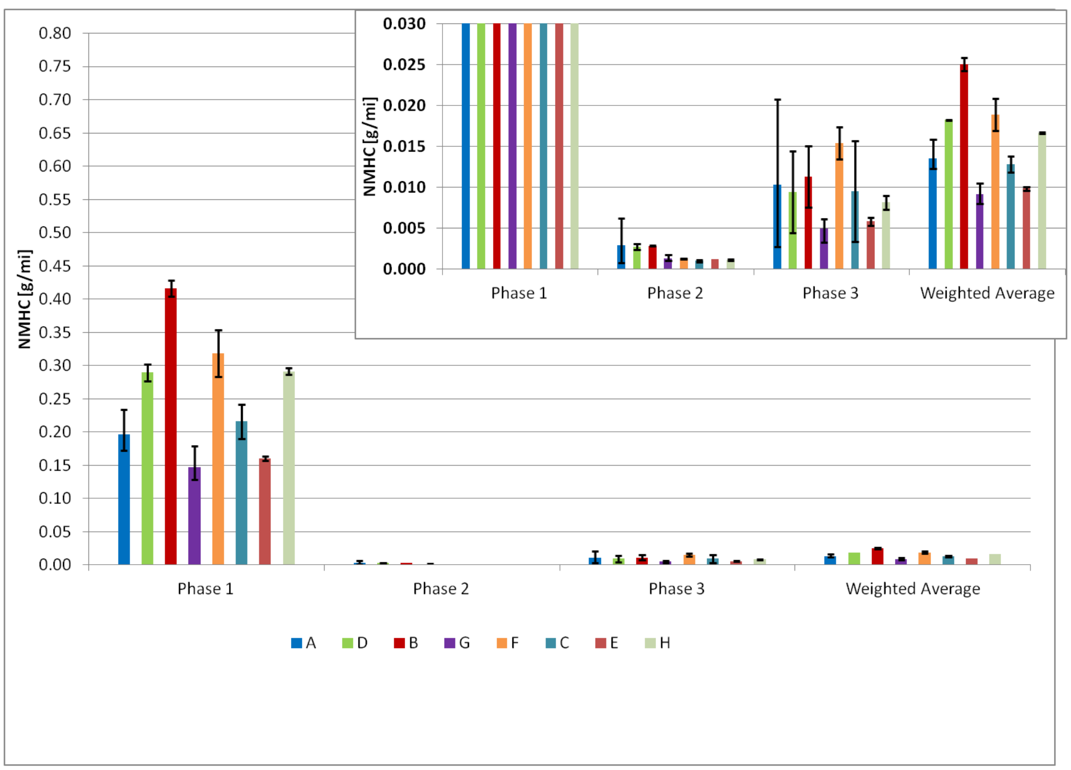


FIGURE E-16. NMHC EMISSIONS FOR VEHICLE D

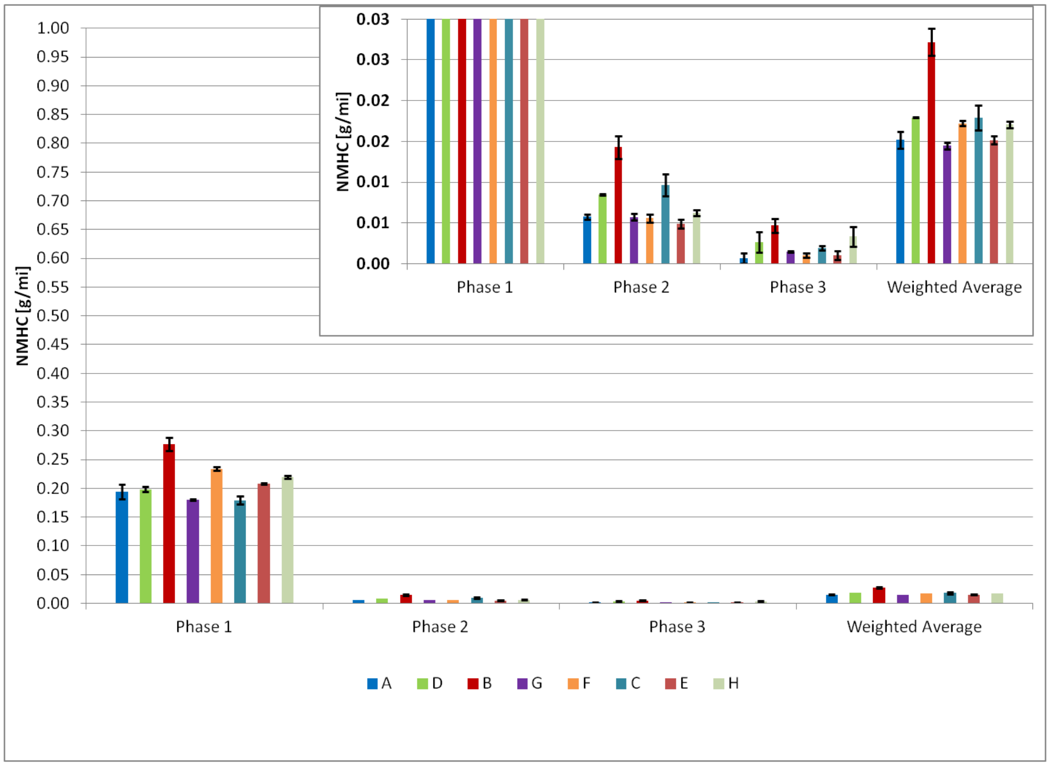


FIGURE E-17. NMHC EMISSIONS FOR VEHICLE E

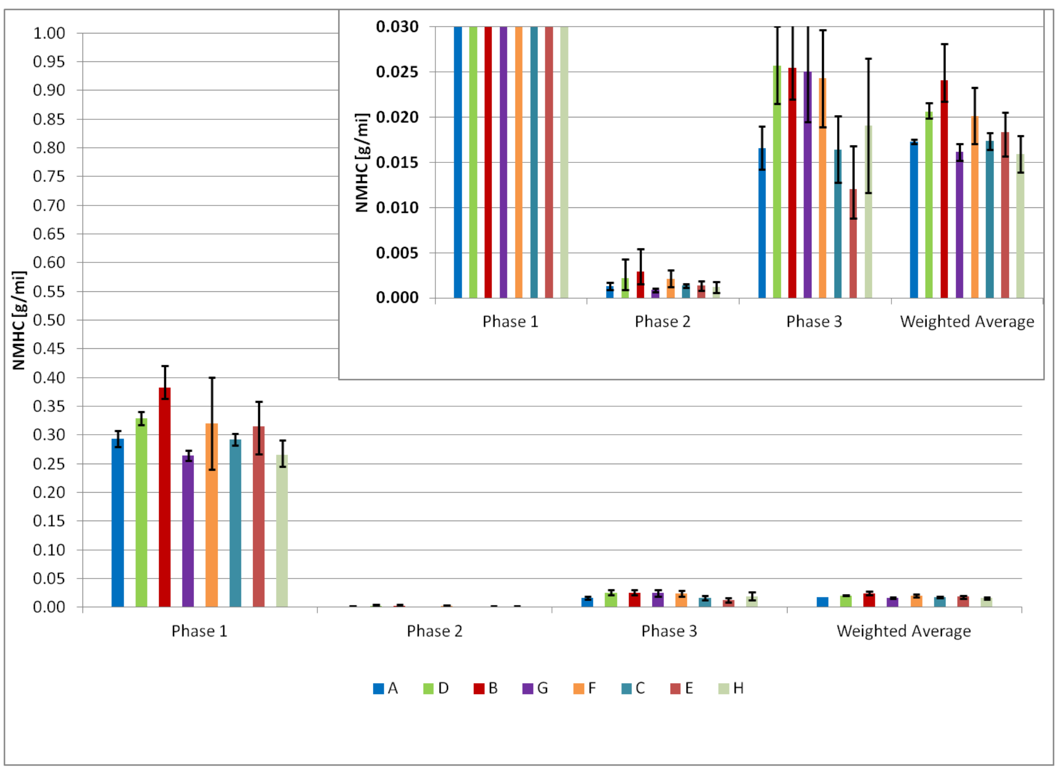


FIGURE E-18. NMHC EMISSIONS FOR VEHICLE F

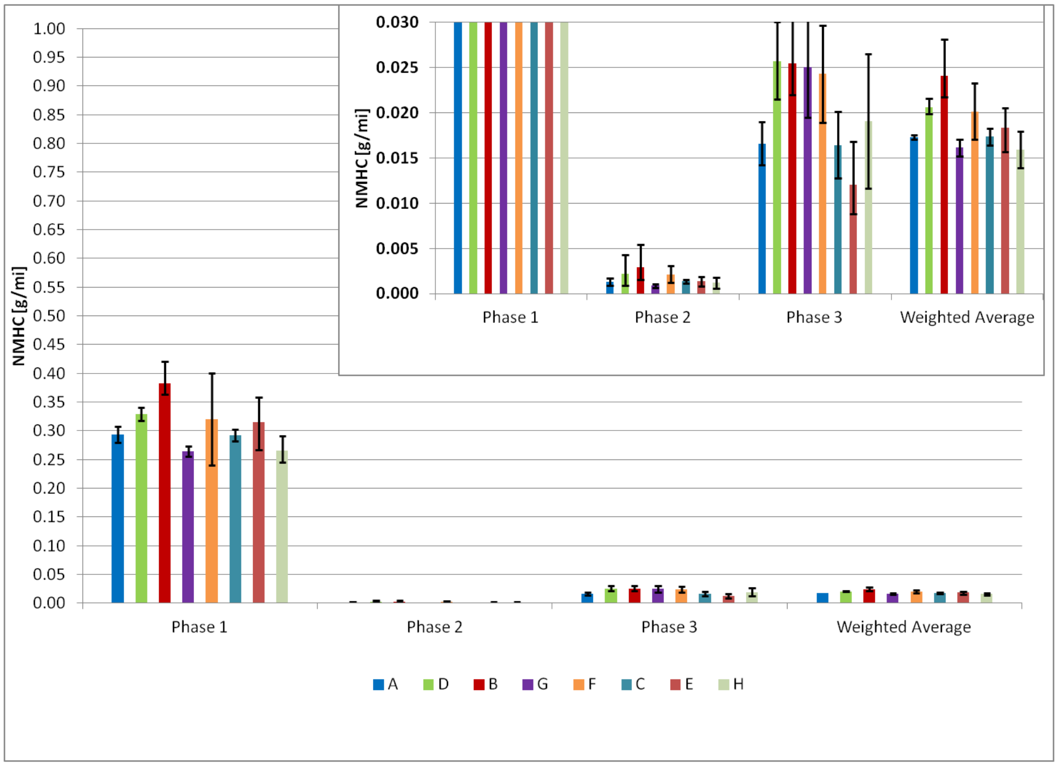


FIGURE E-19. NMHC EMISSIONS FOR VEHICLE G

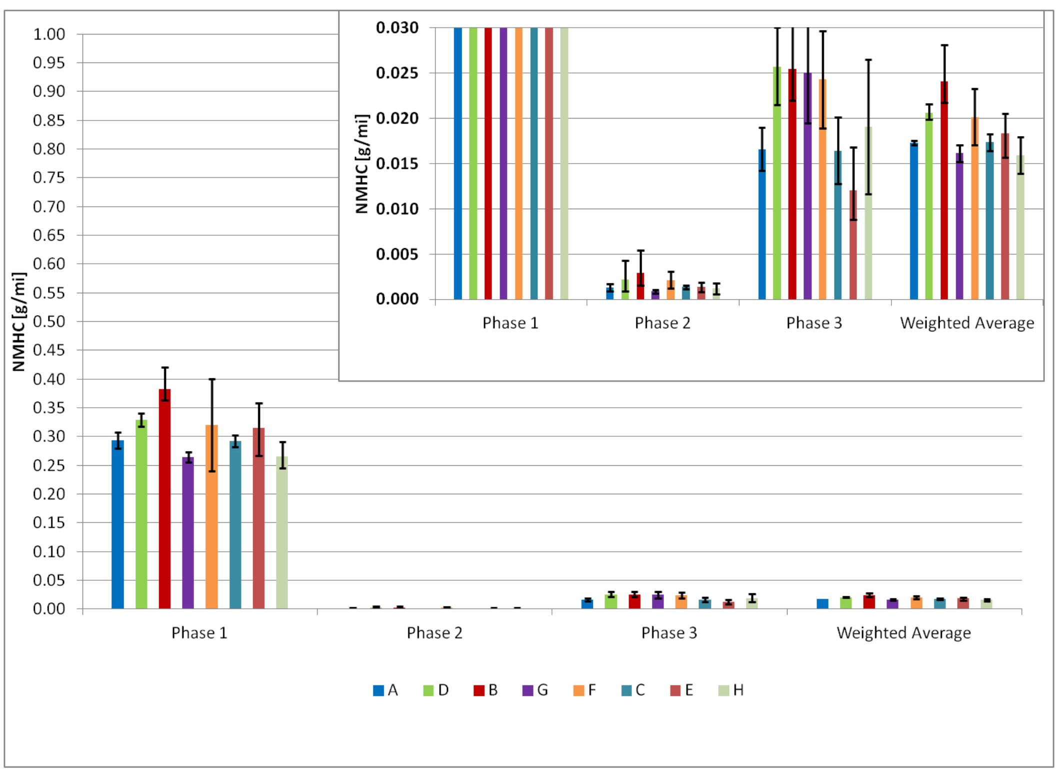


FIGURE E-20. NMHC EMISSIONS FOR VEHICLE H

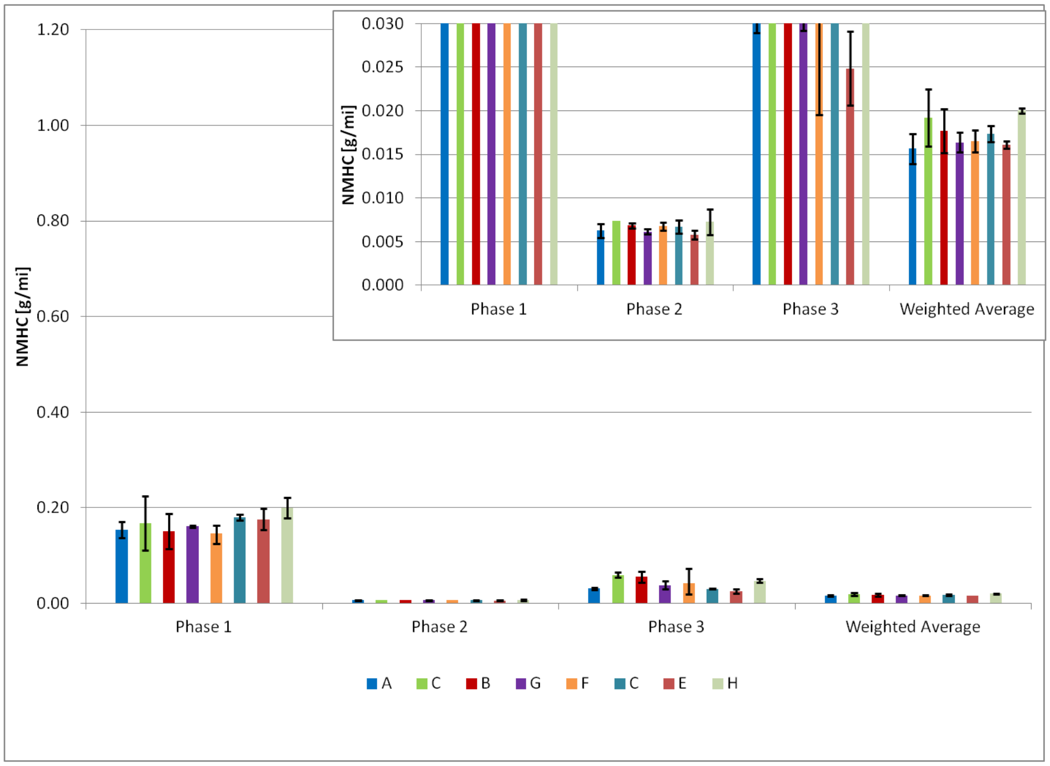


FIGURE E-21. NMHC EMISSIONS FOR VEHICLE I

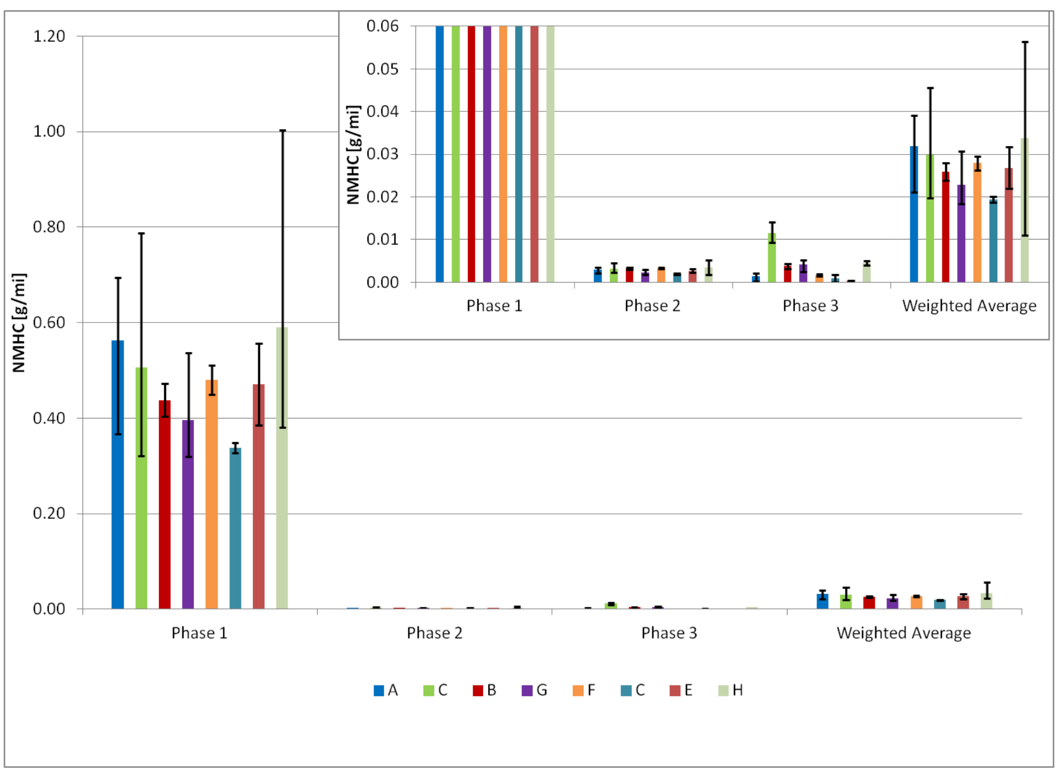


FIGURE E-22. NMHC EMISSIONS FOR VEHICLE J

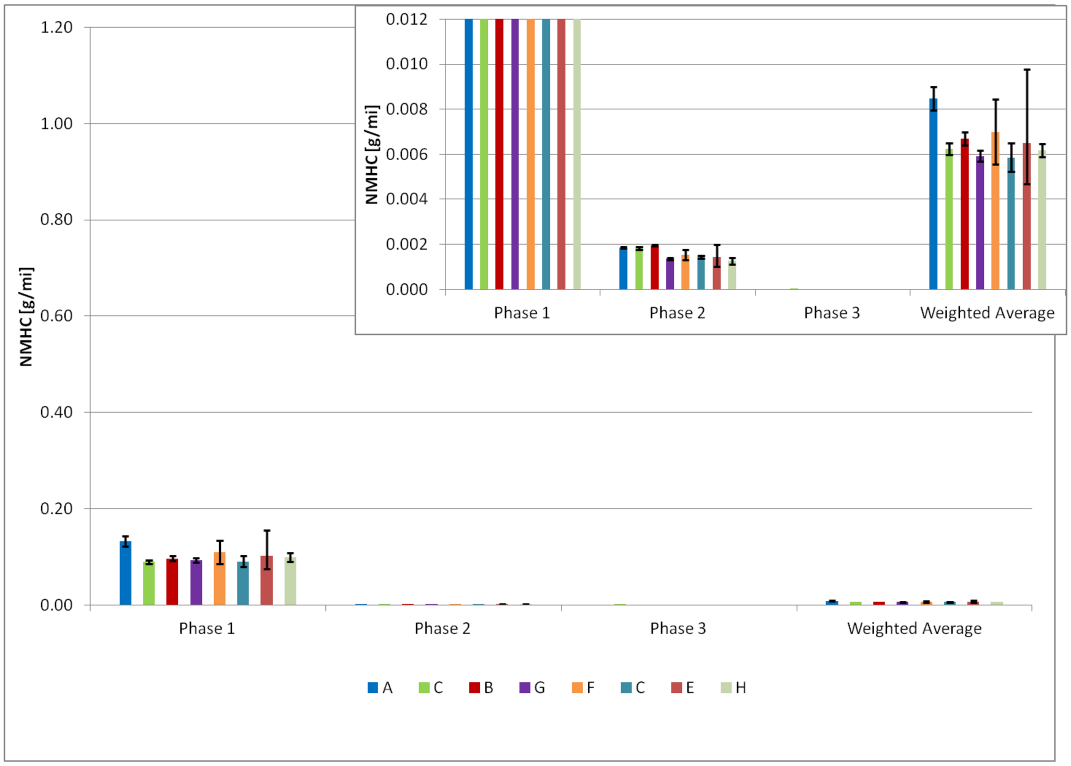


FIGURE E-23. NMHC EMISSIONS FOR VEHICLE K

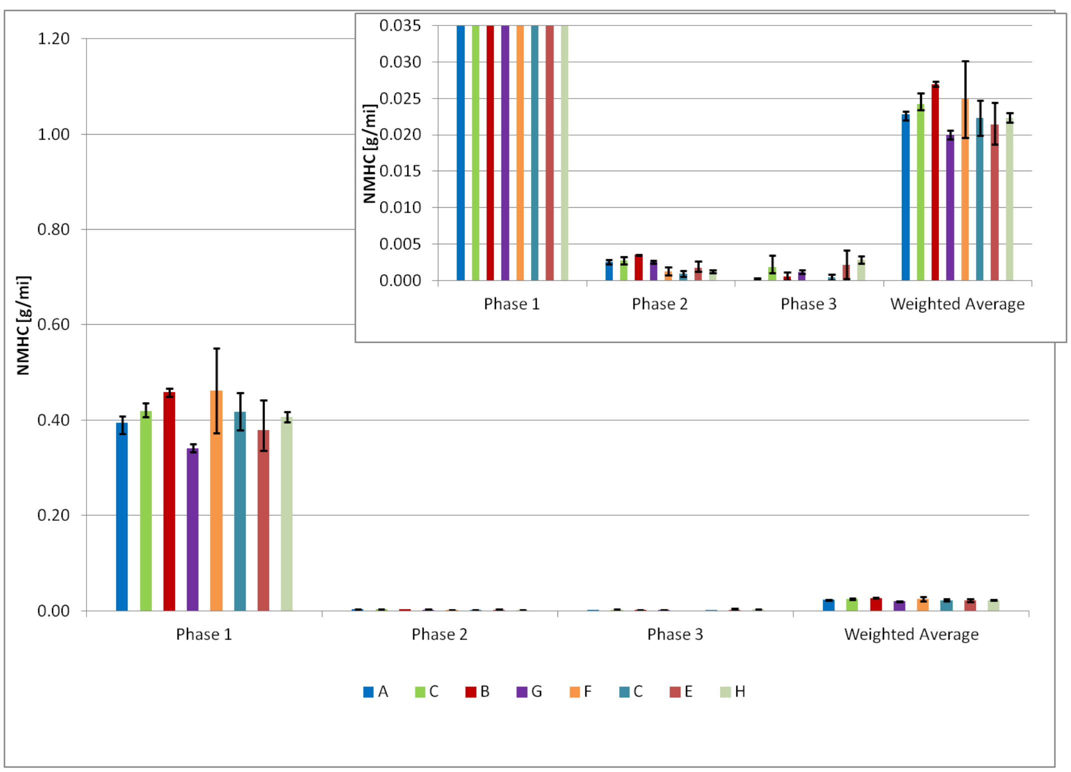


FIGURE E-24. NMHC EMISSIONS FOR VEHICLE L

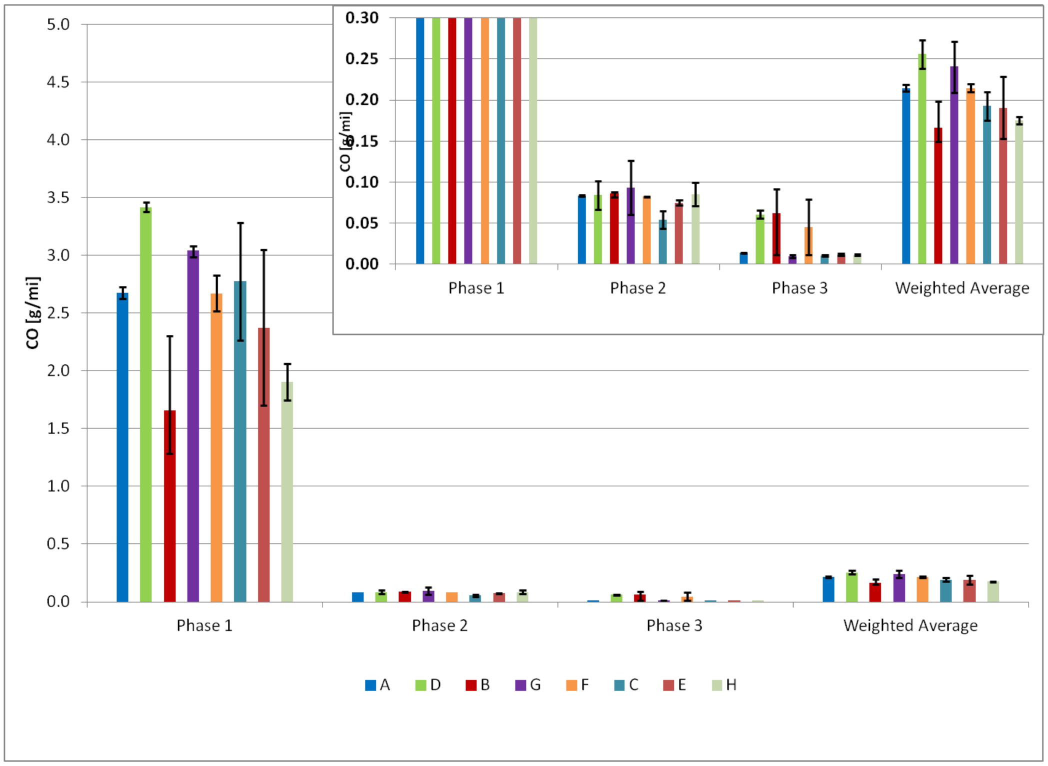


FIGURE E-25. CO EMISSIONS FOR VEHICLE A

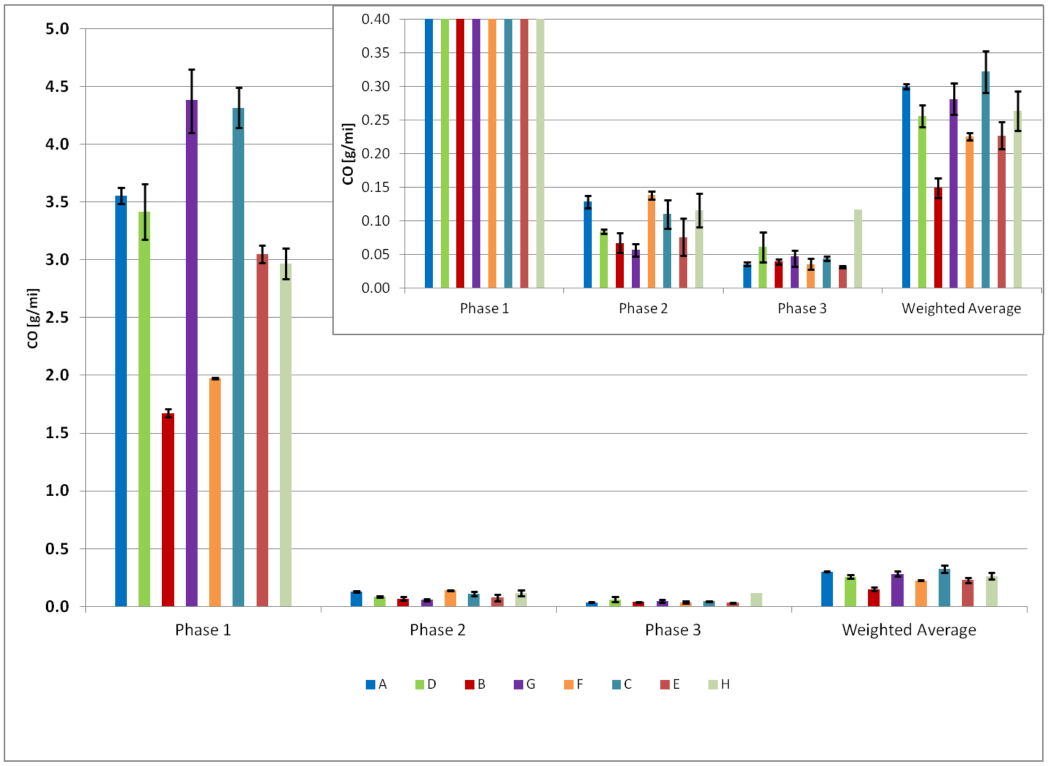


FIGURE E-26. CO EMISSIONS FOR VEHICLE B

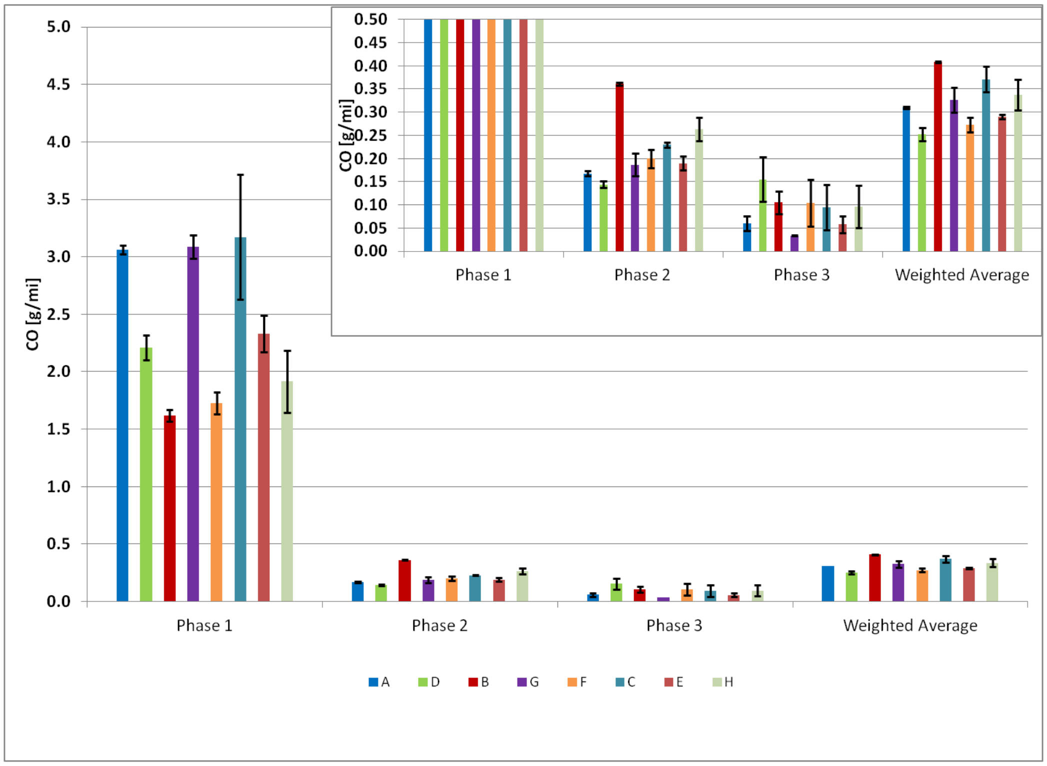


FIGURE E-27. CO EMISSIONS FOR VEHICLE C

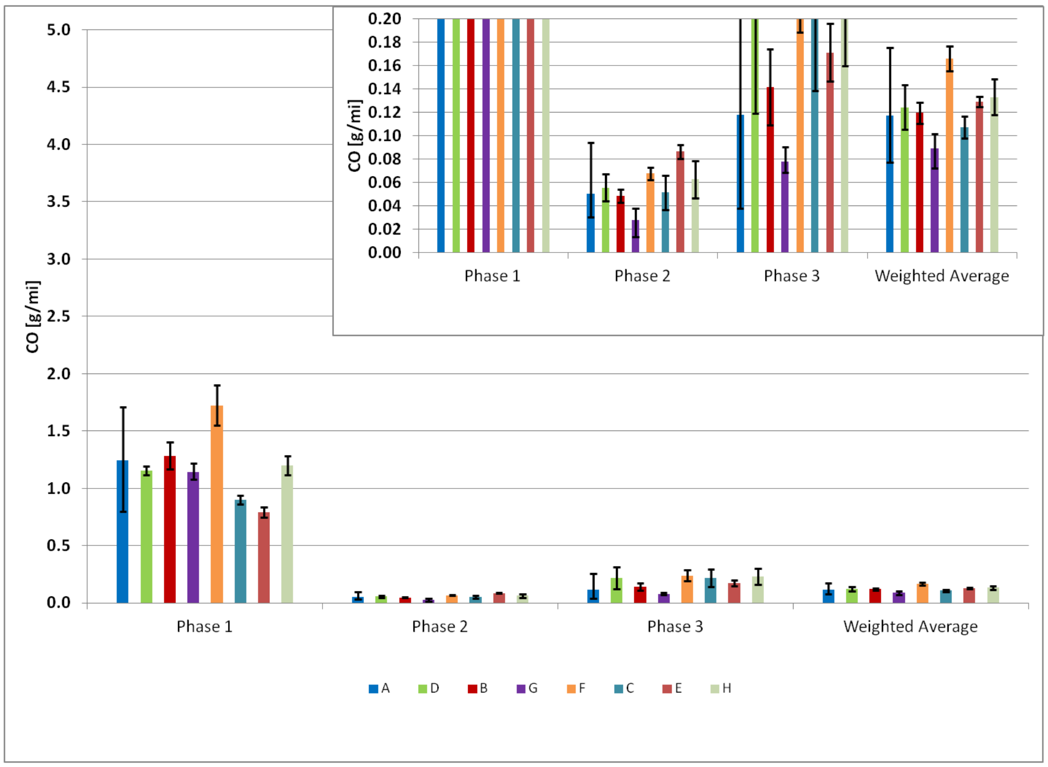


FIGURE E-28. CO EMISSIONS FOR VEHICLE D

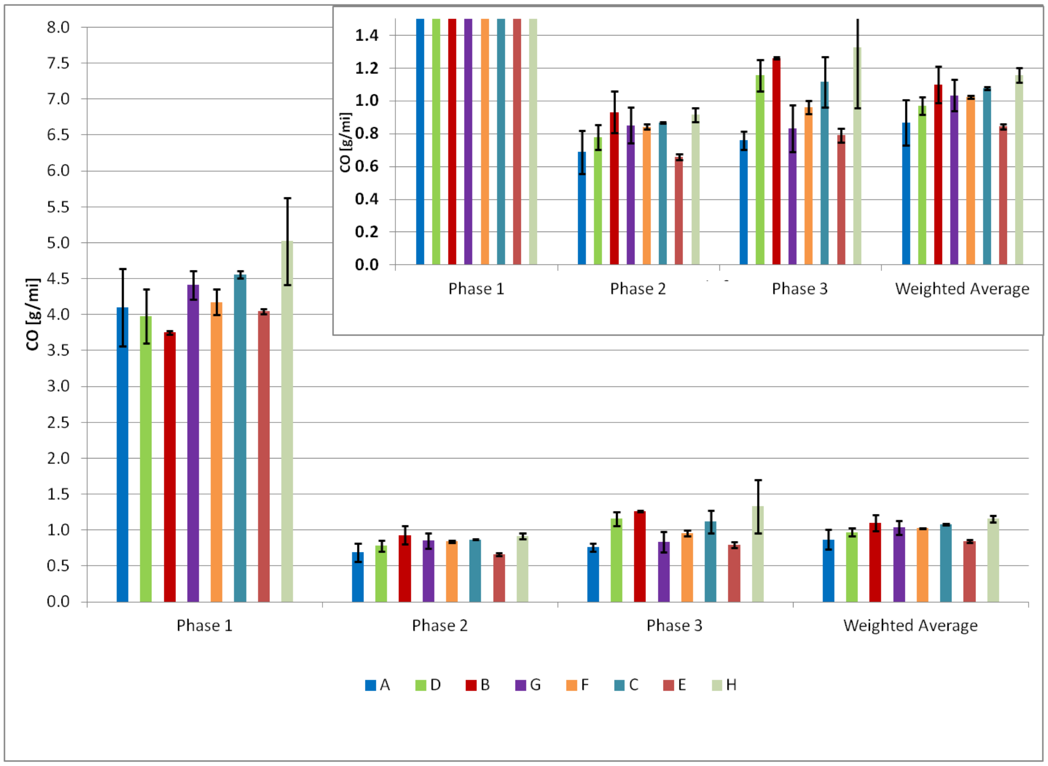


FIGURE E-29. CO EMISSIONS FOR VEHICLE E

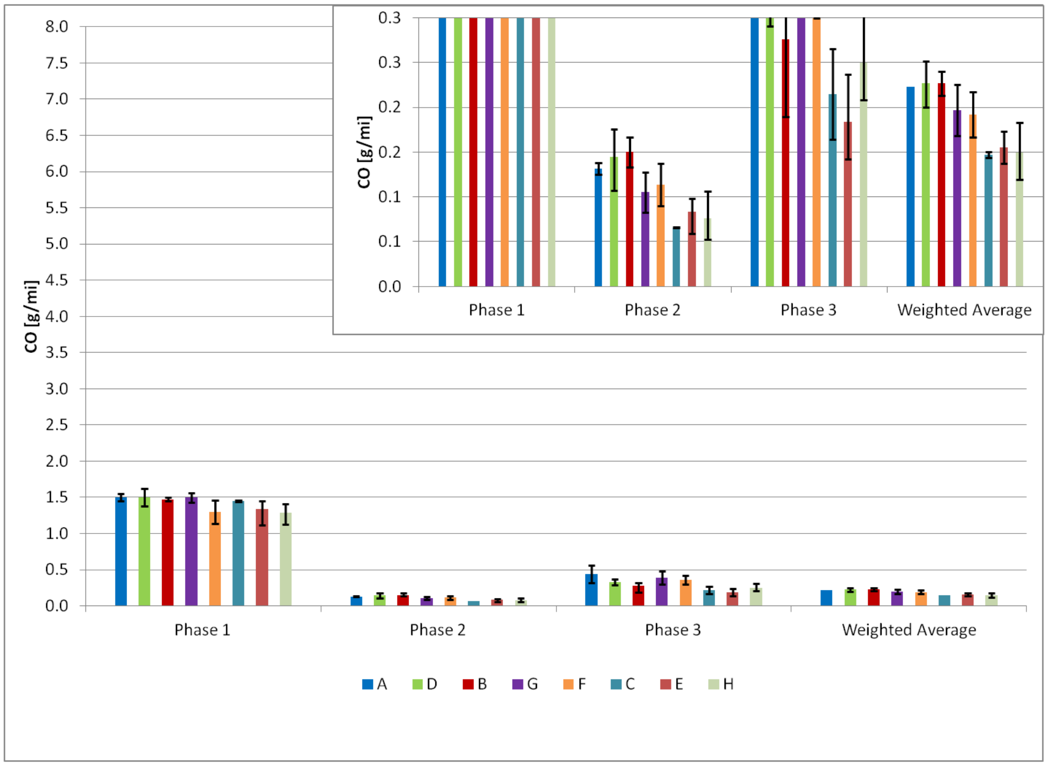


FIGURE E-30. CO EMISSIONS FOR VEHICLE F

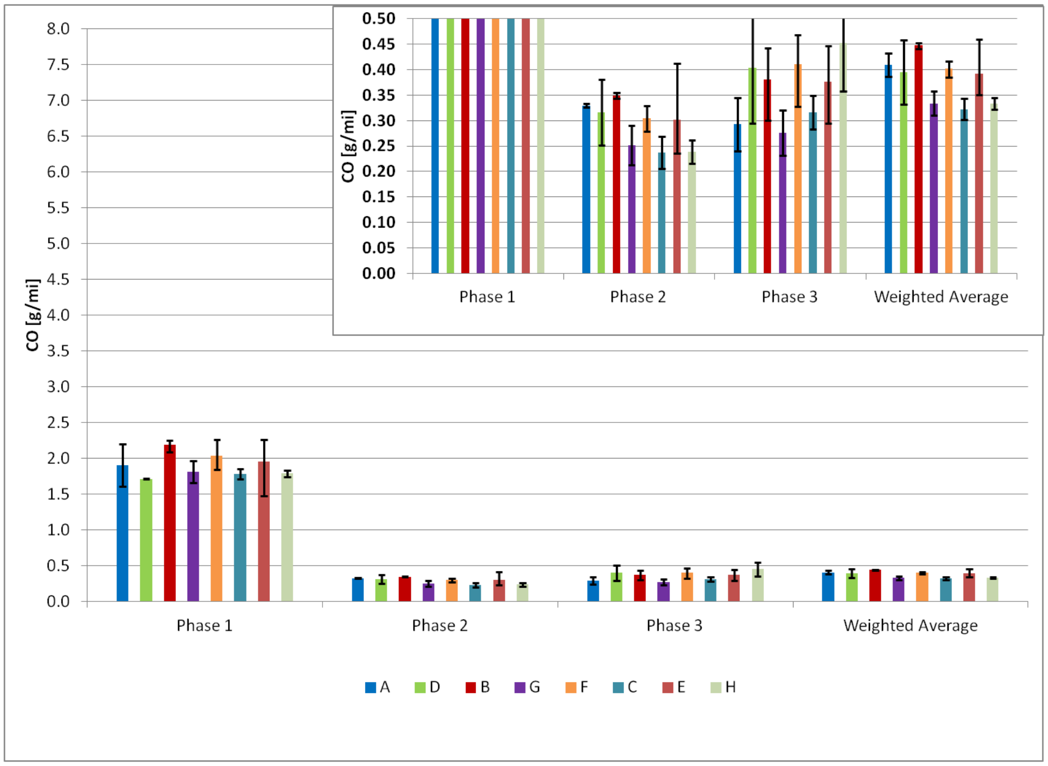


FIGURE E-31. CO EMISSIONS FOR VEHICLE G

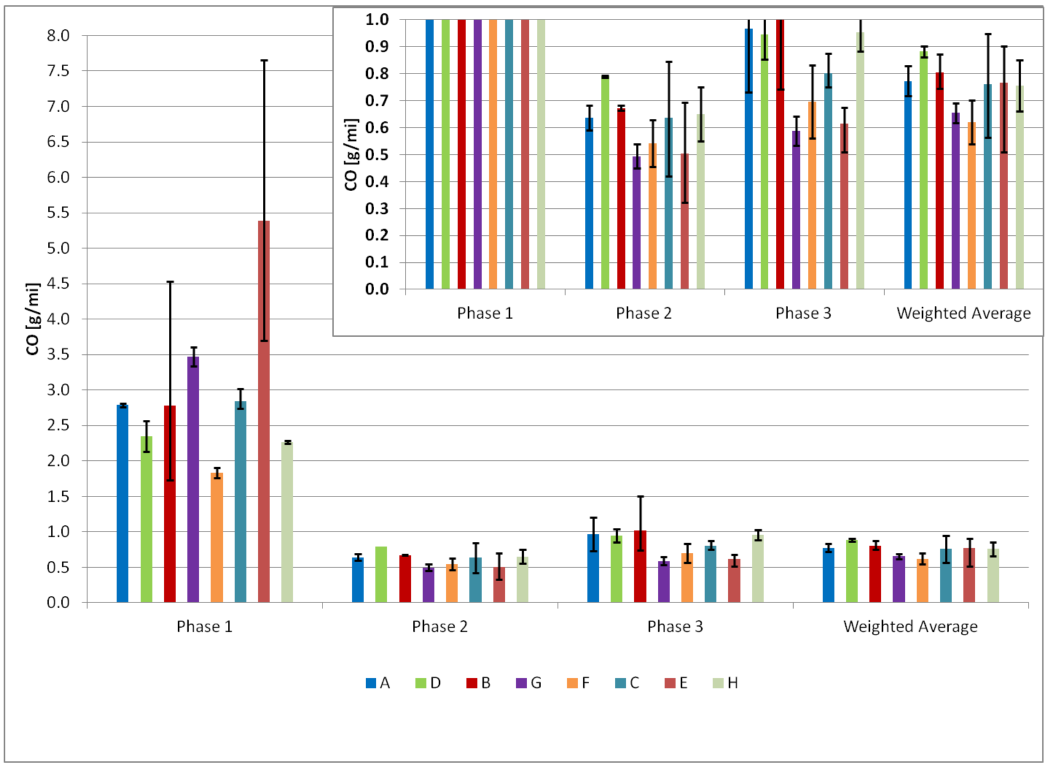


FIGURE E-32. CO EMISSIONS FOR VEHICLE H

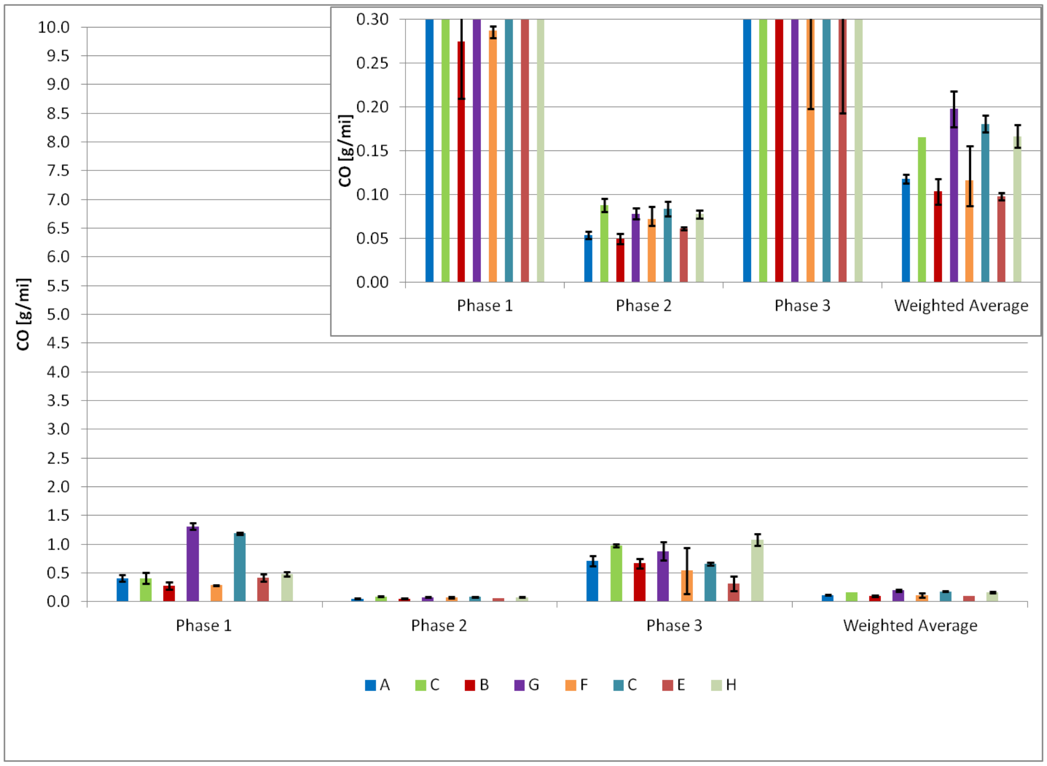


FIGURE E-33. CO EMISSIONS FOR VEHICLE I

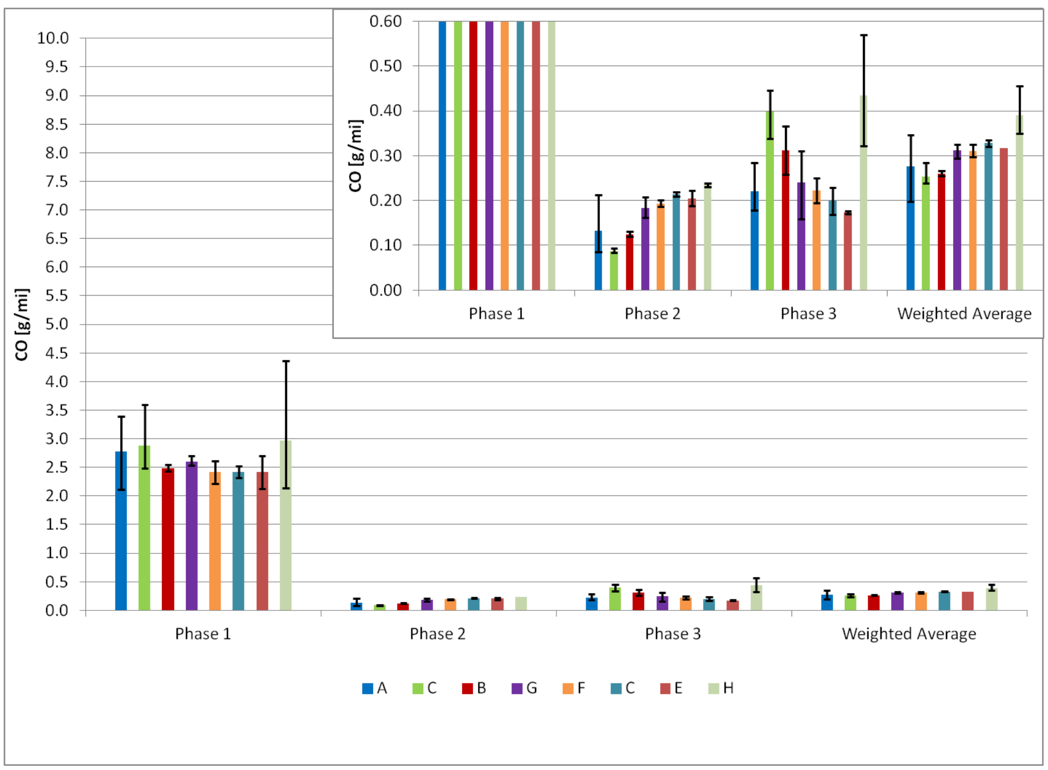


FIGURE E-34. CO EMISSIONS FOR VEHICLE J

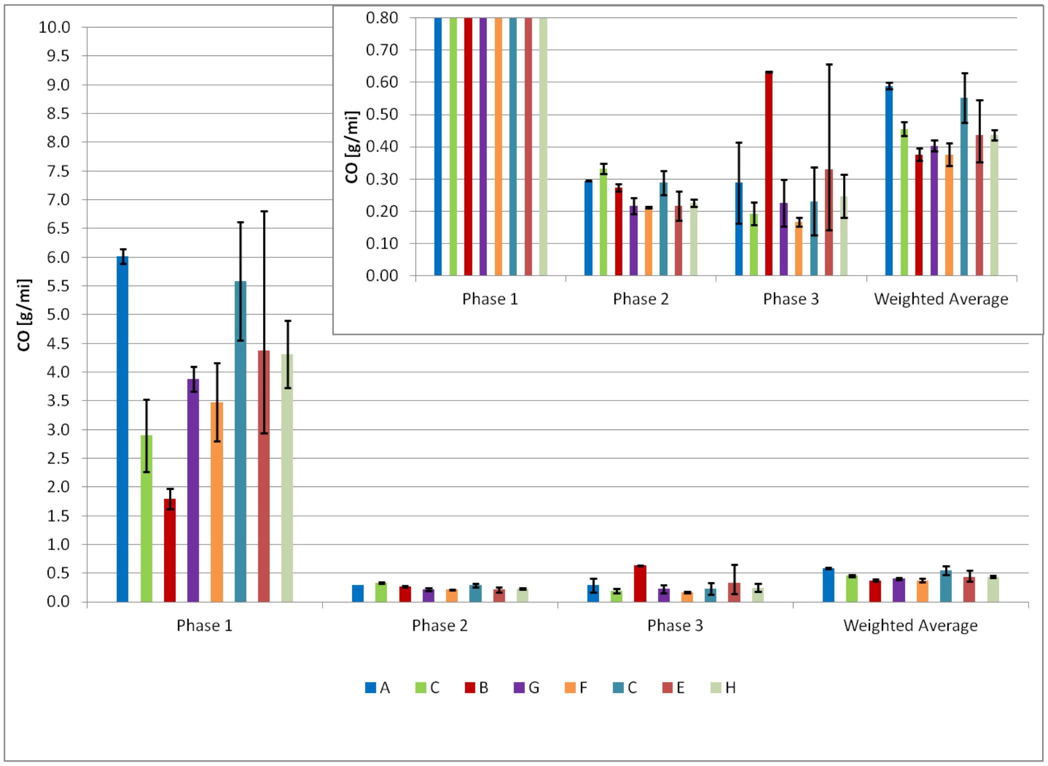


FIGURE E-35. CO EMISSIONS FOR VEHICLE K

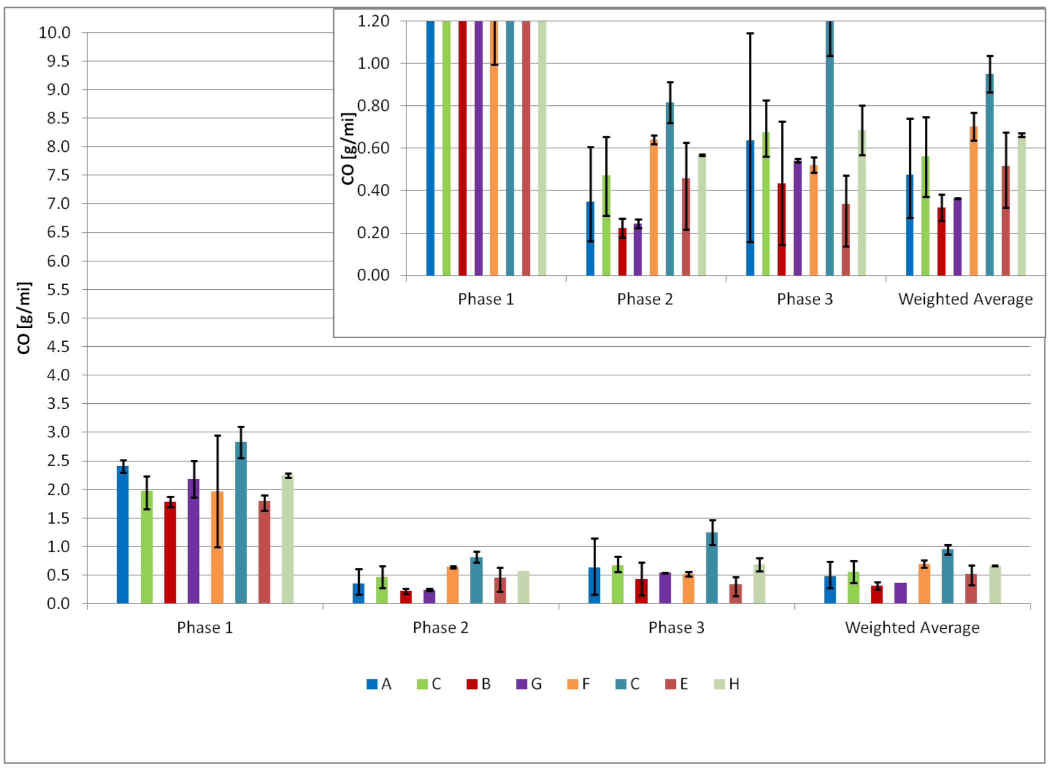


FIGURE E-36. CO EMISSIONS FOR VEHICLE L

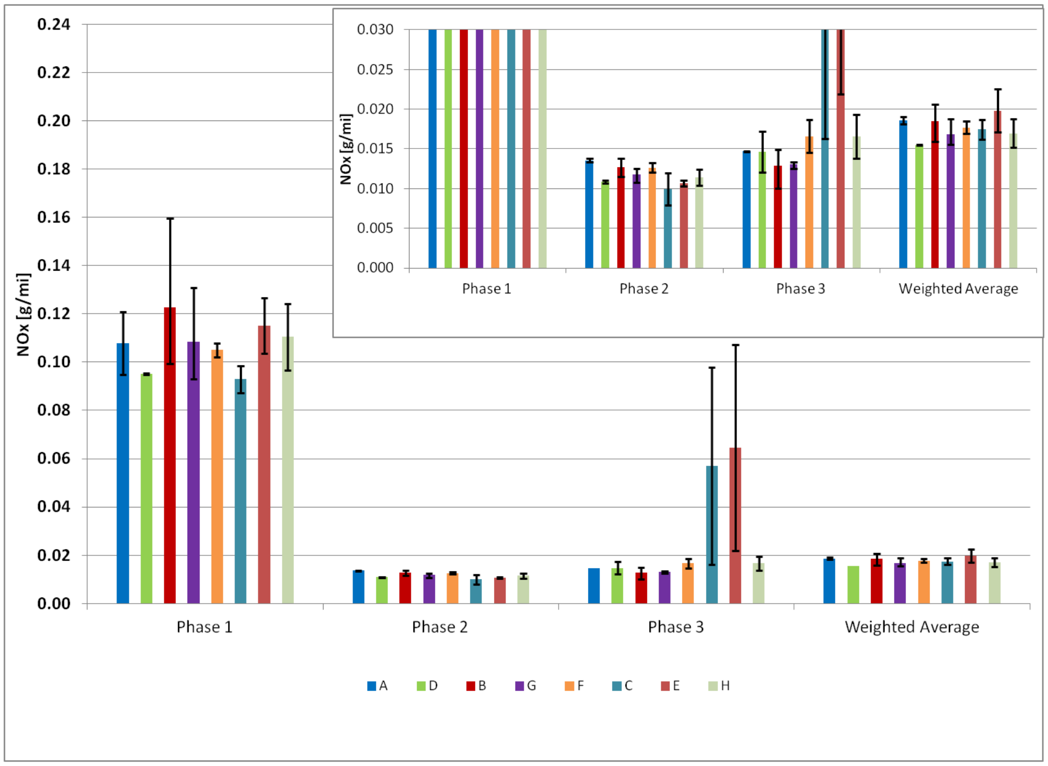


FIGURE E-37. NO_X EMISSIONS FOR VEHICLE A

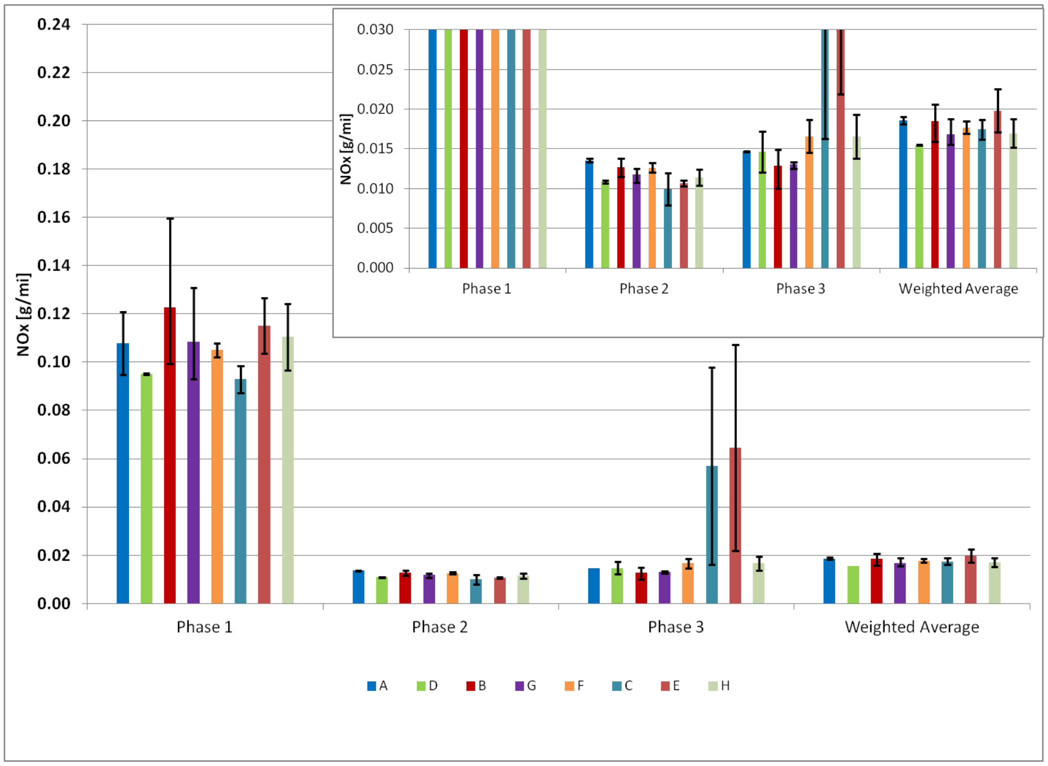


FIGURE E-38. NO_X EMISSIONS FOR VEHICLE B

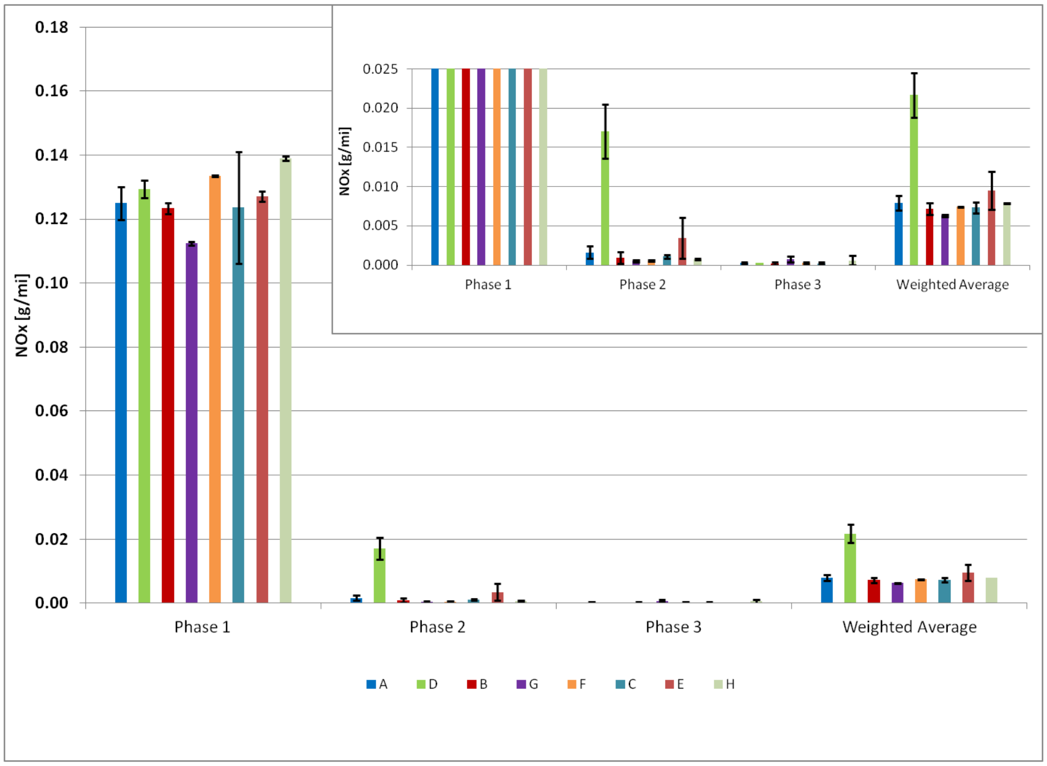


FIGURE E-39. NO_X EMISSIONS FOR VEHICLE C

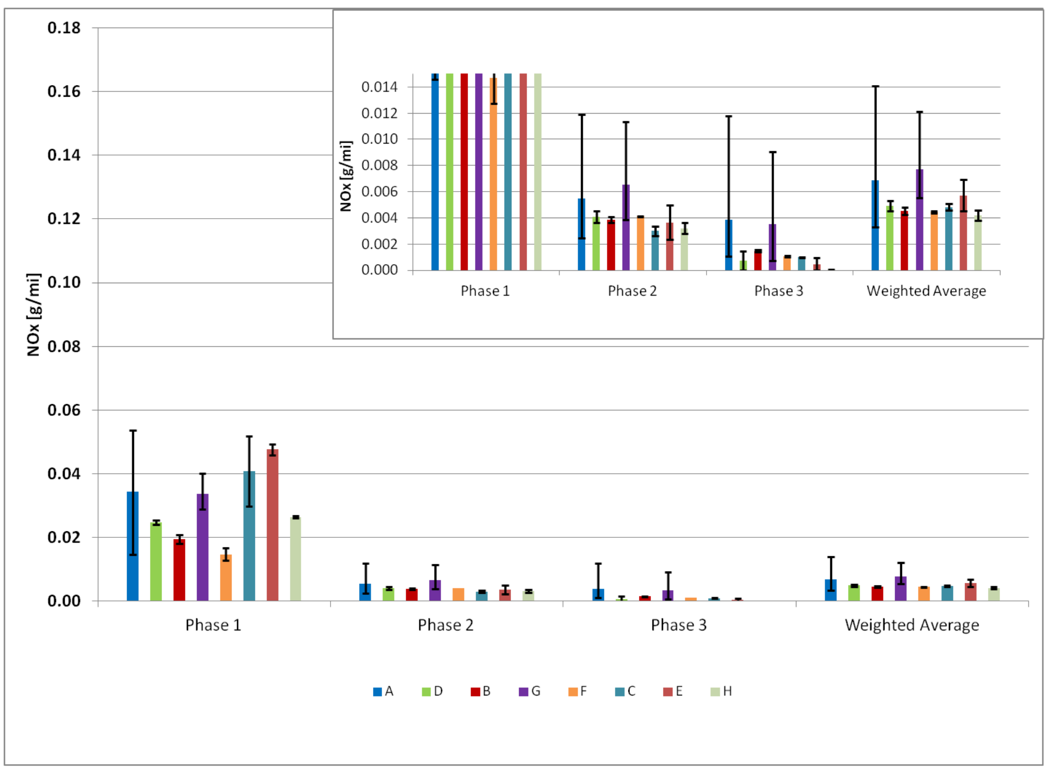


FIGURE E-40. NO_X EMISSIONS FOR VEHICLE D

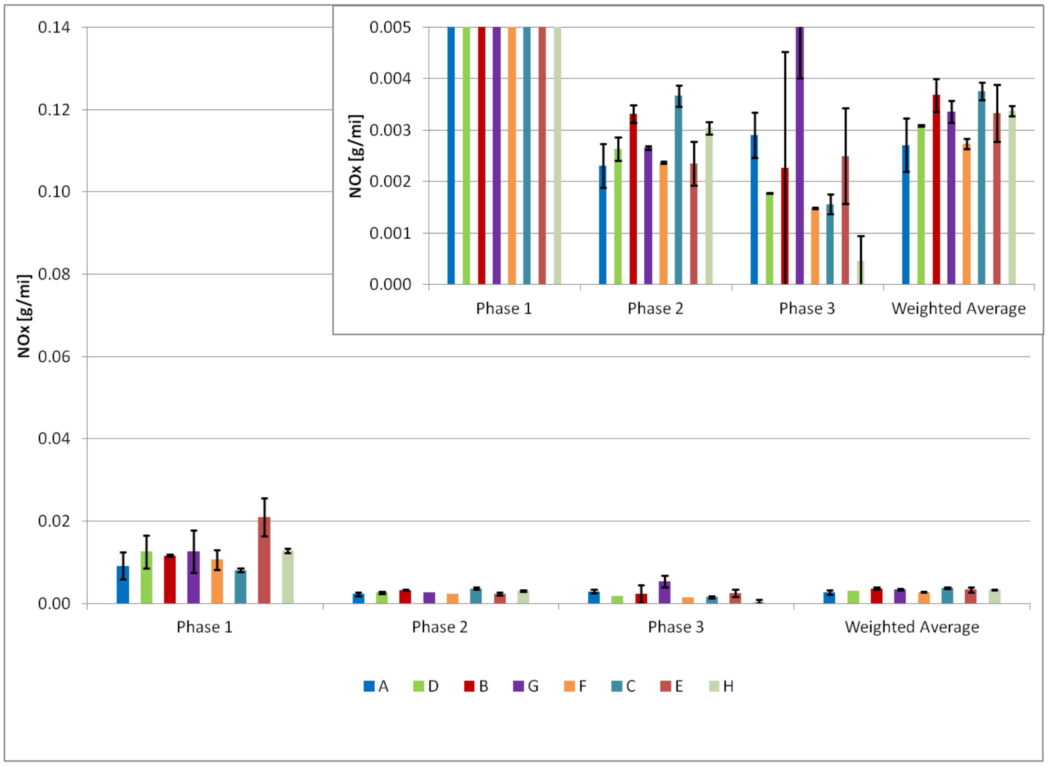


FIGURE E-41. NO_X EMISSIONS FOR VEHICLE E

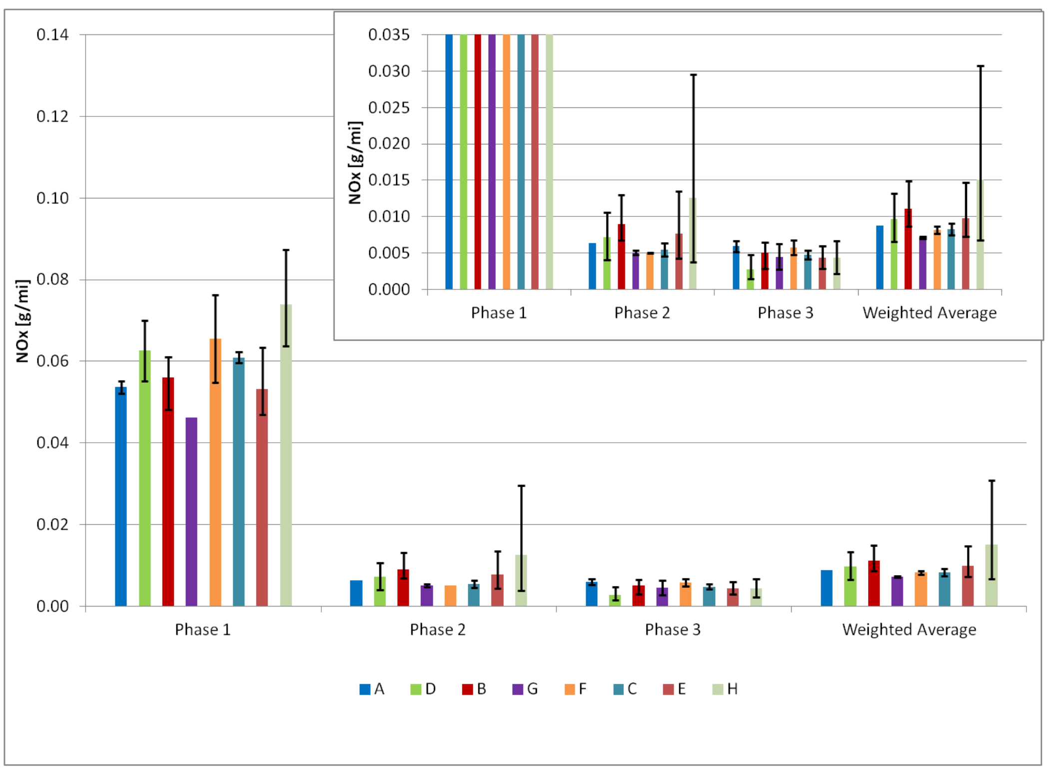


FIGURE E-42. NO_X EMISSIONS FOR VEHICLE F

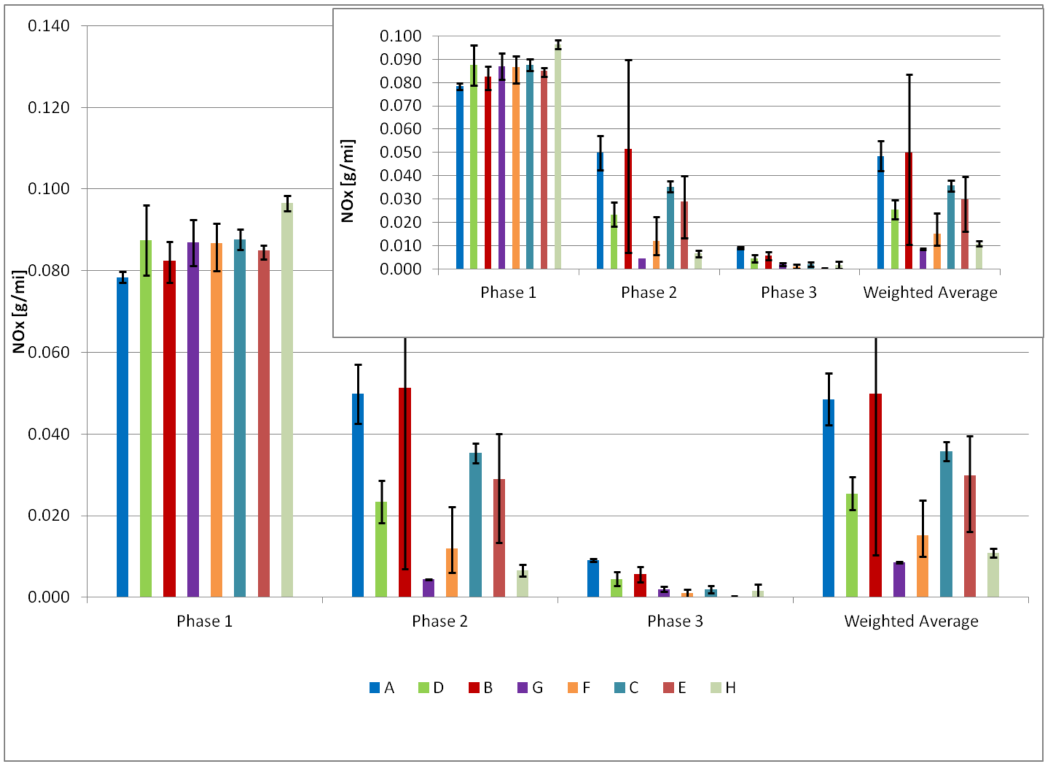


FIGURE E-43. NO_X EMISSIONS FOR VEHICLE G

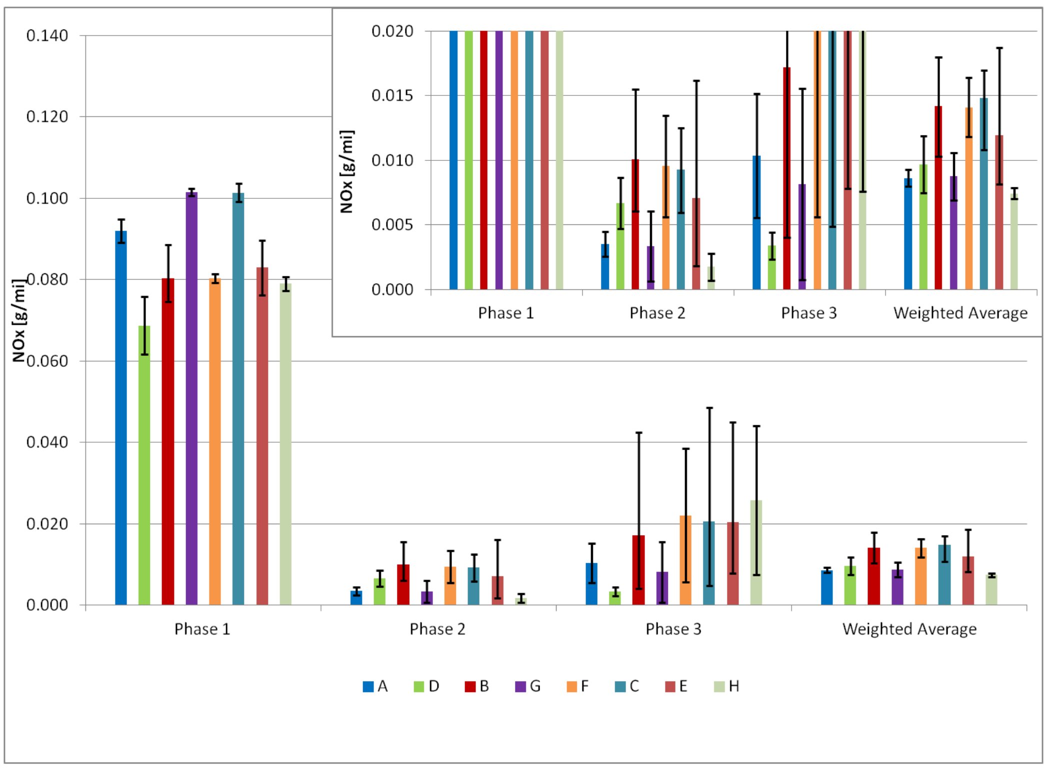


FIGURE E-44. NO_X EMISSIONS FOR VEHICLE H

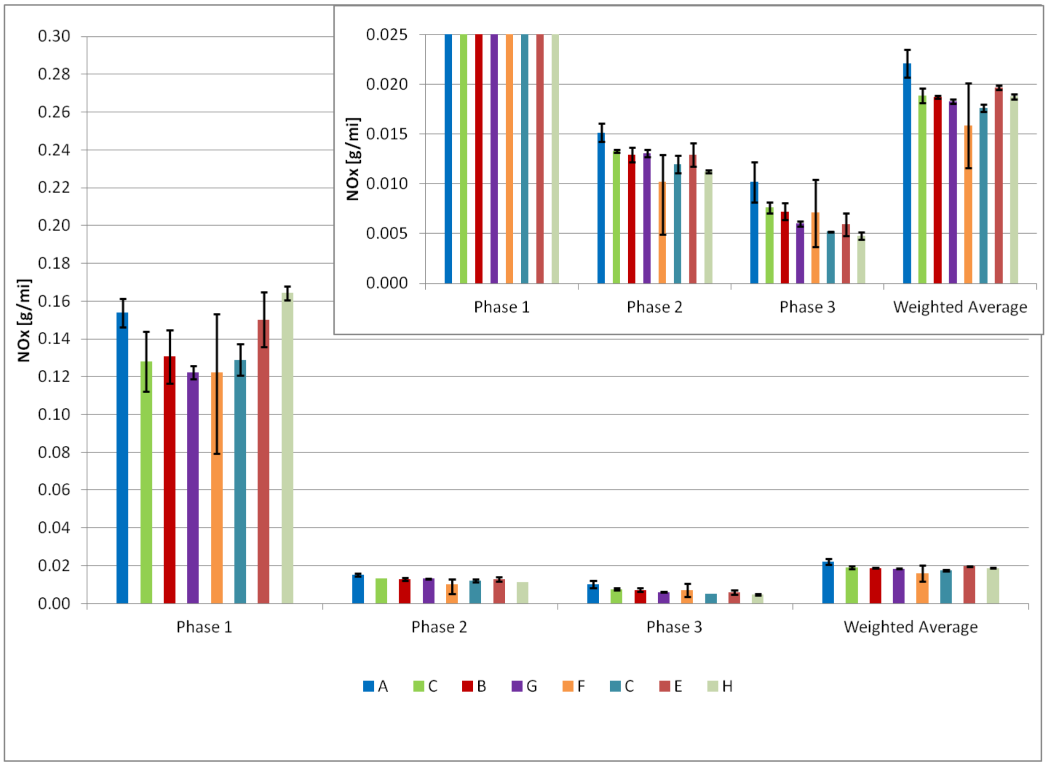


FIGURE E-45. NO_X EMISSIONS FOR VEHICLE I

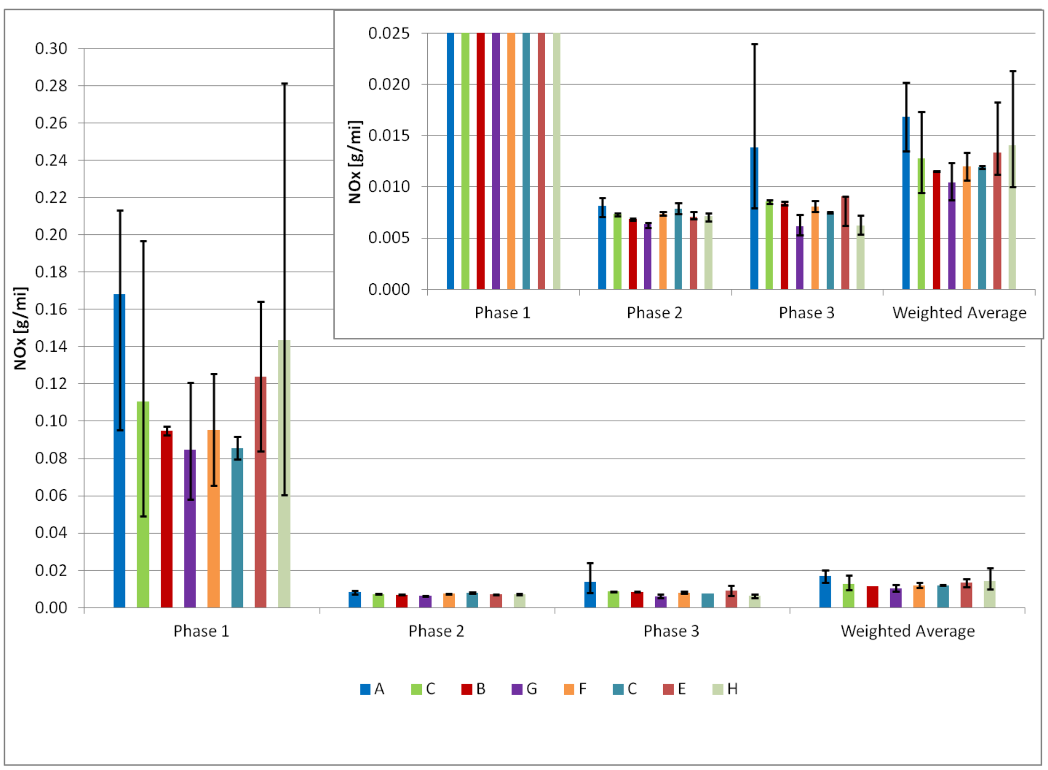


FIGURE E-46. NO_X EMISSIONS FOR VEHICLE J

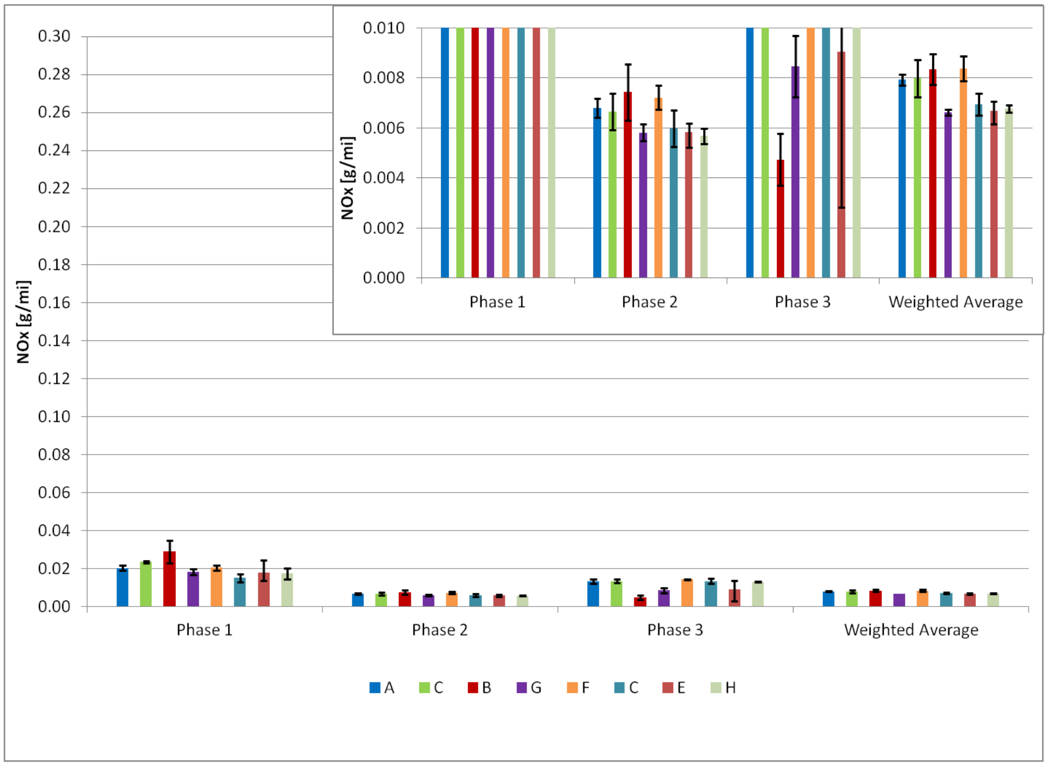


FIGURE E-47. NO_X EMISSIONS FOR VEHICLE K

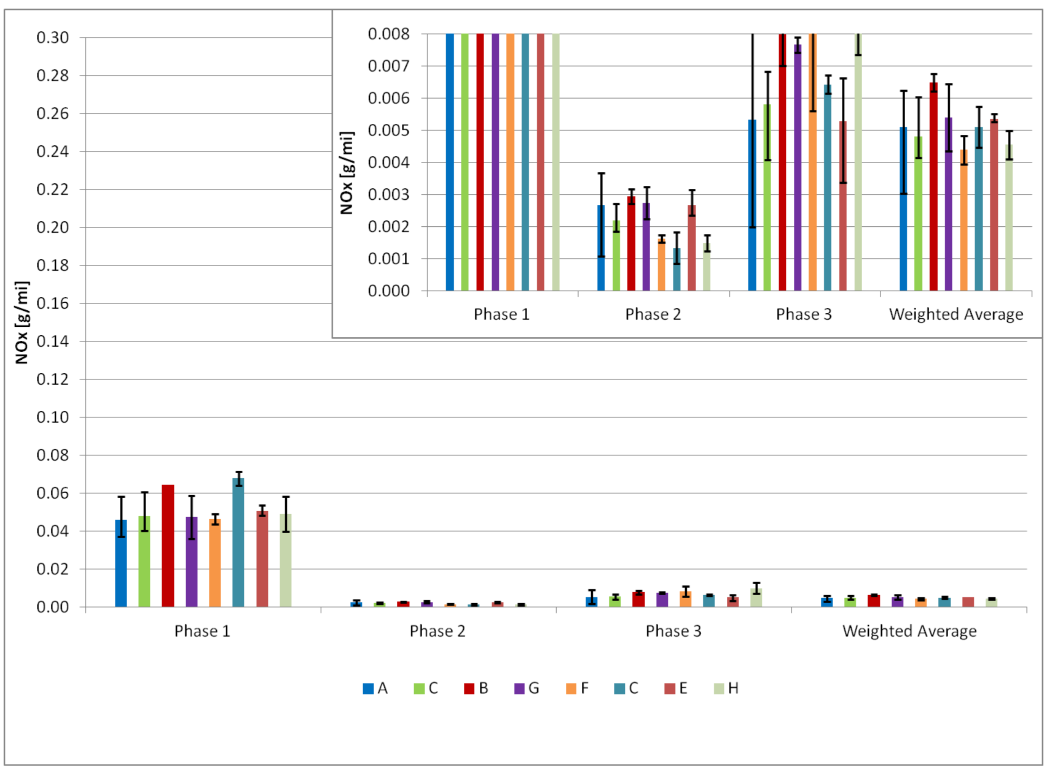


FIGURE E-48. NO_X EMISSIONS FOR VEHICLE L

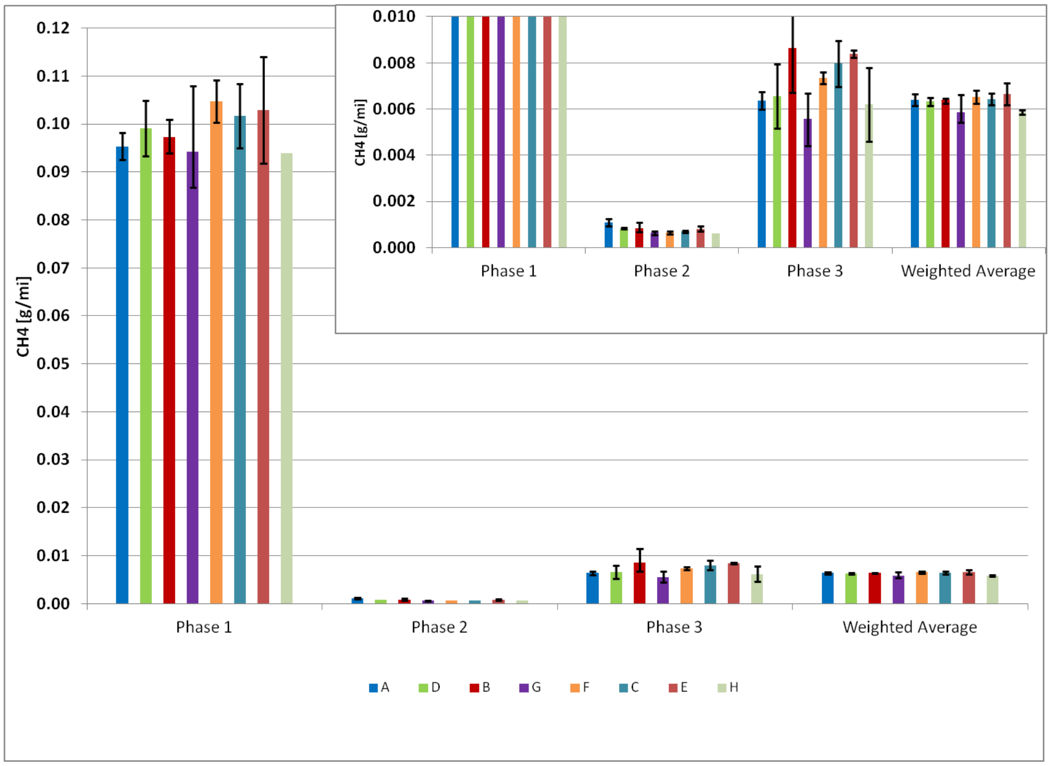


FIGURE E-49. CH_4 EMISSIONS FOR VEHICLE A

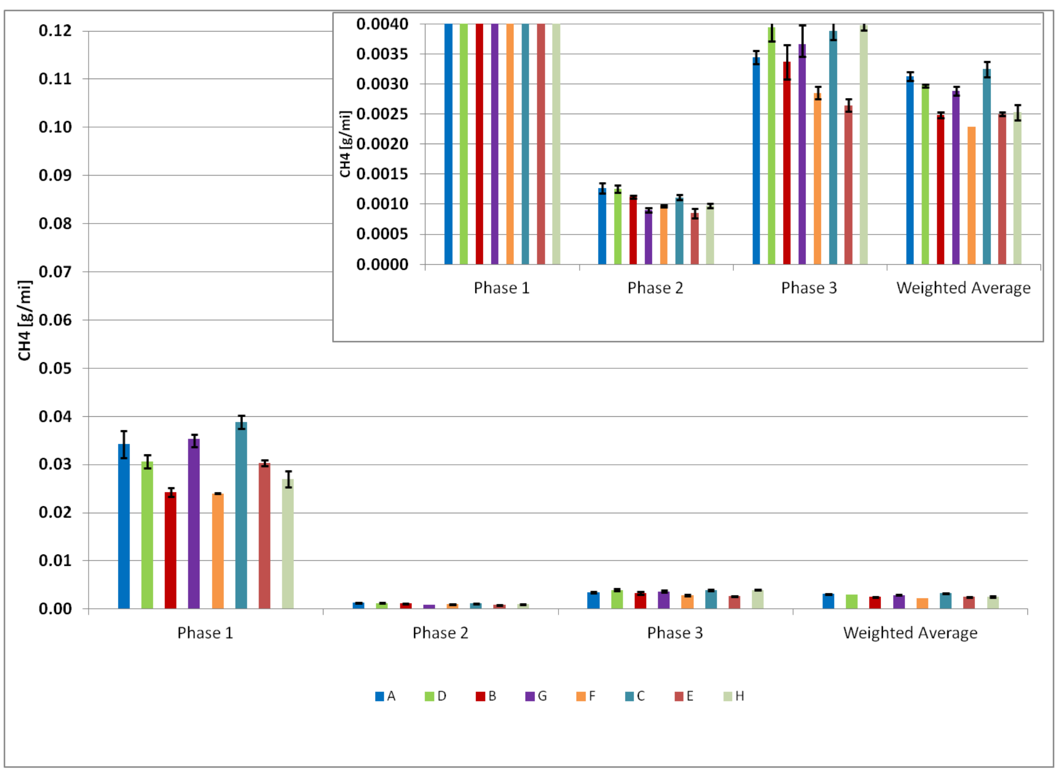


FIGURE E-50. CH_4 EMISSIONS FOR VEHICLE B

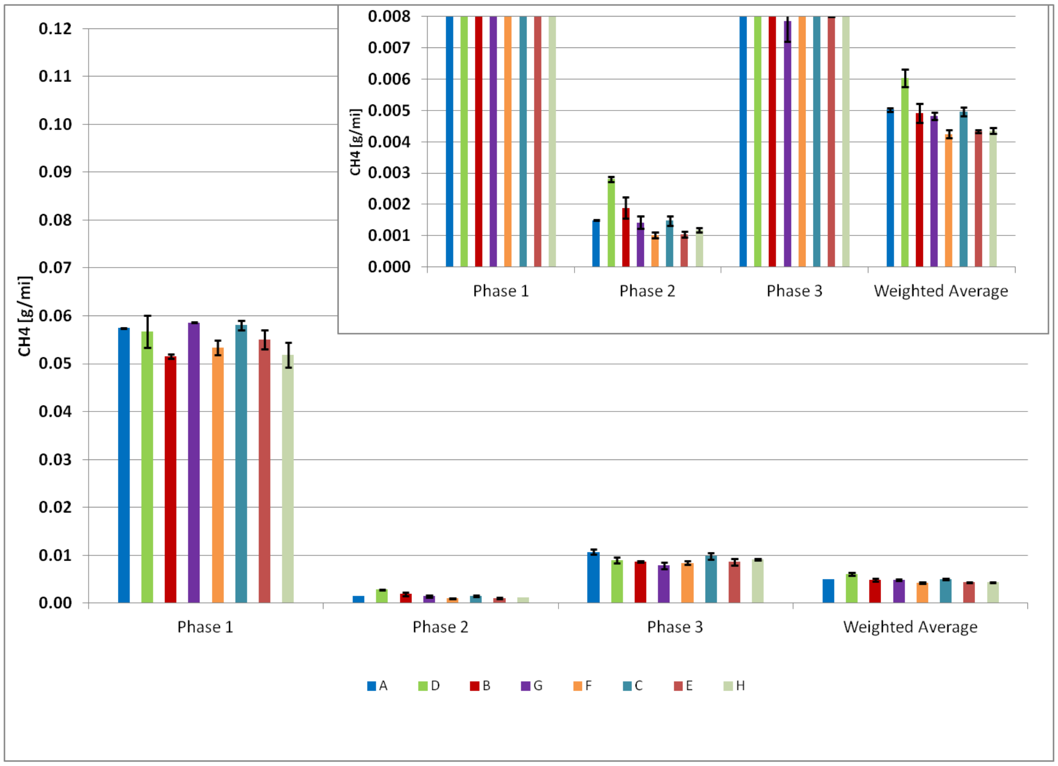


FIGURE E-51. CH_4 EMISSIONS FOR VEHICLE C

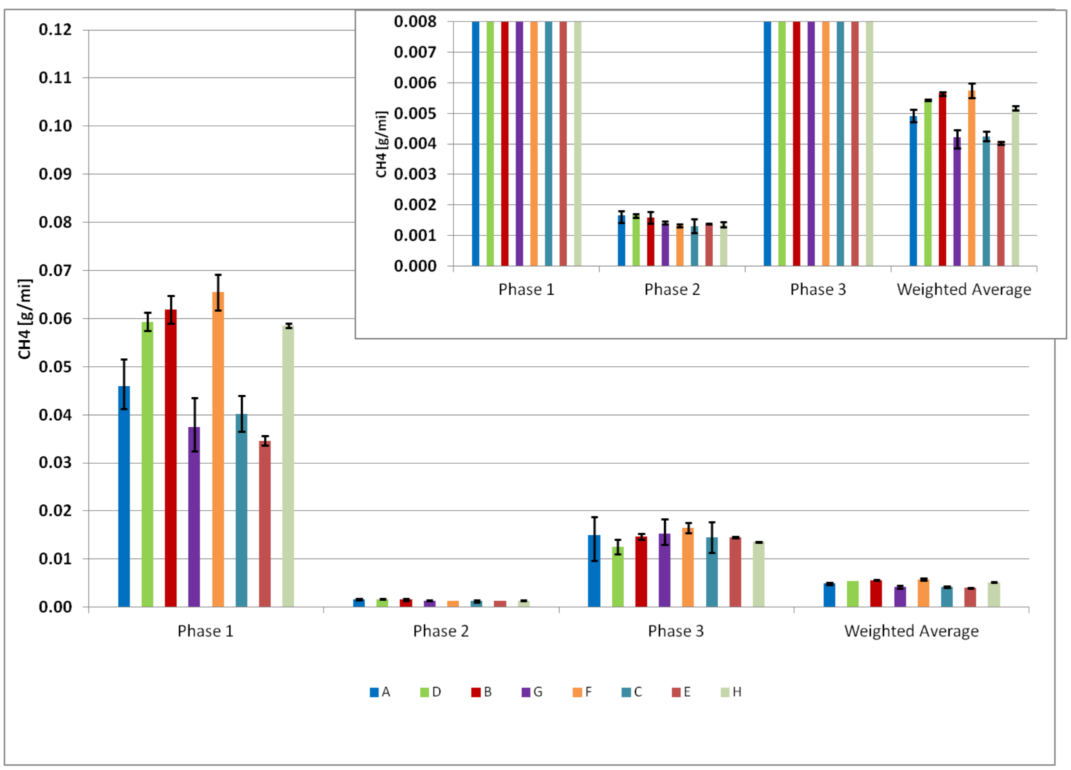


FIGURE E-52. CH_4 EMISSIONS FOR VEHICLE D

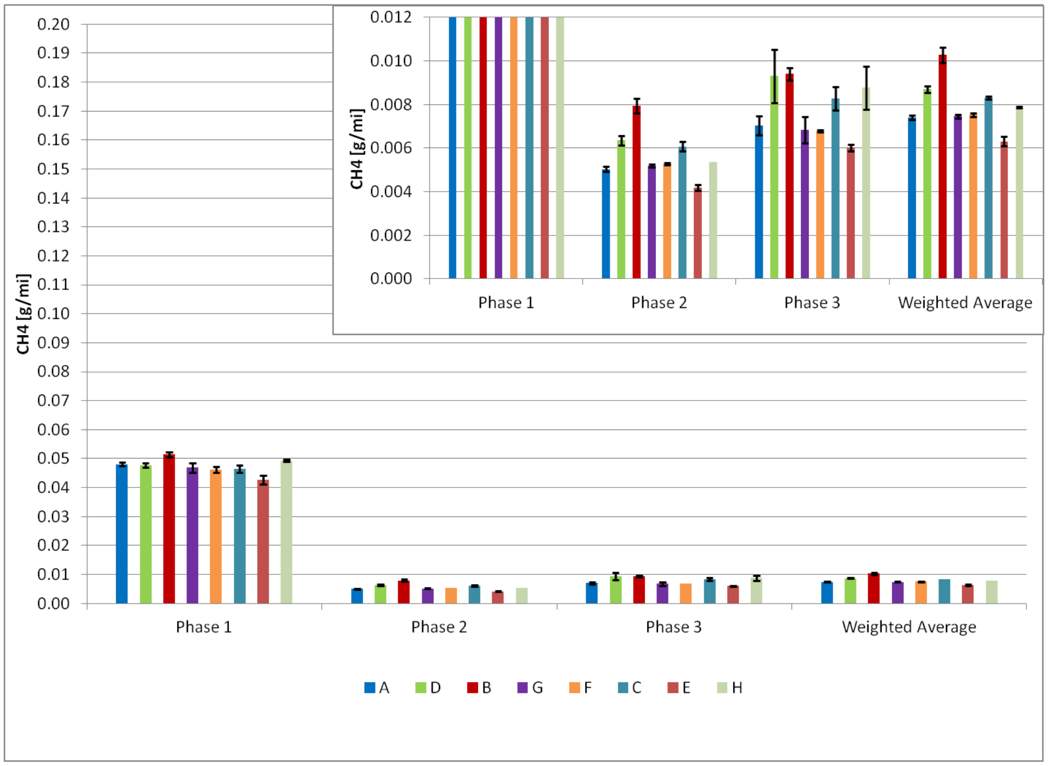


FIGURE E-53. CH_4 EMISSIONS FOR VEHICLE E

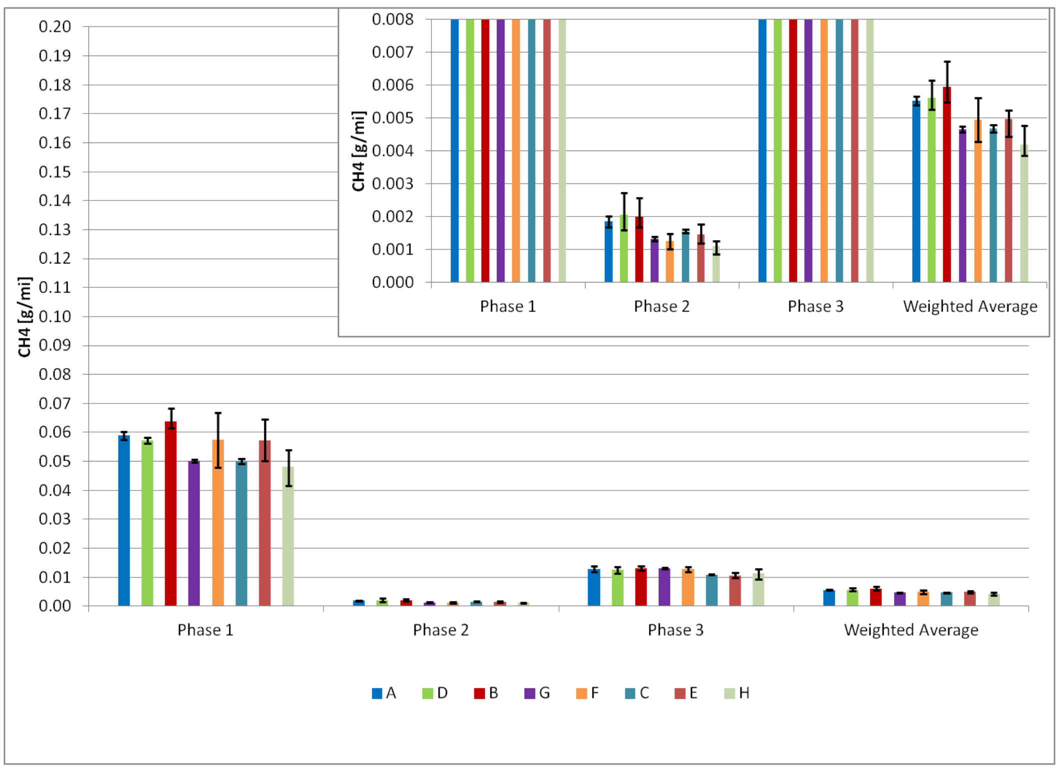


FIGURE E-54. CH_4 EMISSIONS FOR VEHICLE F

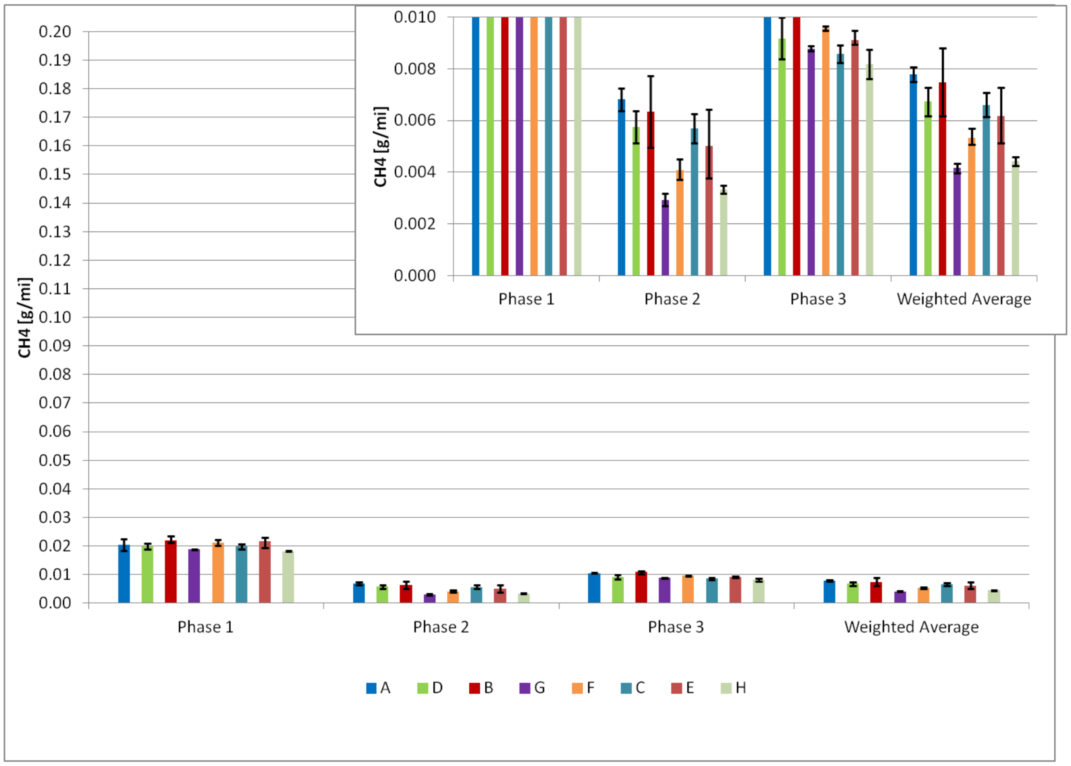


FIGURE E-55. CH_4 EMISSIONS FOR VEHICLE G

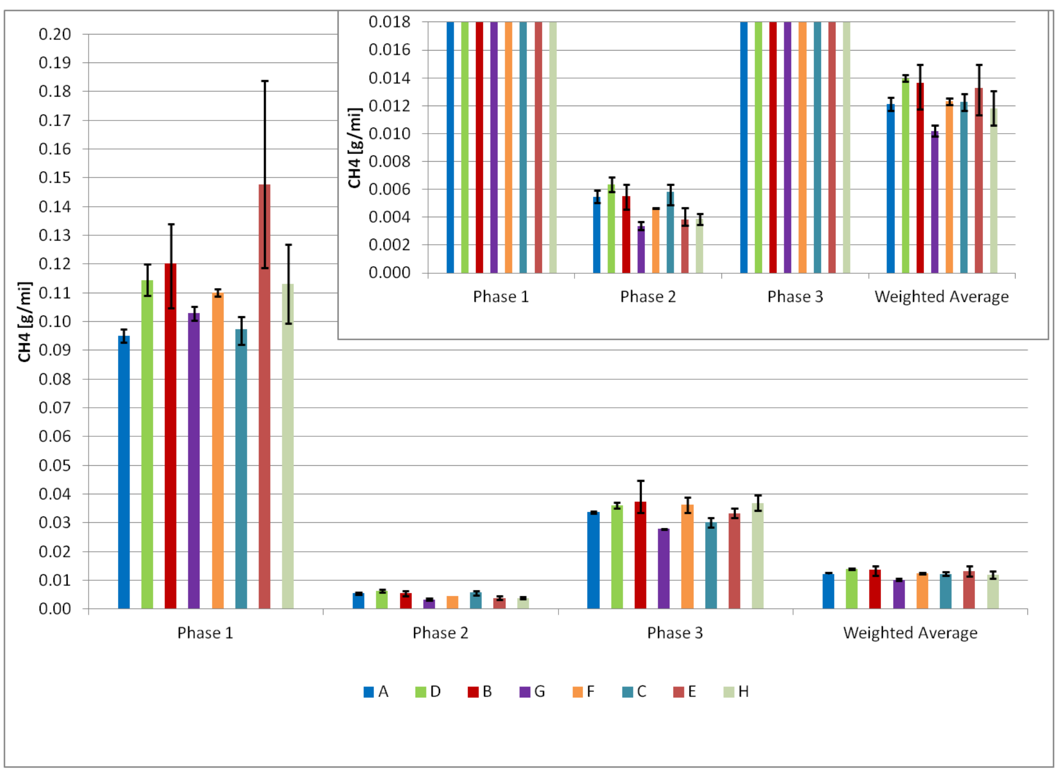


FIGURE E-56. CH_4 EMISSIONS FOR VEHICLE H

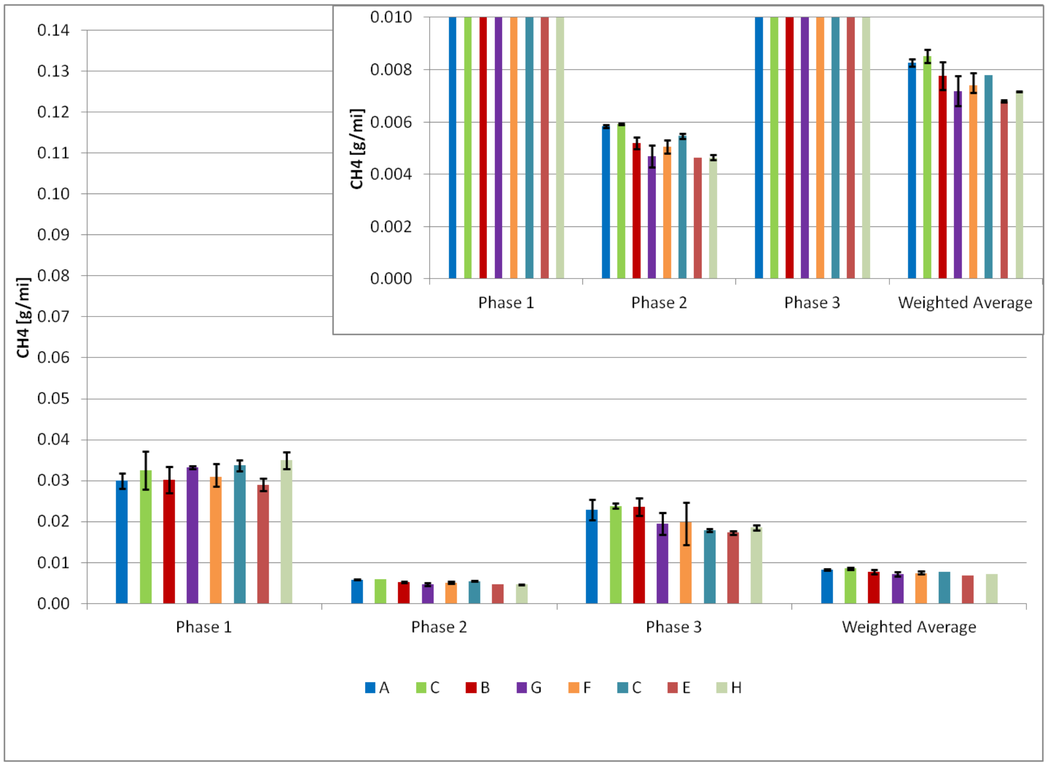


FIGURE E-57. CH_4 EMISSIONS FOR VEHICLE I

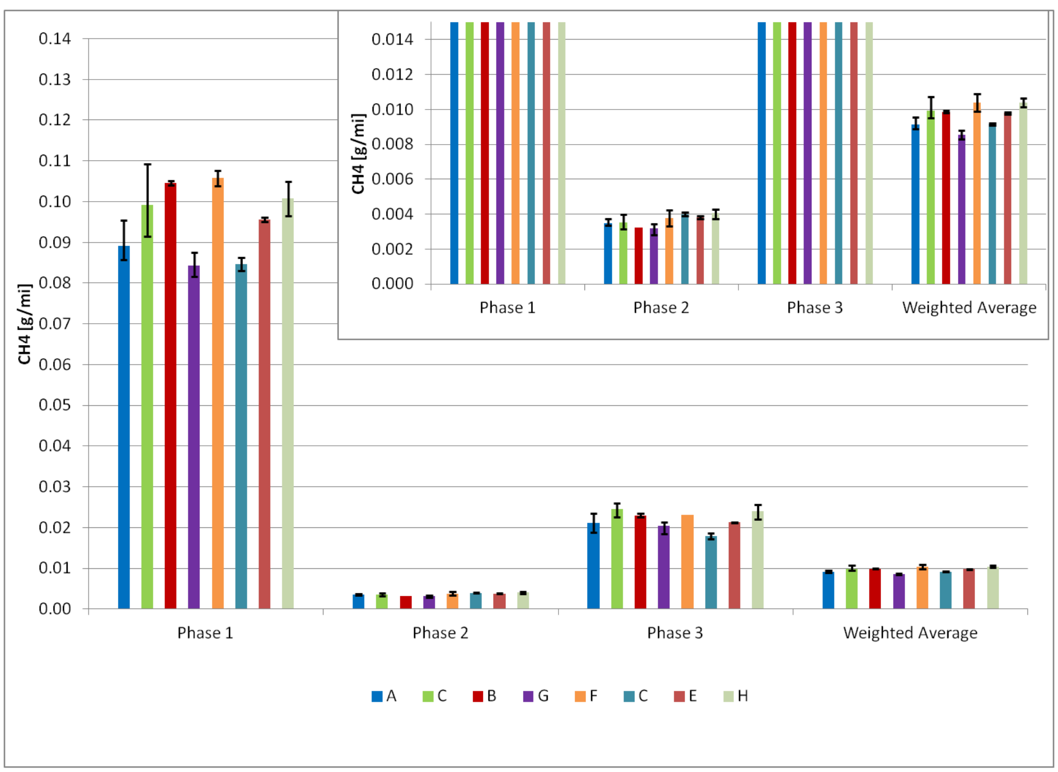


FIGURE E-58. CH_4 EMISSIONS FOR VEHICLE J

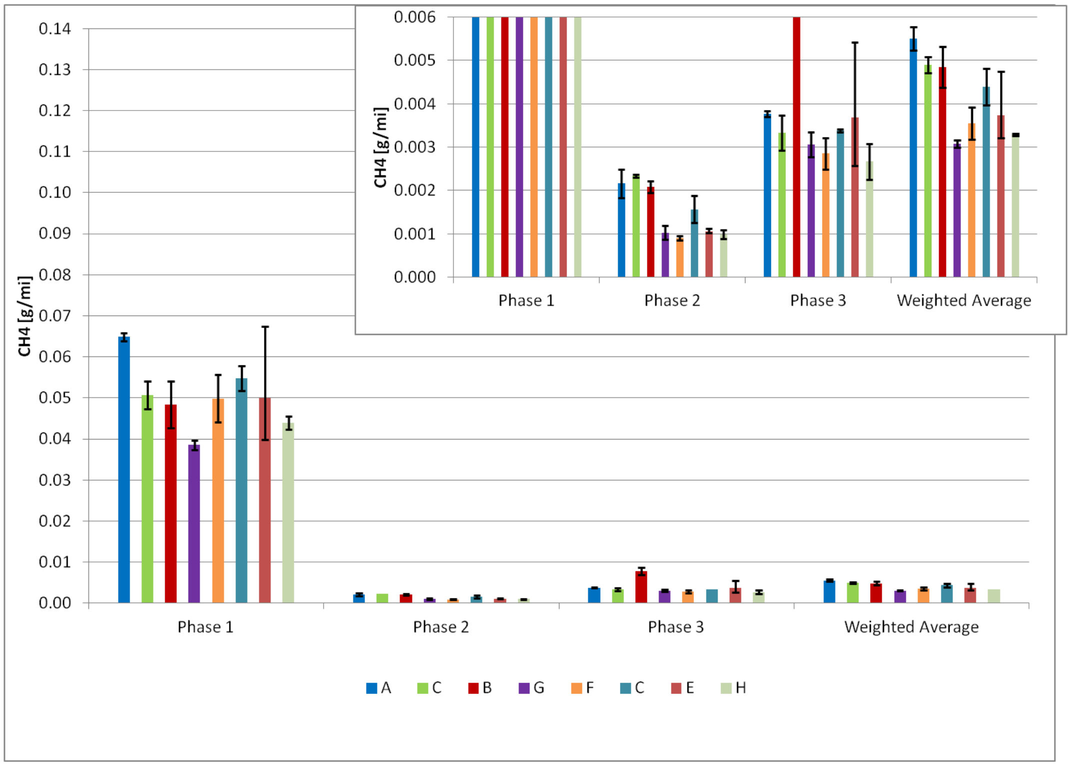


FIGURE E-59. CH_4 EMISSIONS FOR VEHICLE K

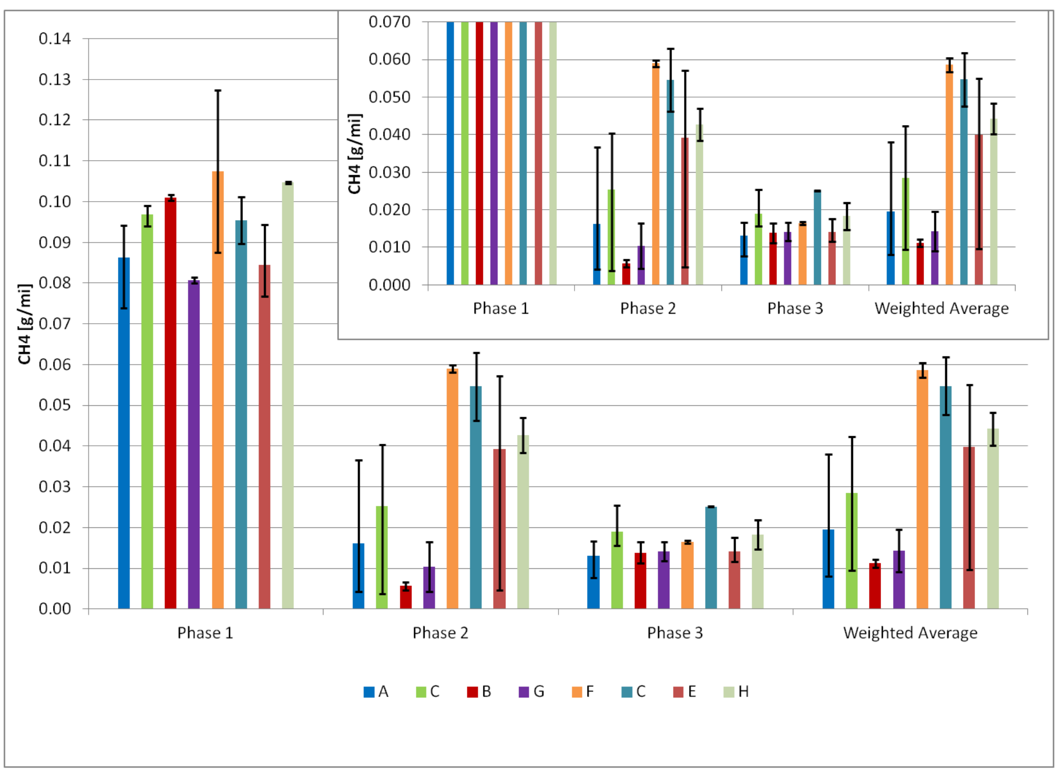


FIGURE E-60. CH_4 EMISSIONS FOR VEHICLE L

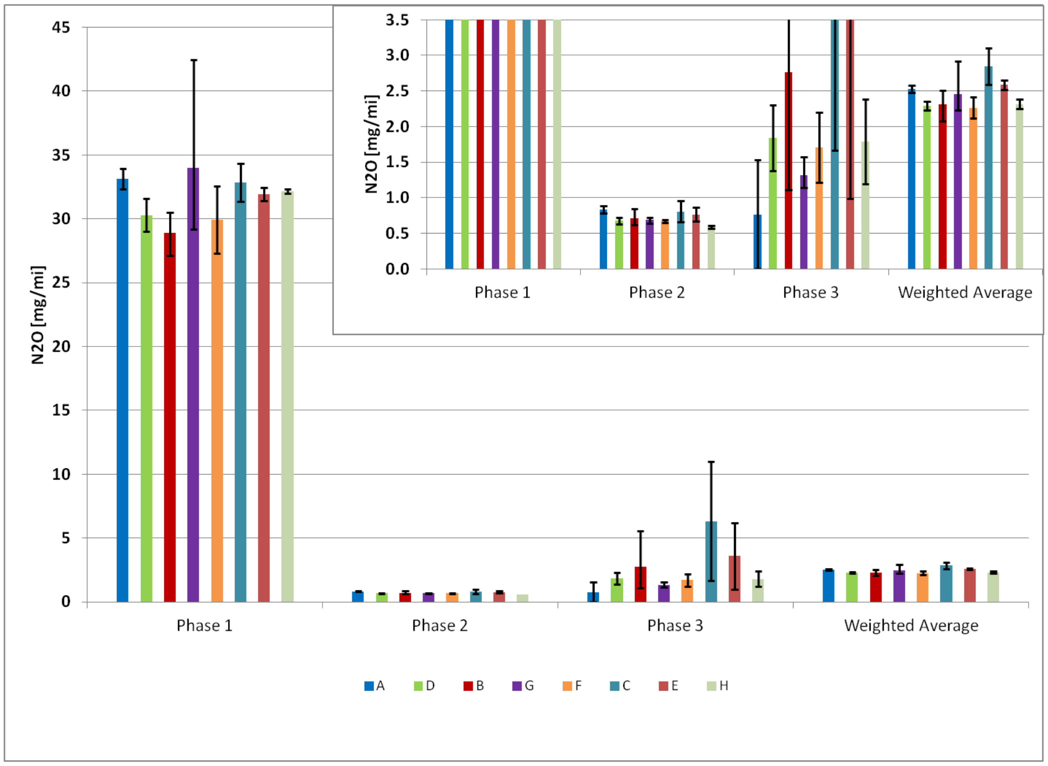


FIGURE E-61. N_2O EMISSIONS FOR VEHICLE A

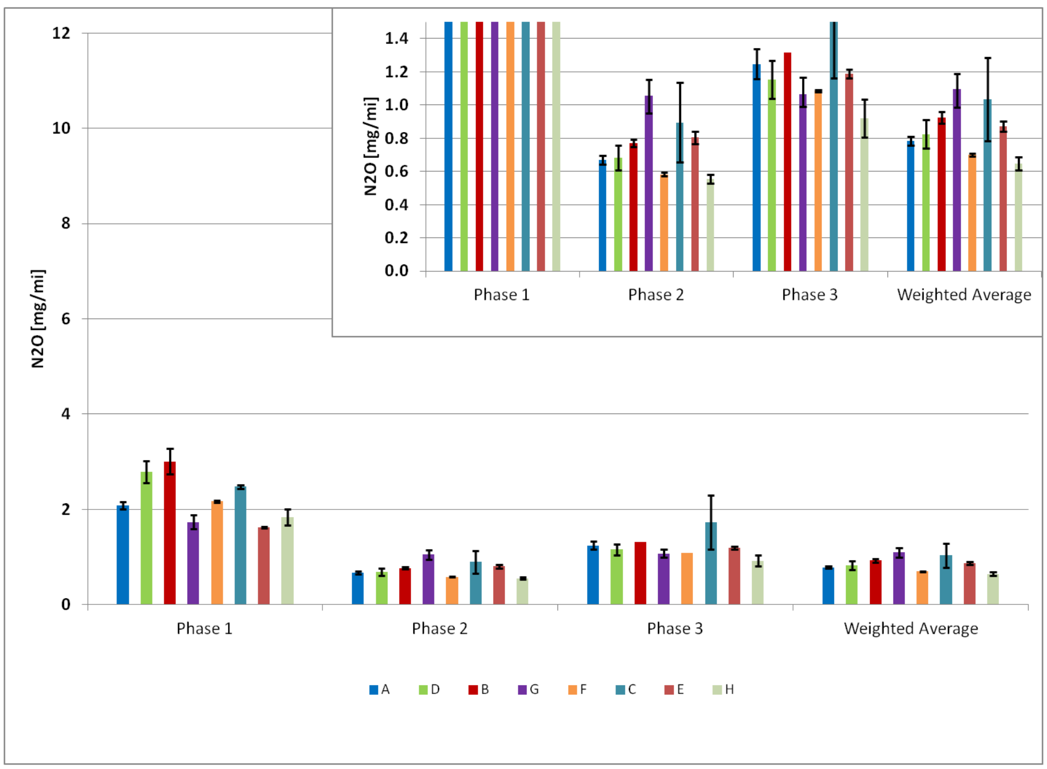


FIGURE E-62. N_2O EMISSIONS FOR VEHICLE B

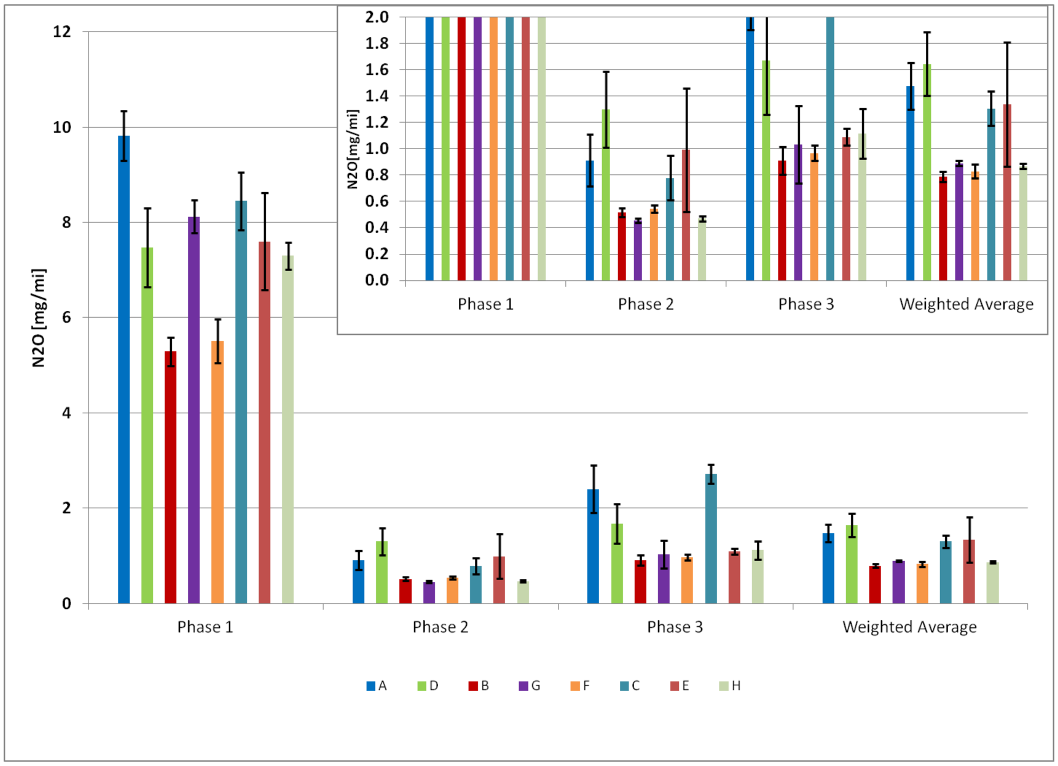


FIGURE E-63. N_2O EMISSIONS FOR VEHICLE C

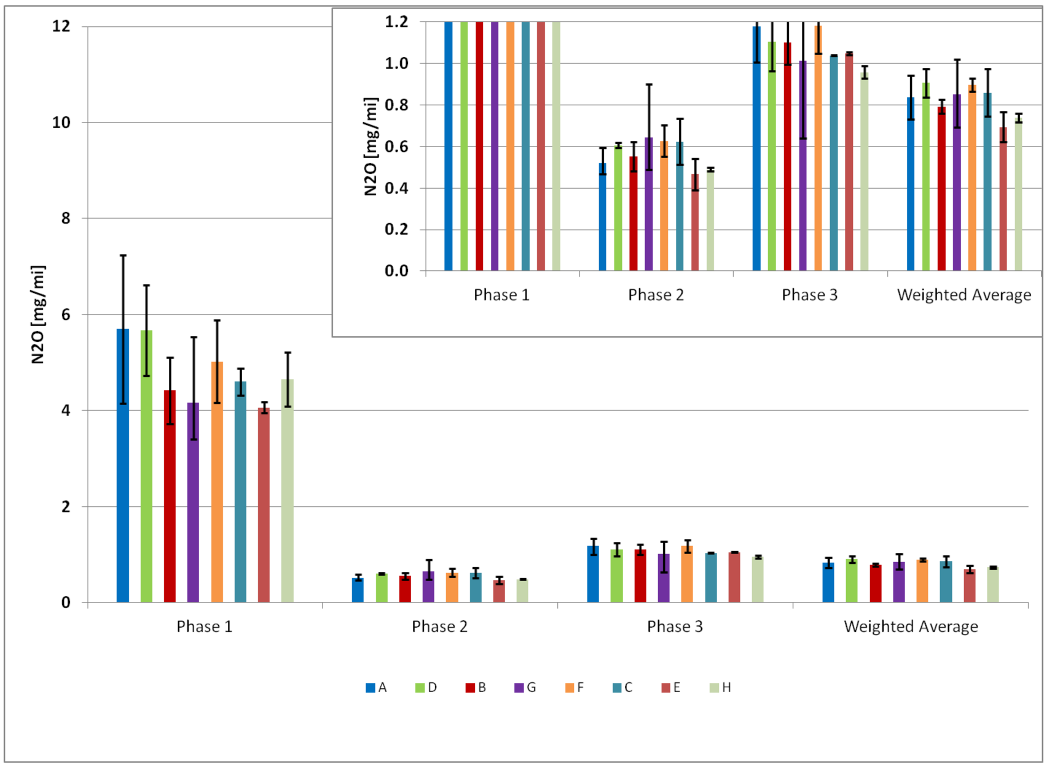


FIGURE E-64. N_2O EMISSIONS FOR VEHICLE D

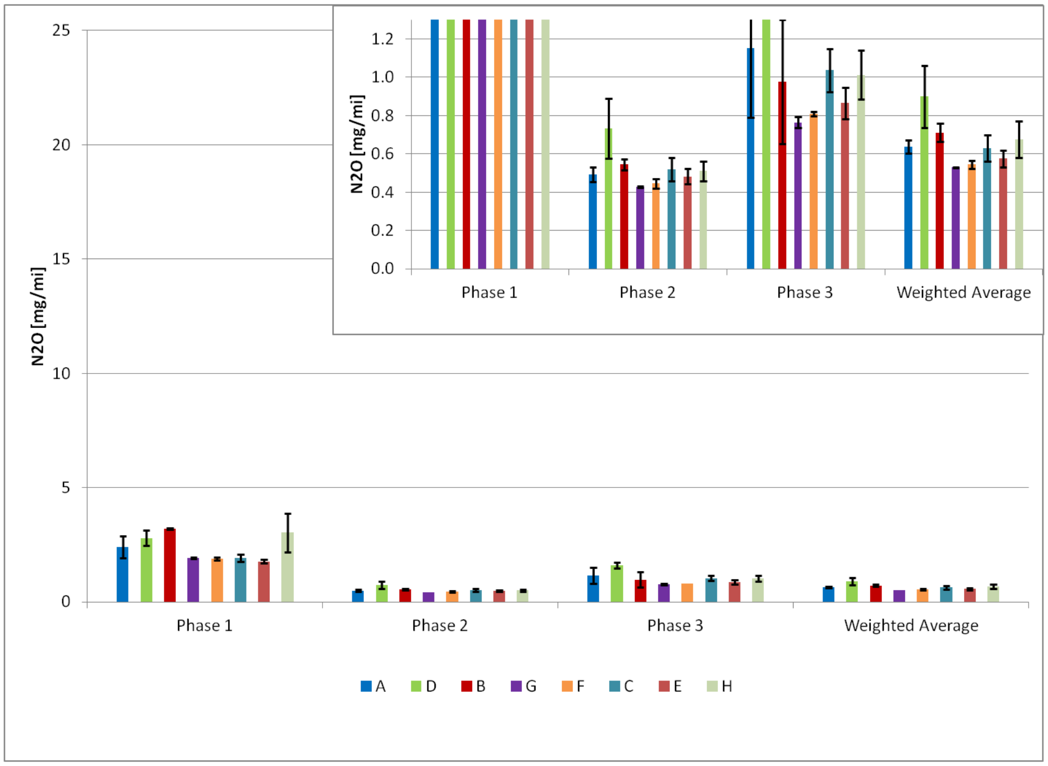


FIGURE E-65. N_2O EMISSIONS FOR VEHICLE E

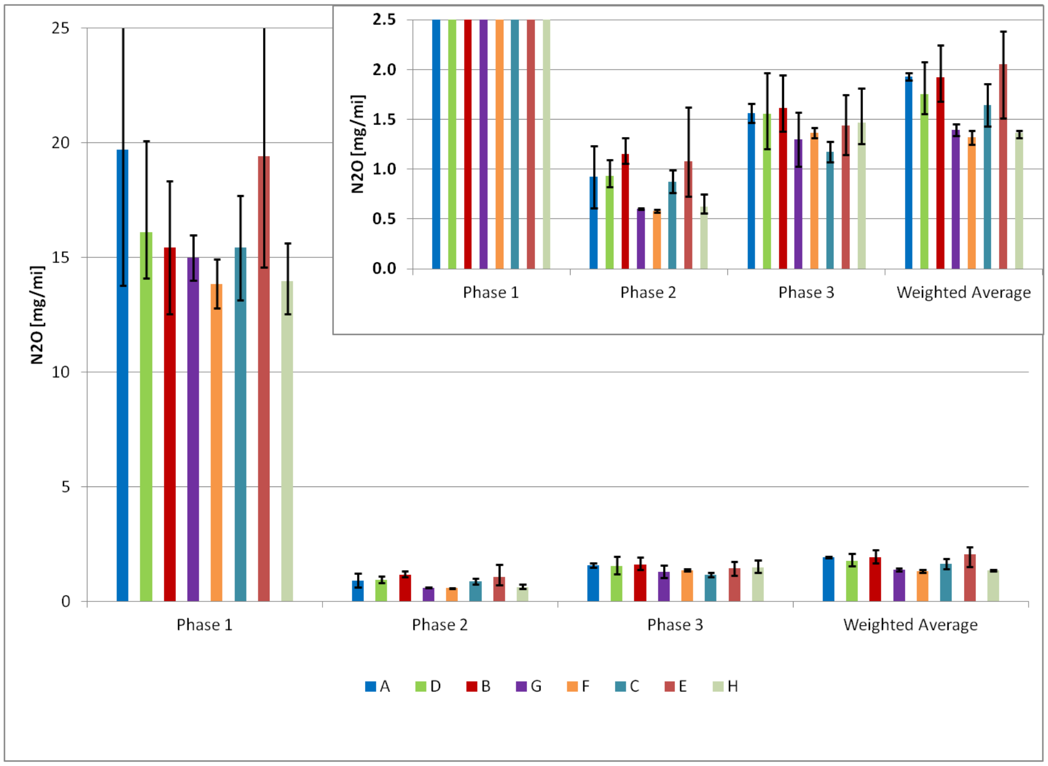


FIGURE E-66. N_2O EMISSIONS FOR VEHICLE F

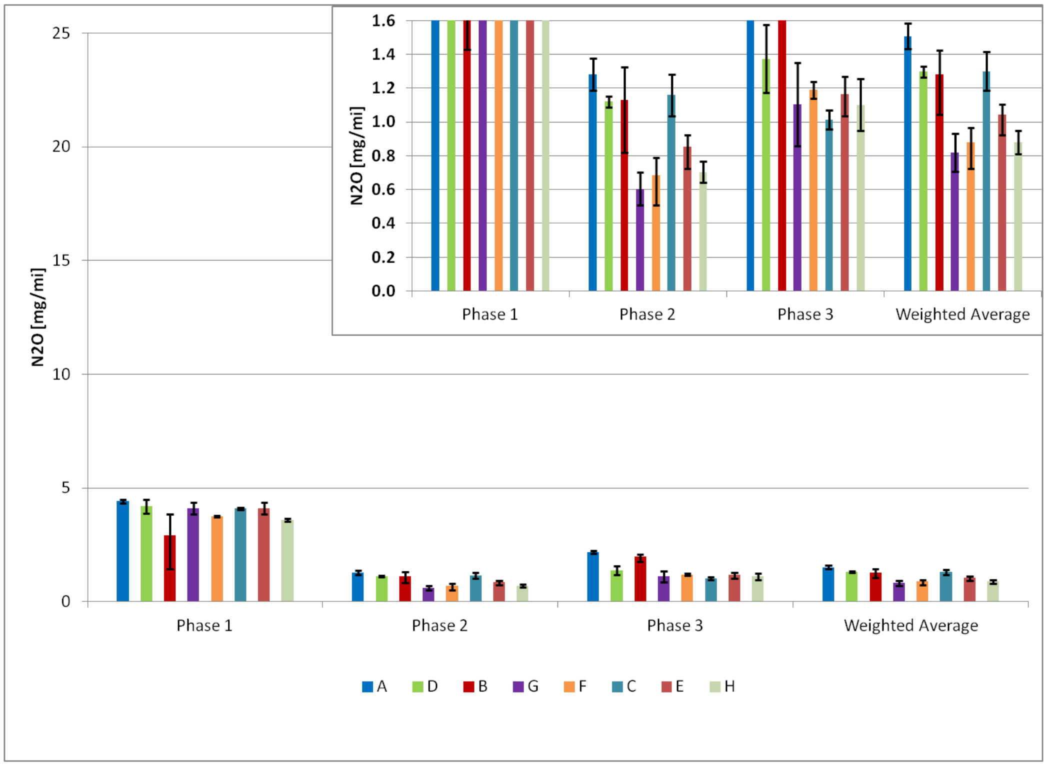


FIGURE E-67. N_2O EMISSIONS FOR VEHICLE G

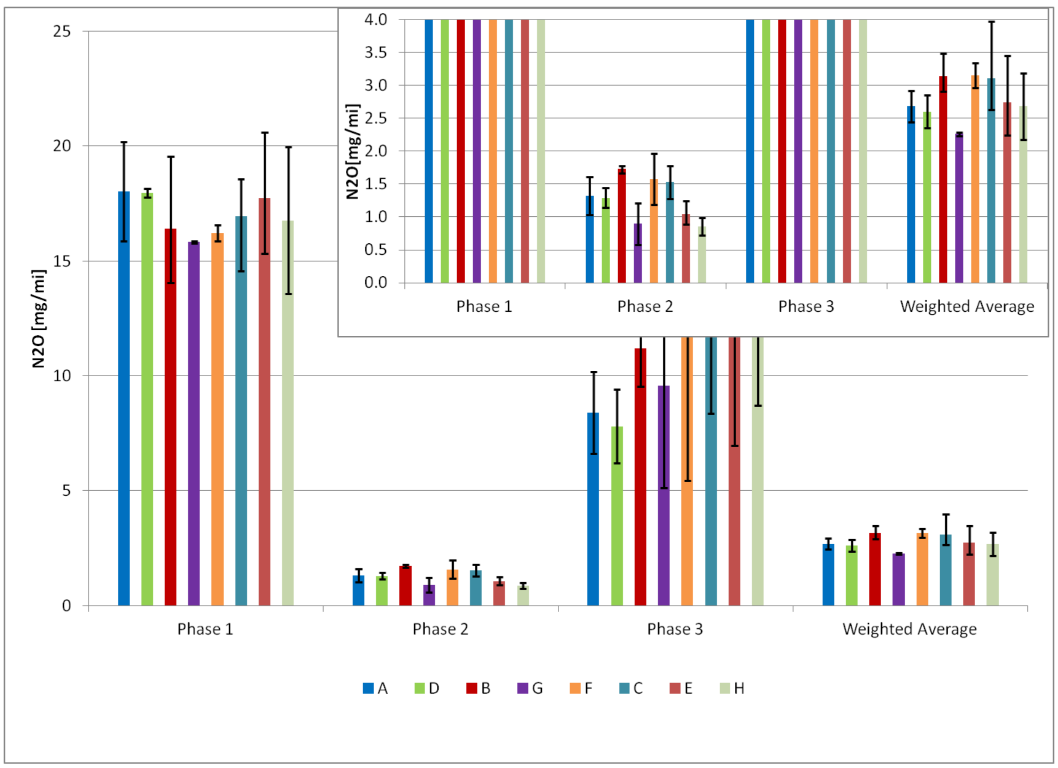


FIGURE E-68. N_2O EMISSIONS FOR VEHICLE H

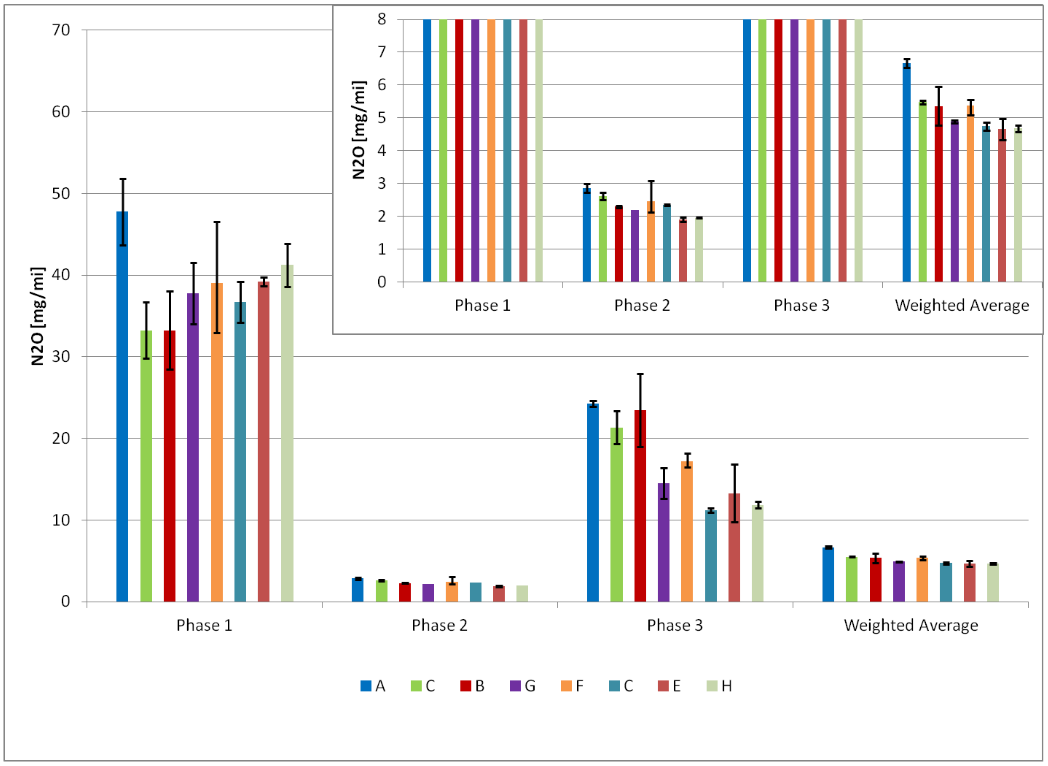


FIGURE E-69. N_2O EMISSIONS FOR VEHICLE I

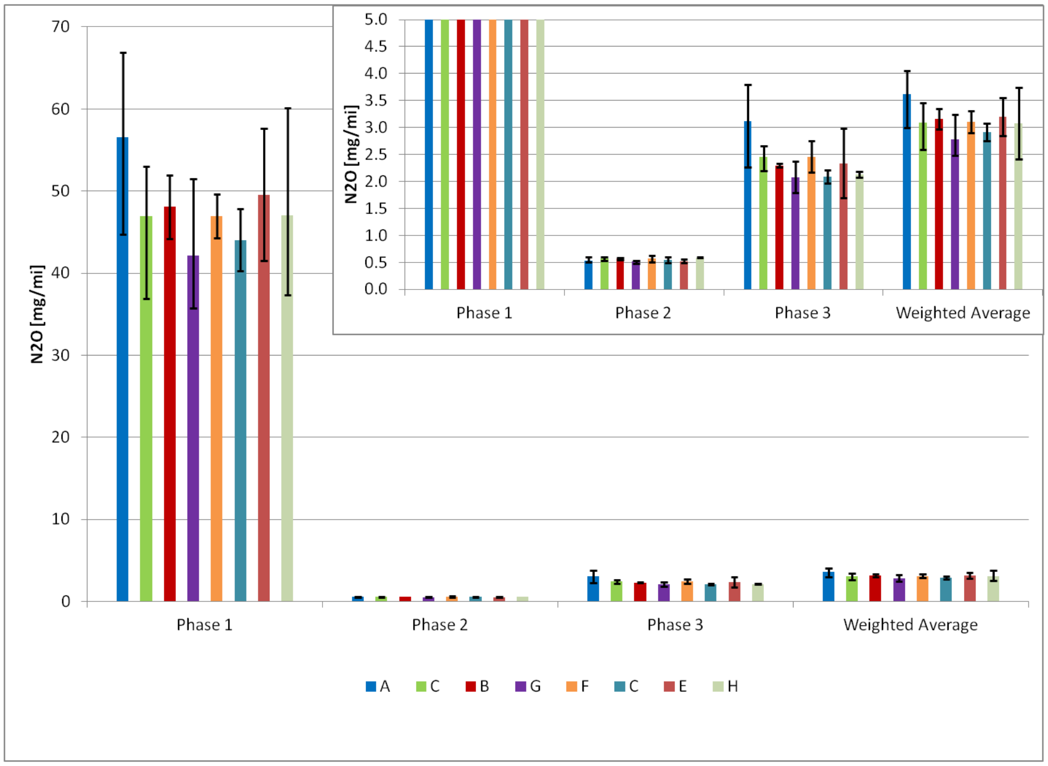


FIGURE E-70. N_2O EMISSIONS FOR VEHICLE J

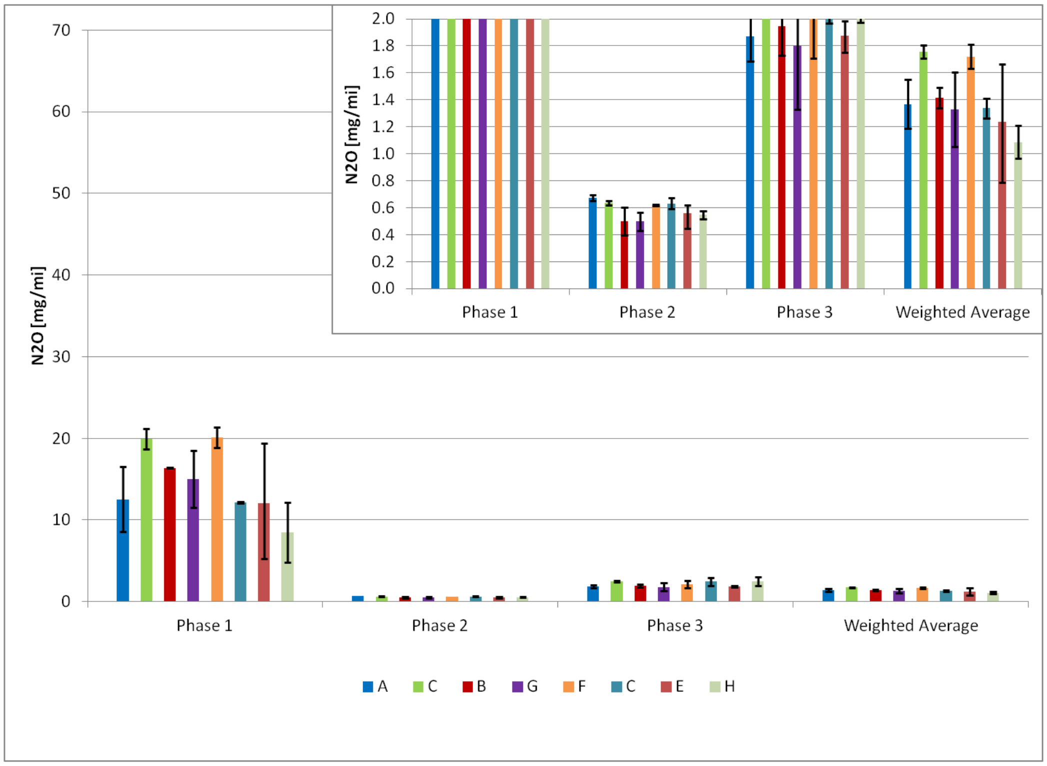


FIGURE E-71. N_2O EMISSIONS FOR VEHICLE K

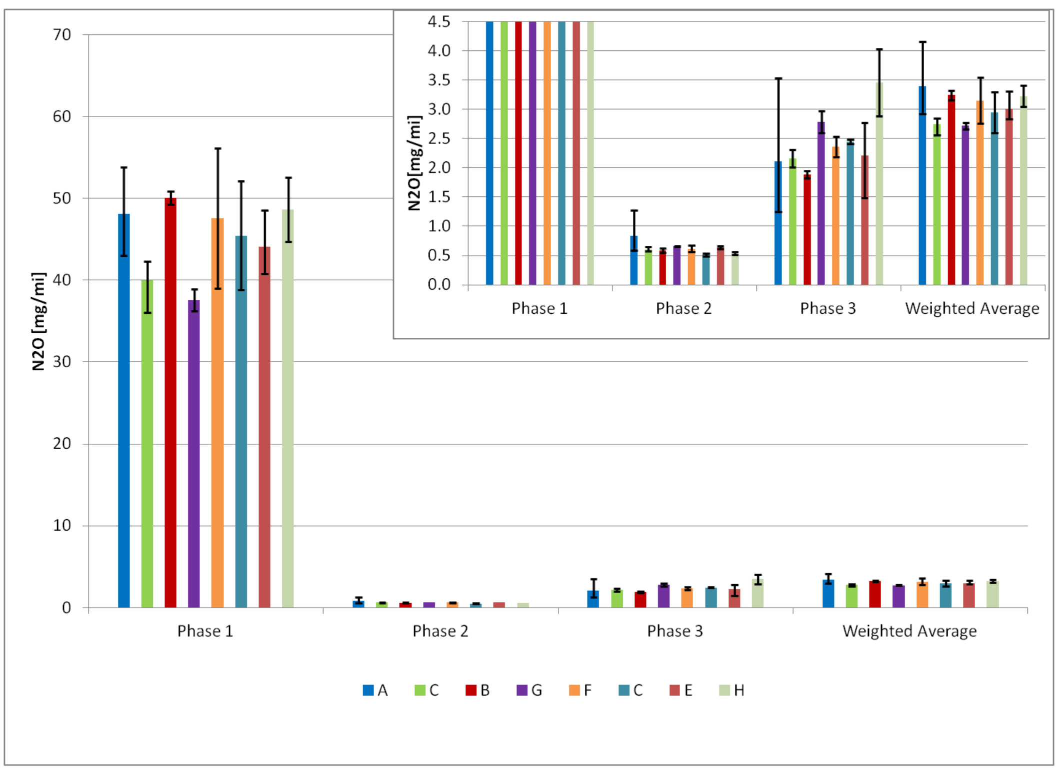


FIGURE E-72. N_2O EMISSIONS FOR VEHICLE L

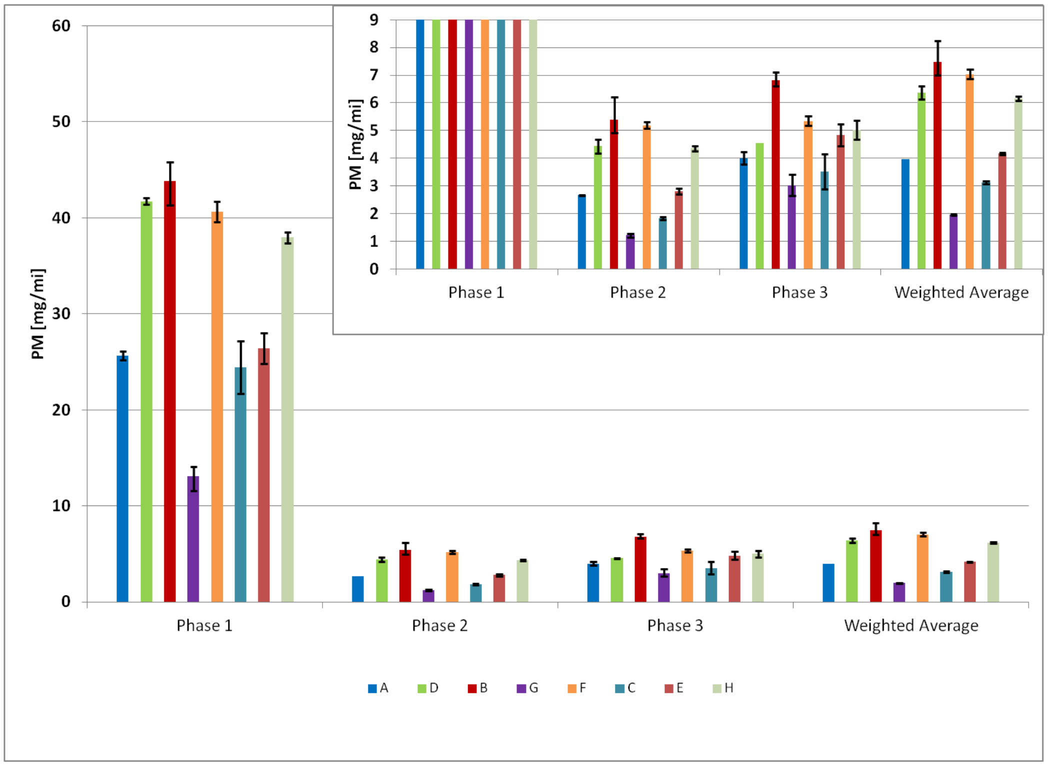


FIGURE E-73. PM EMISSIONS FOR VEHICLE A

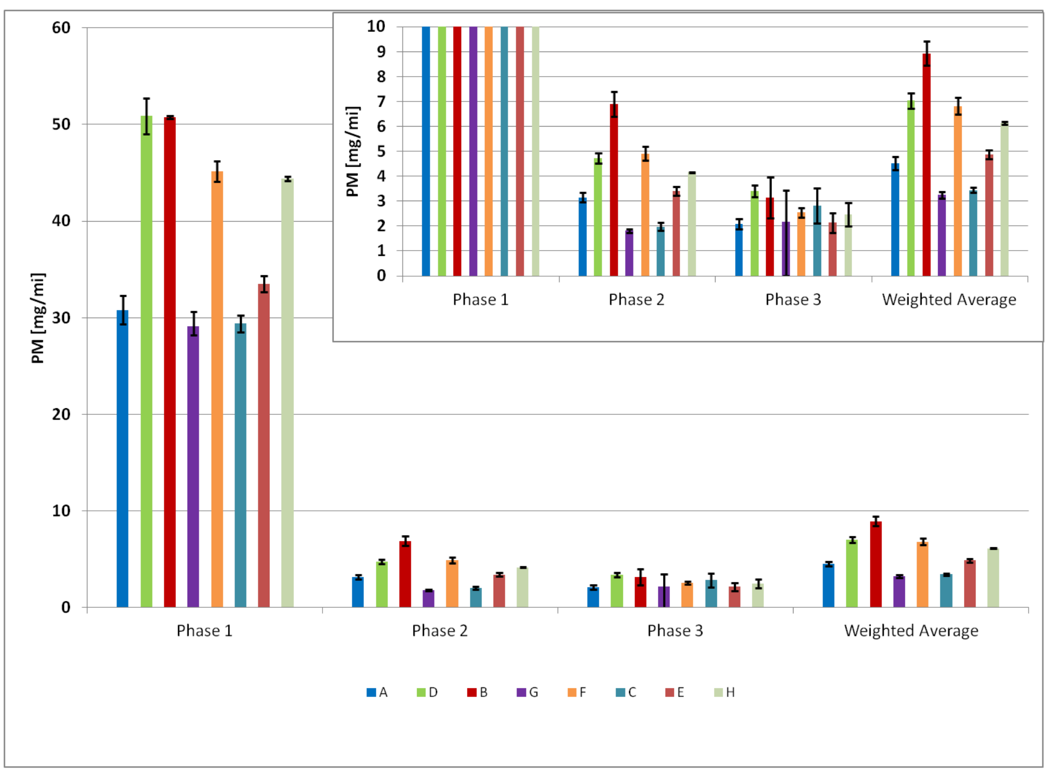


FIGURE E-74. PM EMISSIONS FOR VEHICLE B

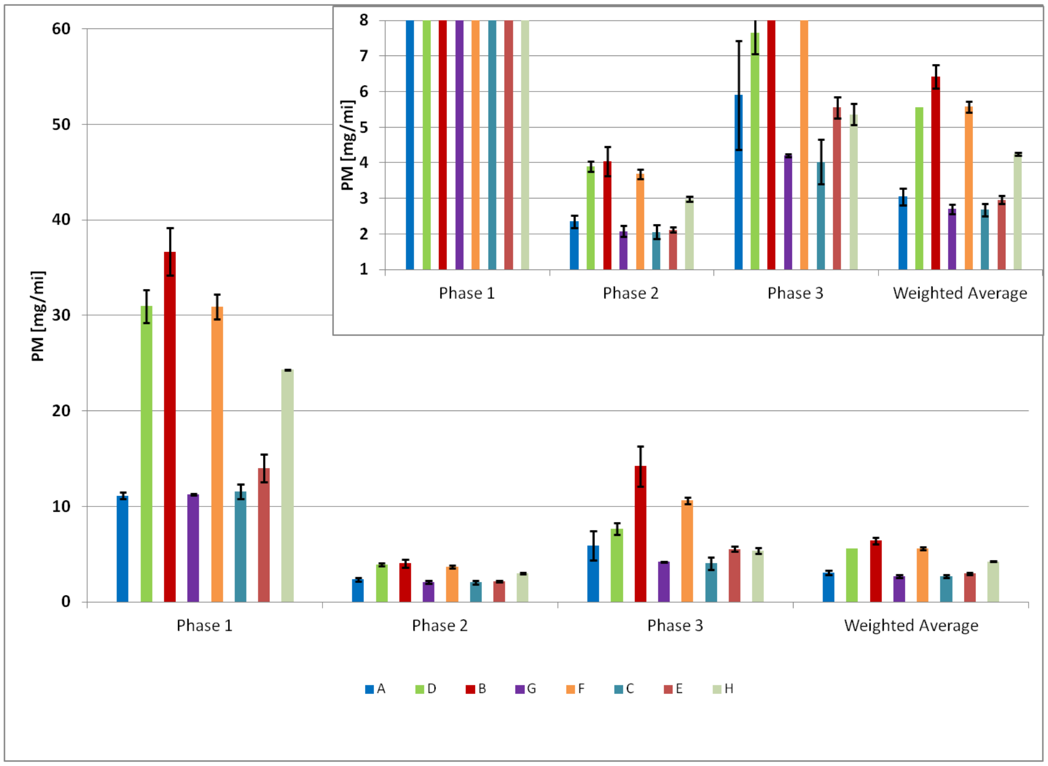


FIGURE E-75. PM EMISSIONS FOR VEHICLE C

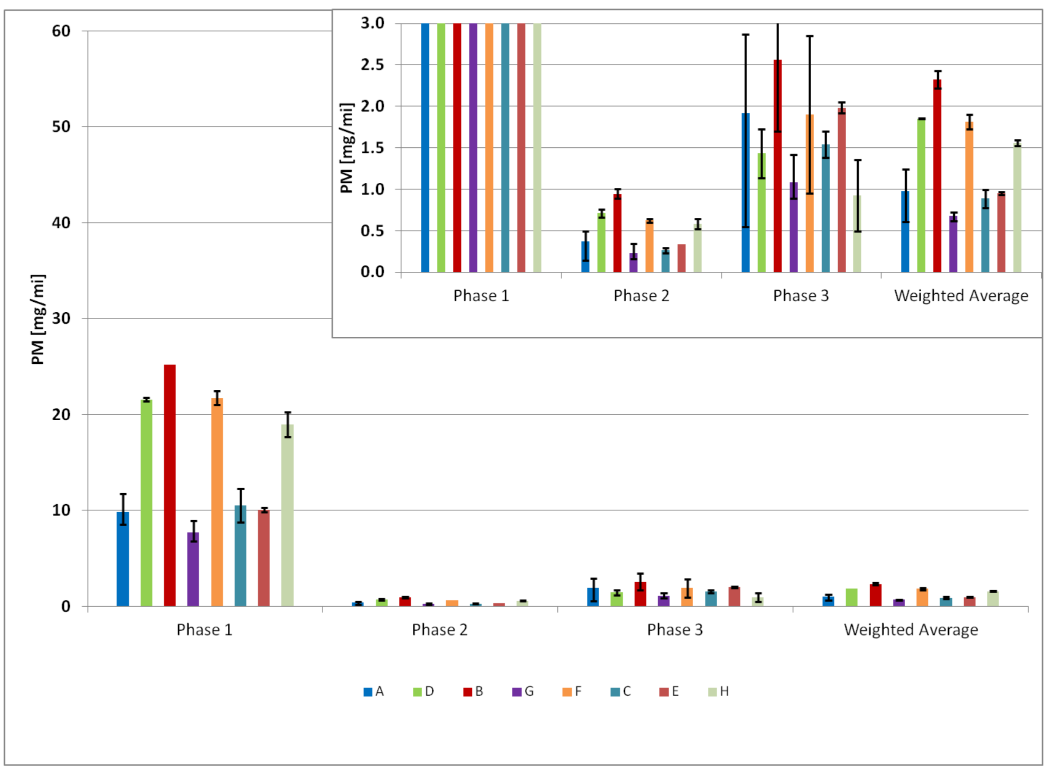


FIGURE E-76. PM EMISSIONS FOR VEHICLE D

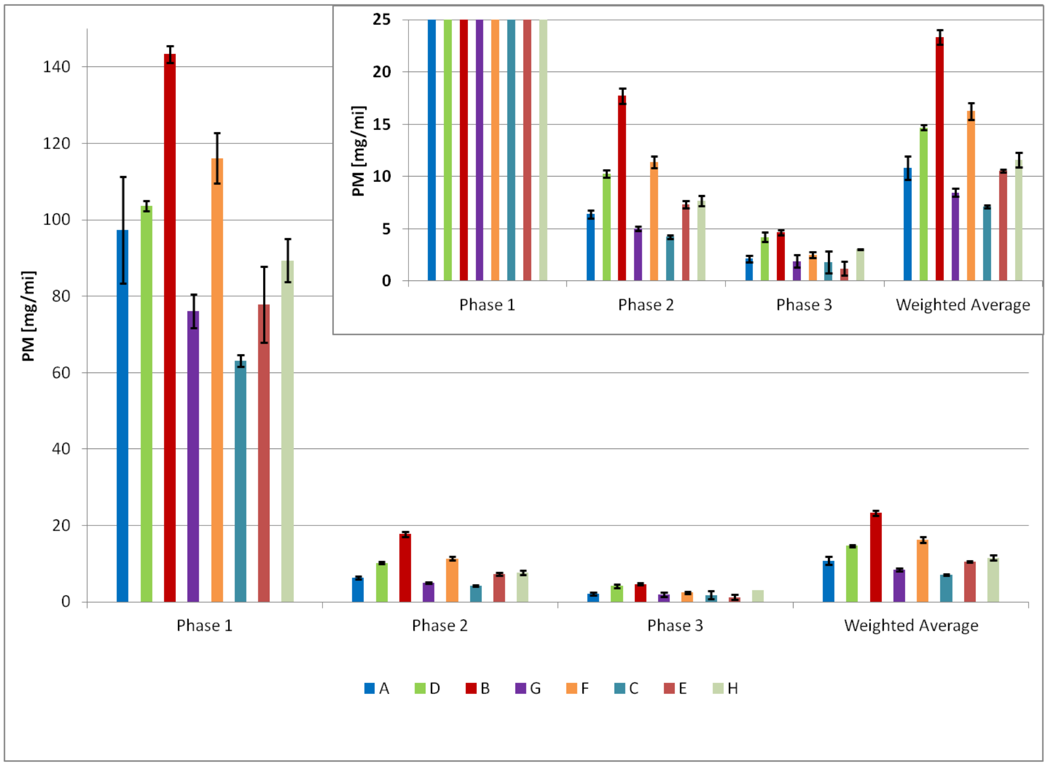


FIGURE E-77. PM EMISSIONS FOR VEHICLE E

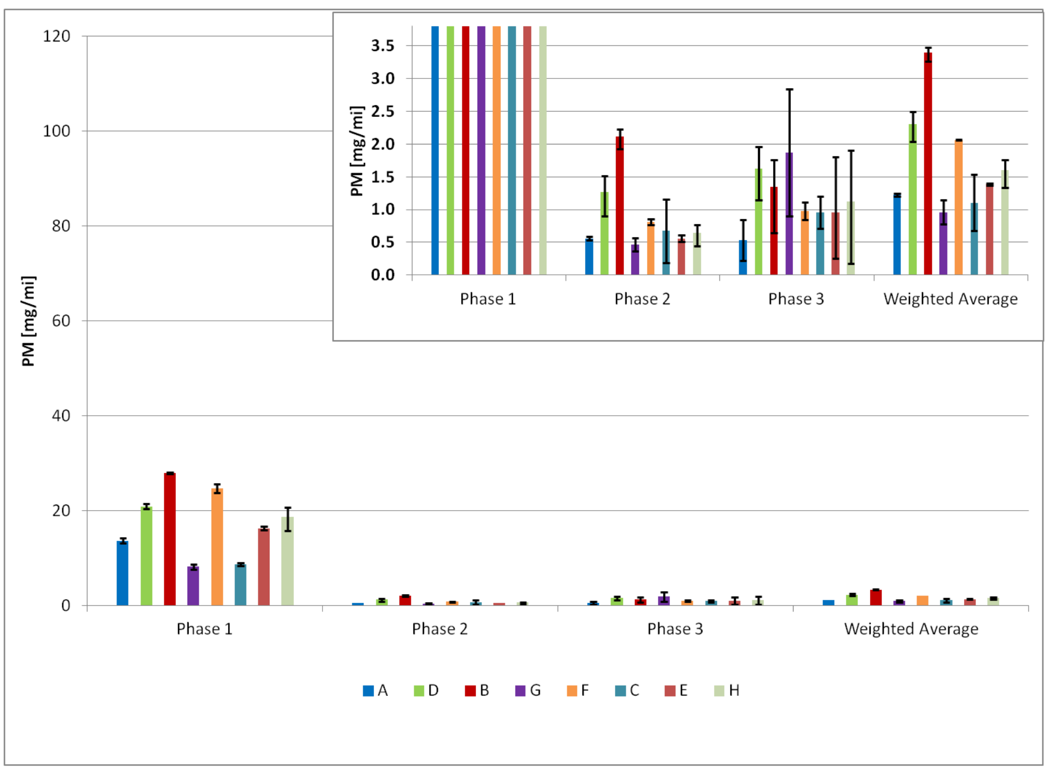


FIGURE E-78. PM EMISSIONS FOR VEHICLE F

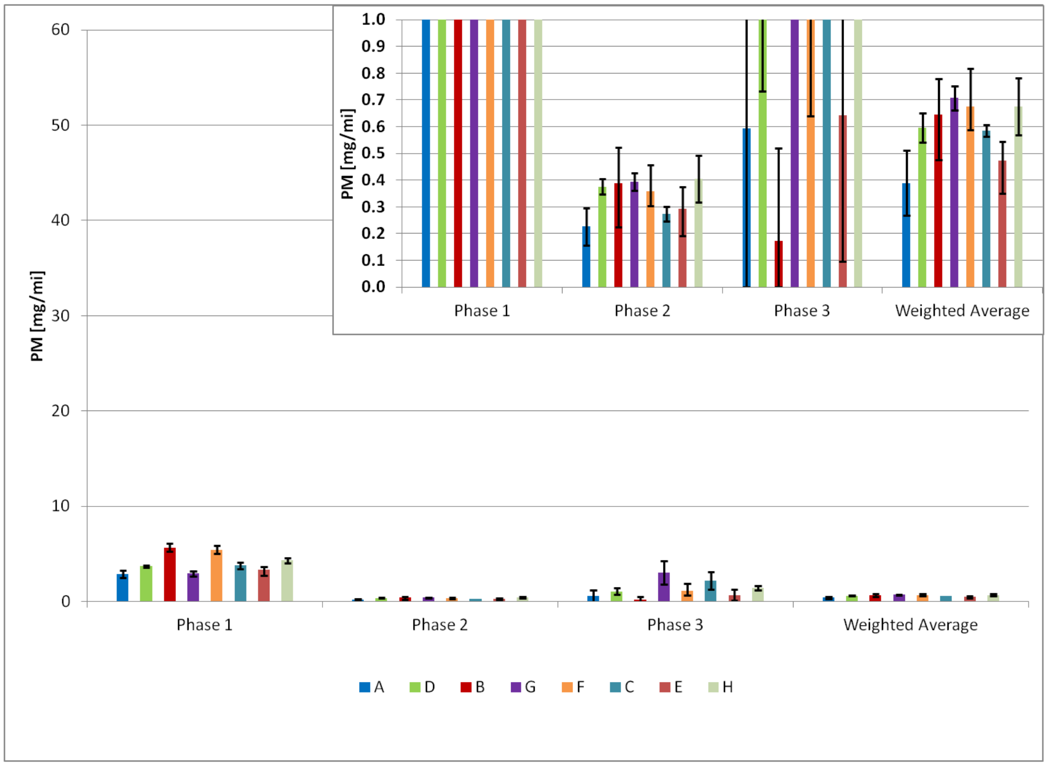


FIGURE E-79. PM EMISSIONS FOR VEHICLE G

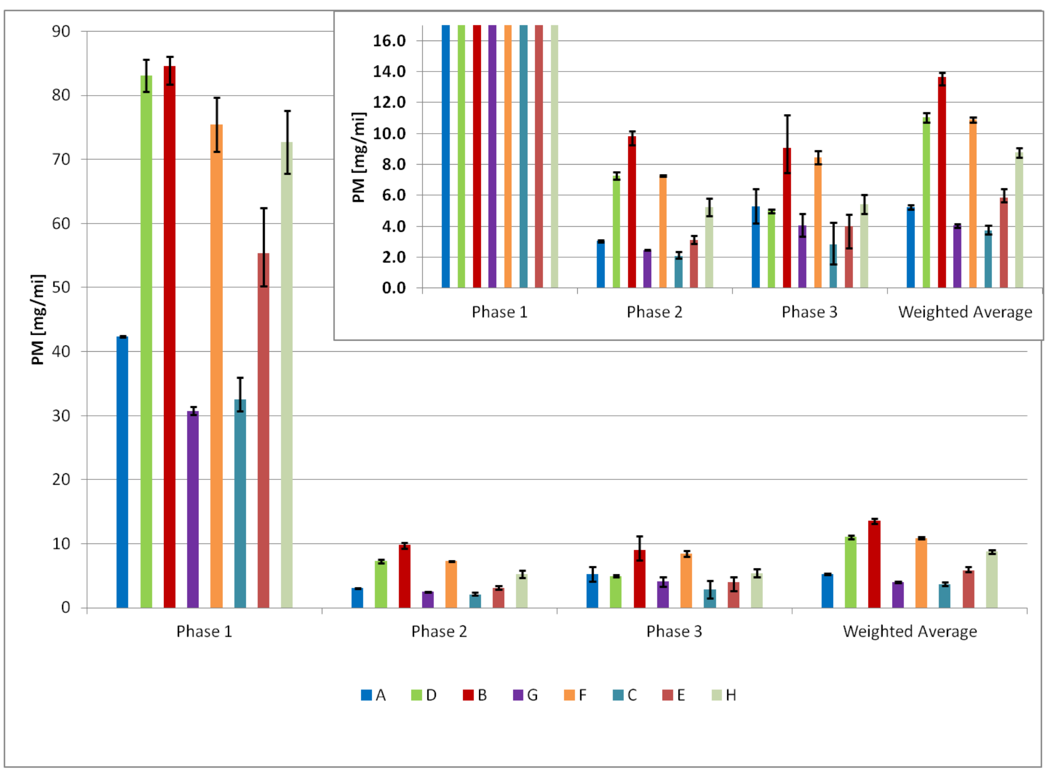


FIGURE E-80. PM EMISSIONS FOR VEHICLE H

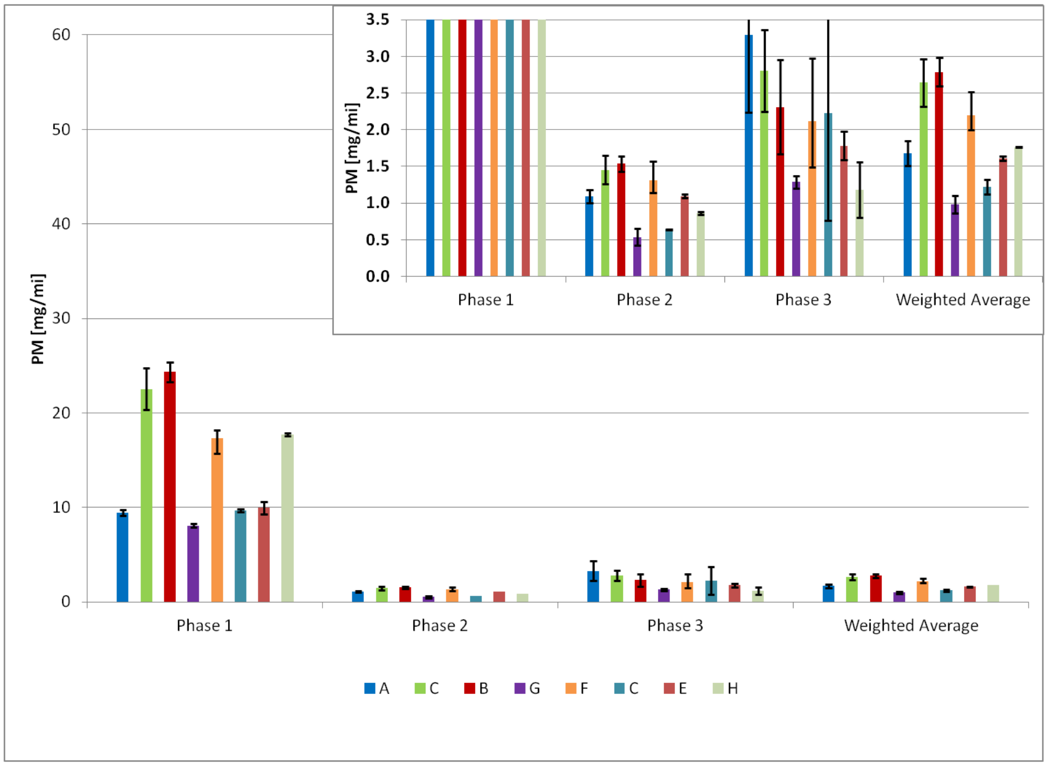


FIGURE E-81. PM EMISSIONS FOR VEHICLE I

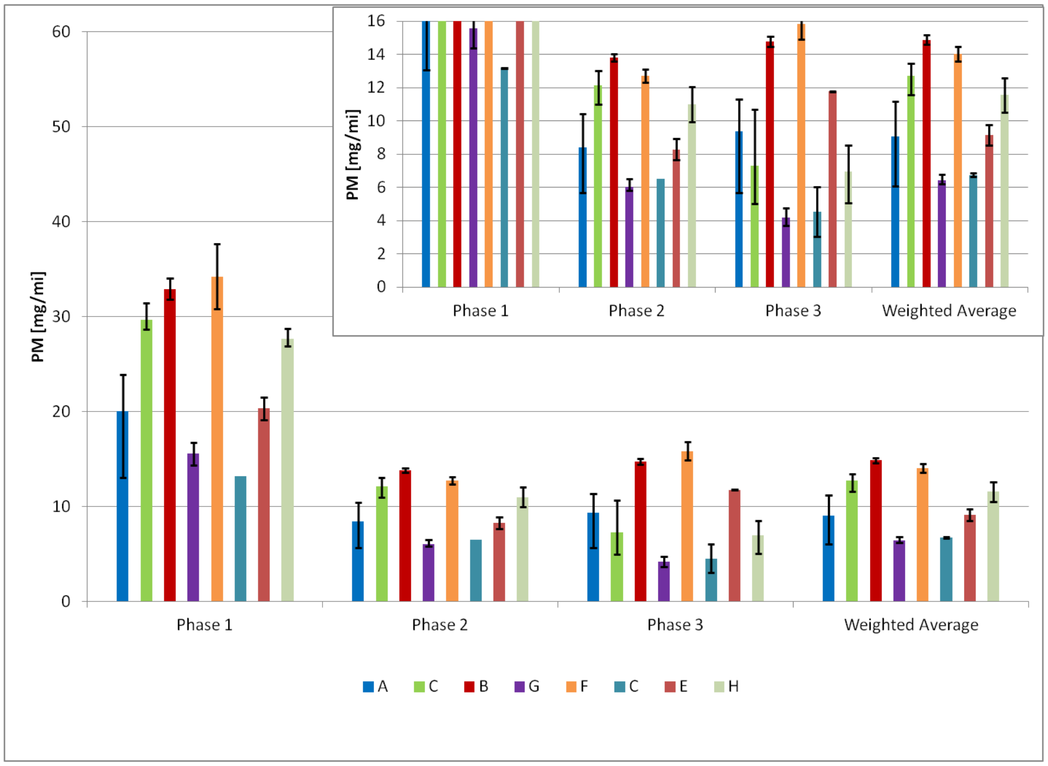


FIGURE E-82. PM EMISSIONS FOR VEHICLE J

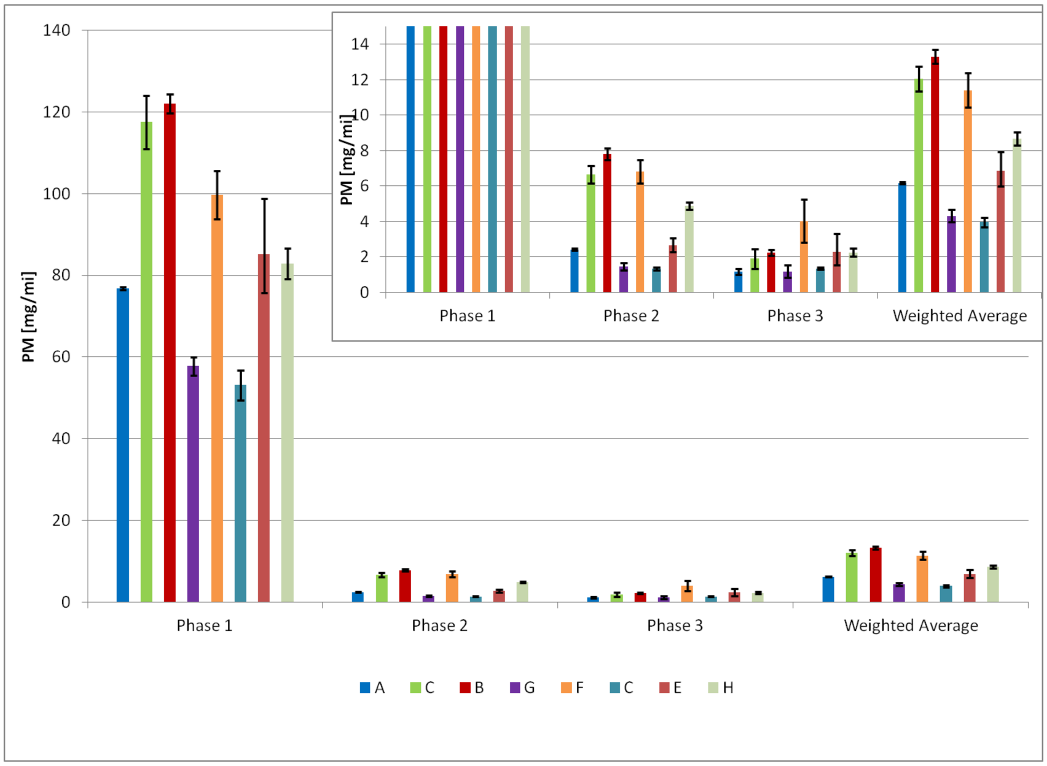


FIGURE E-83. PM EMISSIONS FOR VEHICLE K

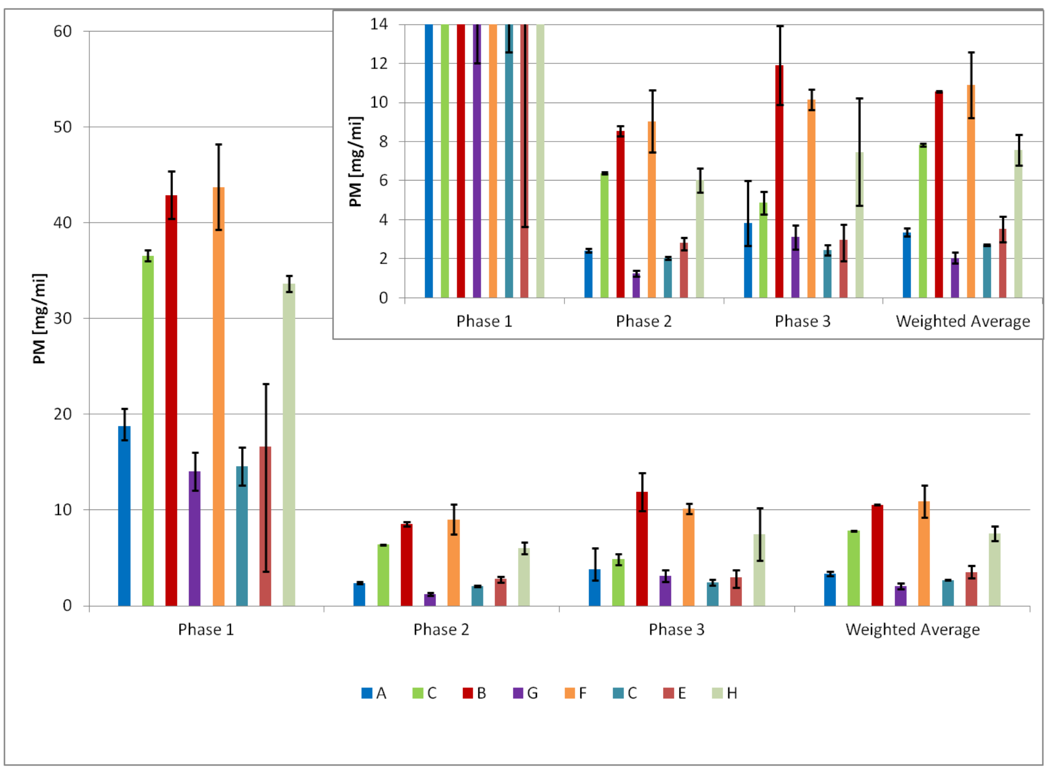


FIGURE E-84. PM EMISSIONS FOR VEHICLE L

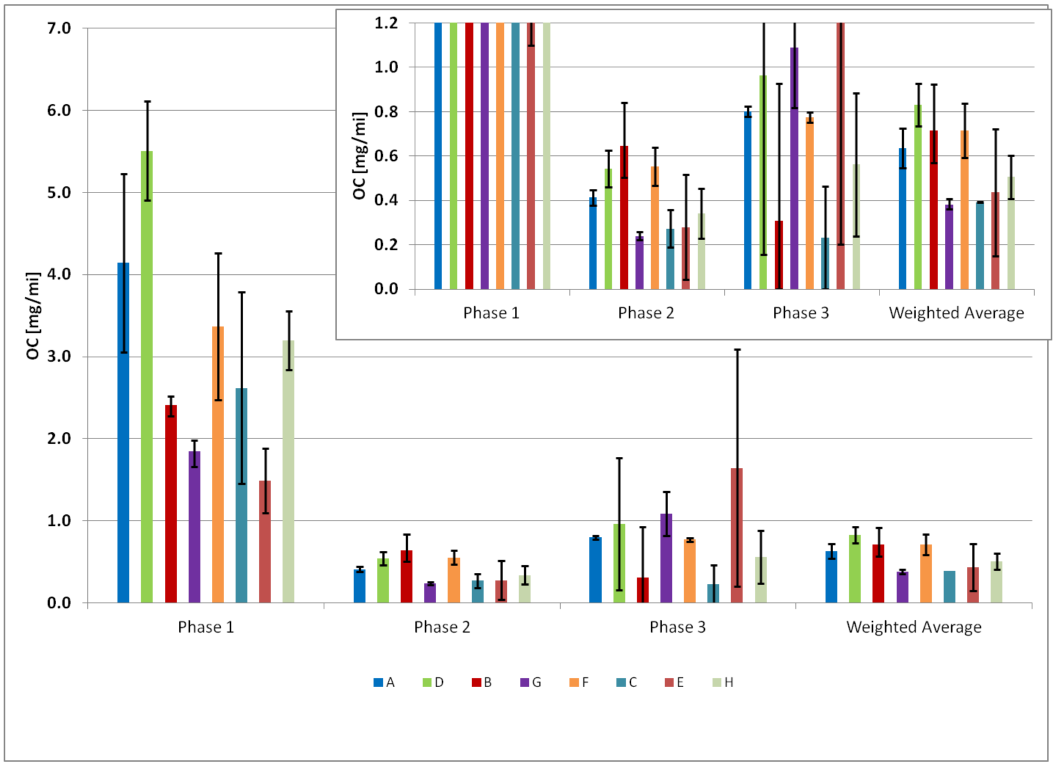


FIGURE E-85. OC EMISSIONS FOR VEHICLE A

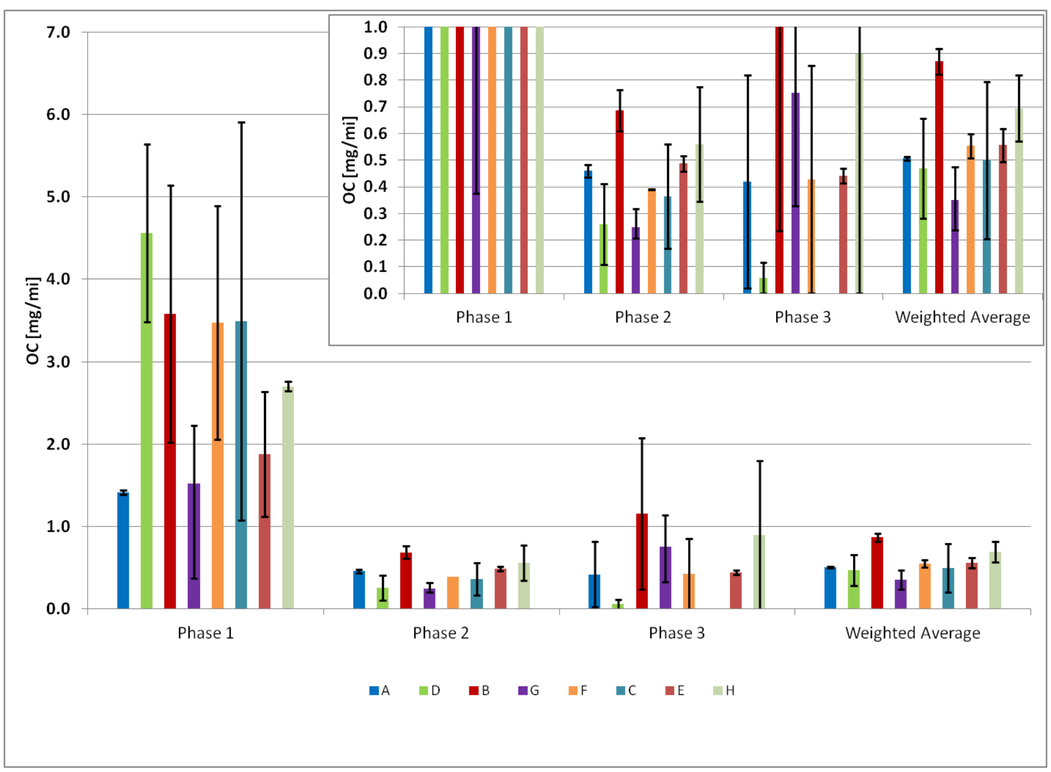


FIGURE E-86. OC EMISSIONS FOR VEHICLE B

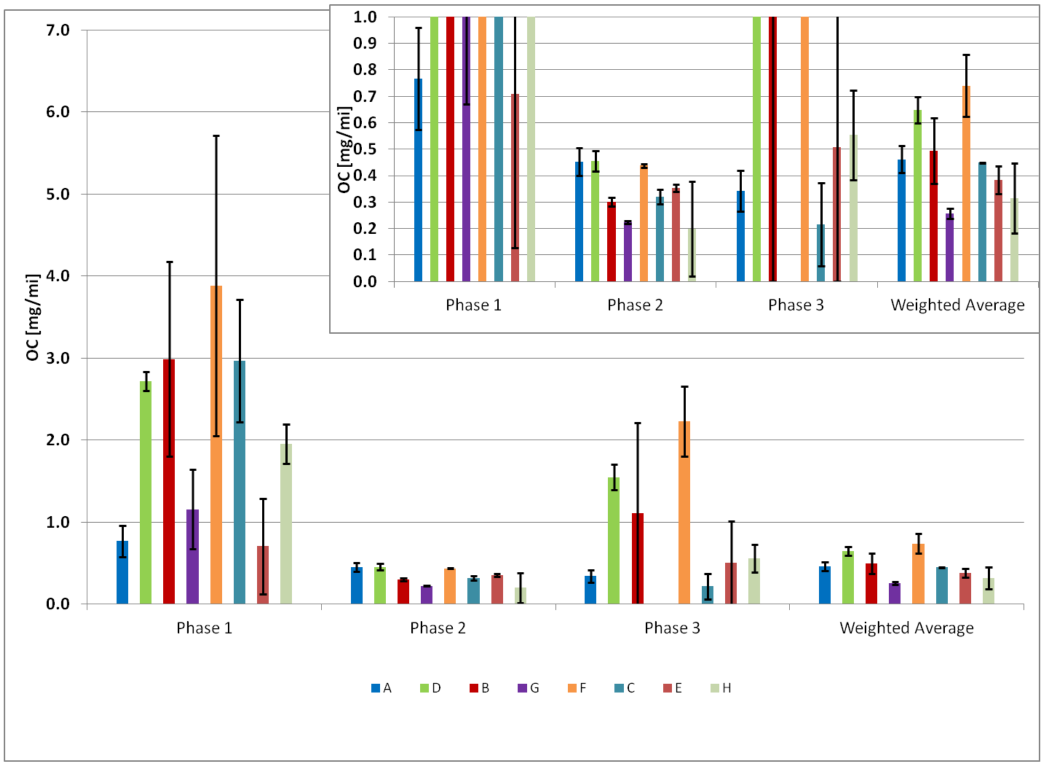


FIGURE E-87. OC EMISSIONS FOR VEHICLE C

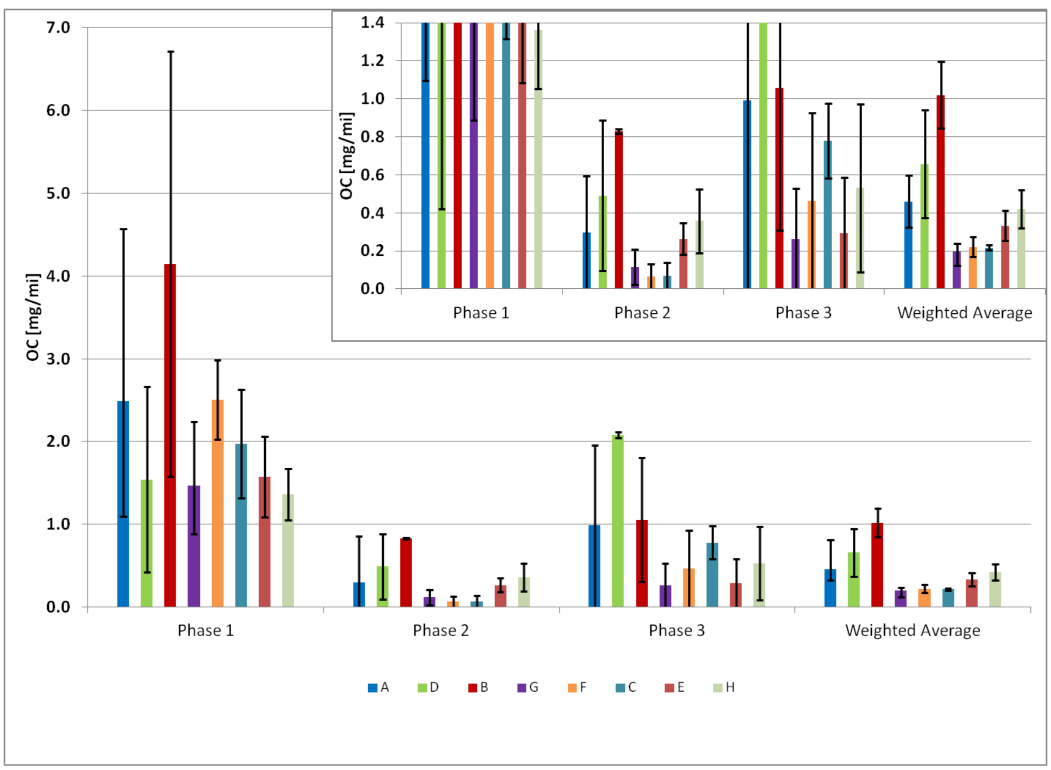


FIGURE E-88. OC EMISSIONS FOR VEHICLE D

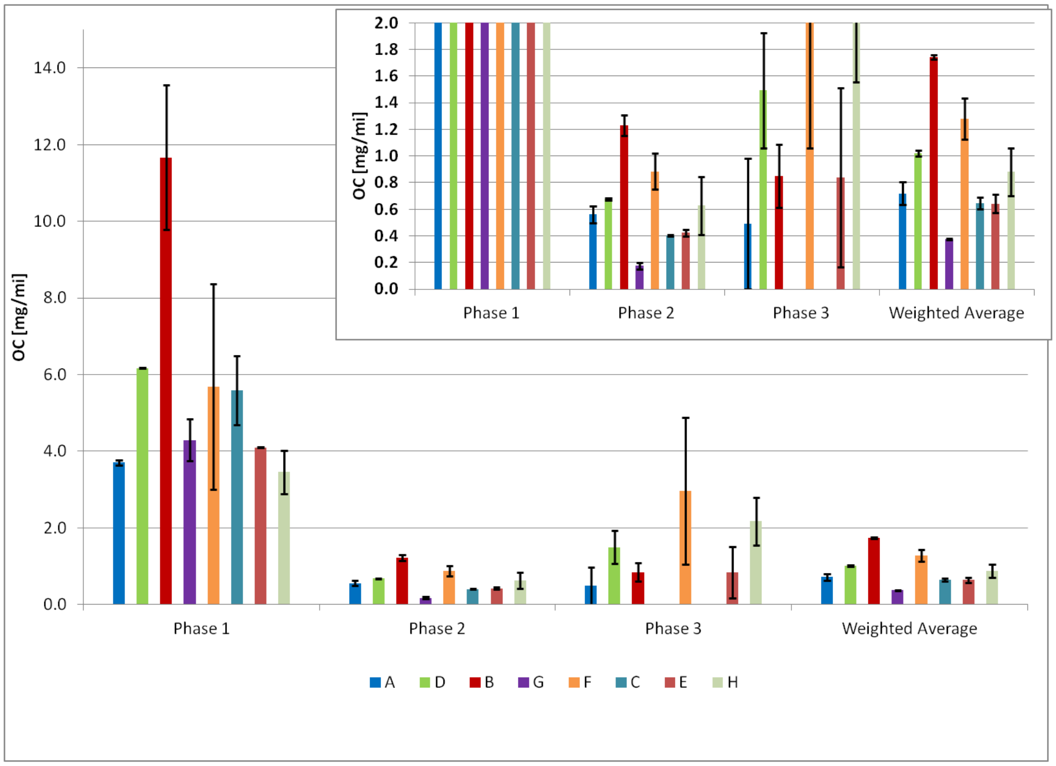


FIGURE E-89. OC EMISSIONS FOR VEHICLE E

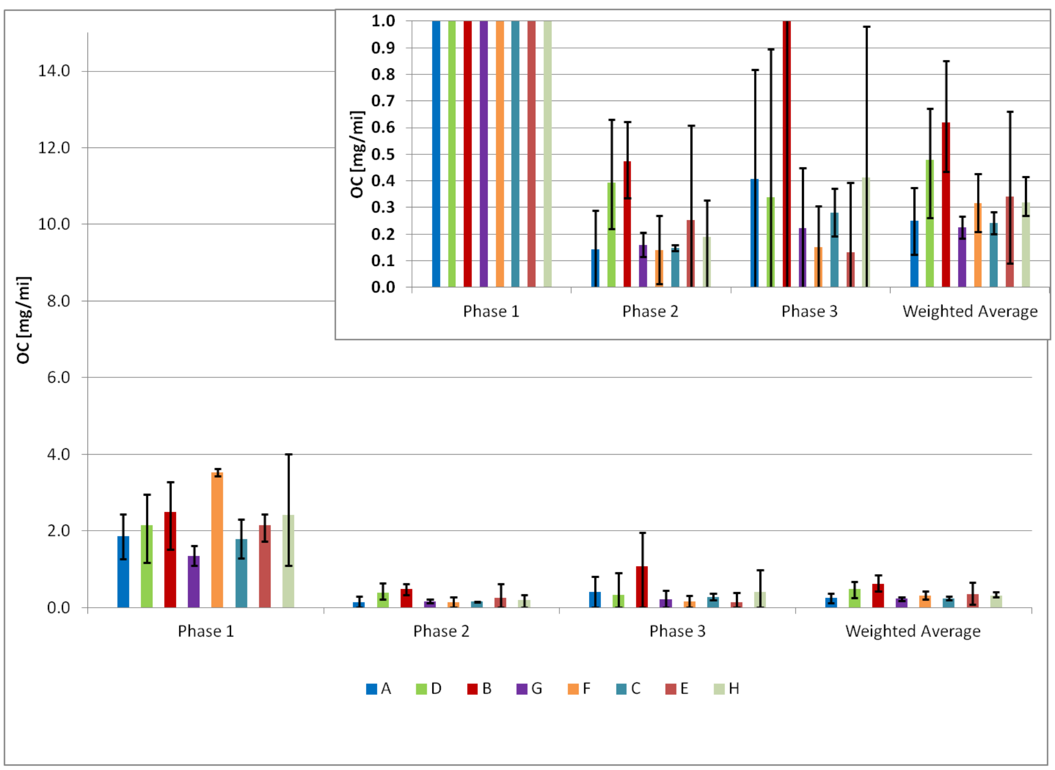


FIGURE E-90. OC EMISSIONS FOR VEHICLE F

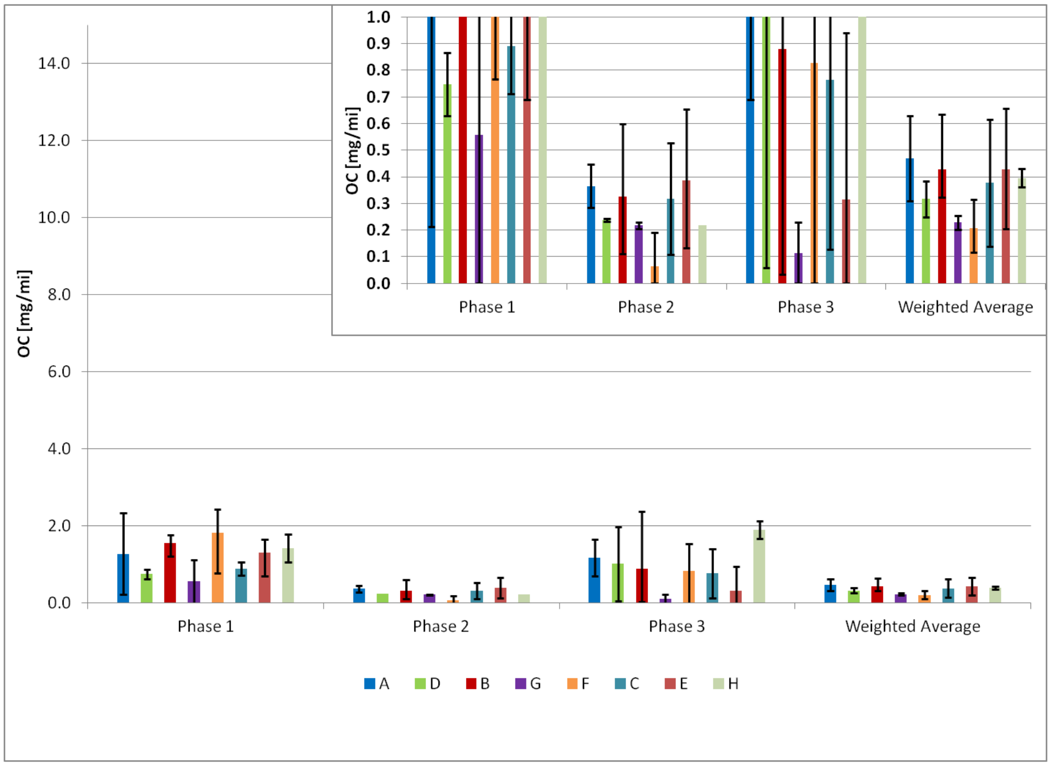


FIGURE E-91. OC EMISSIONS FOR VEHICLE G

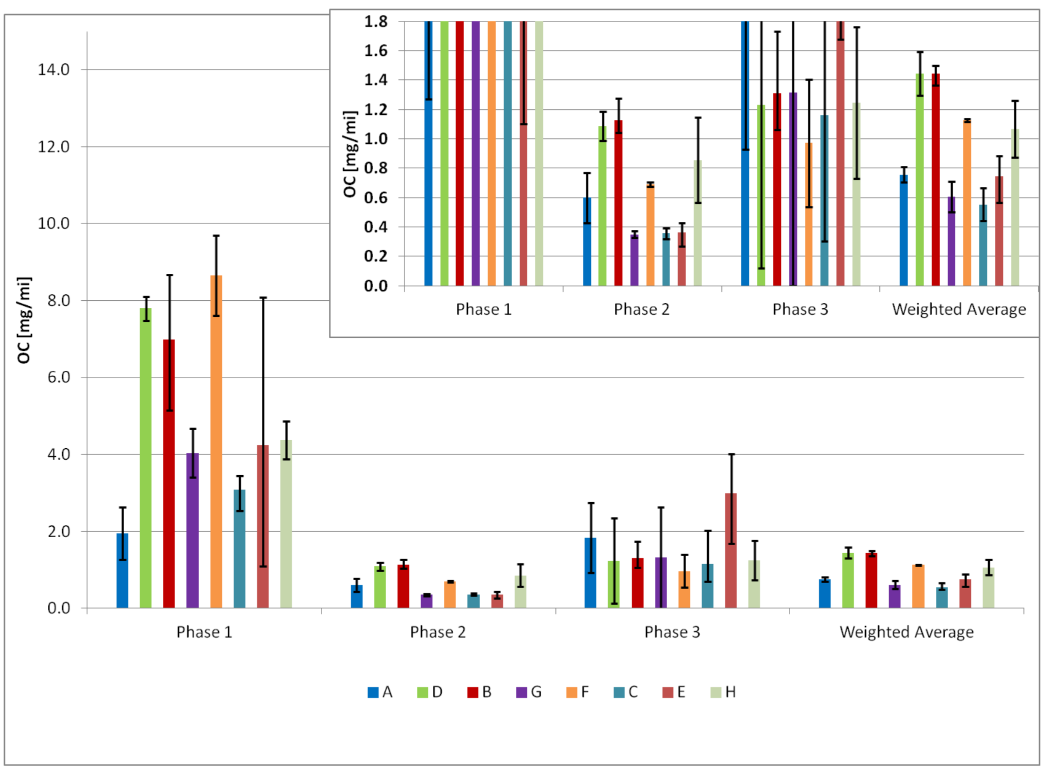


FIGURE E-92. OC EMISSIONS FOR VEHICLE H

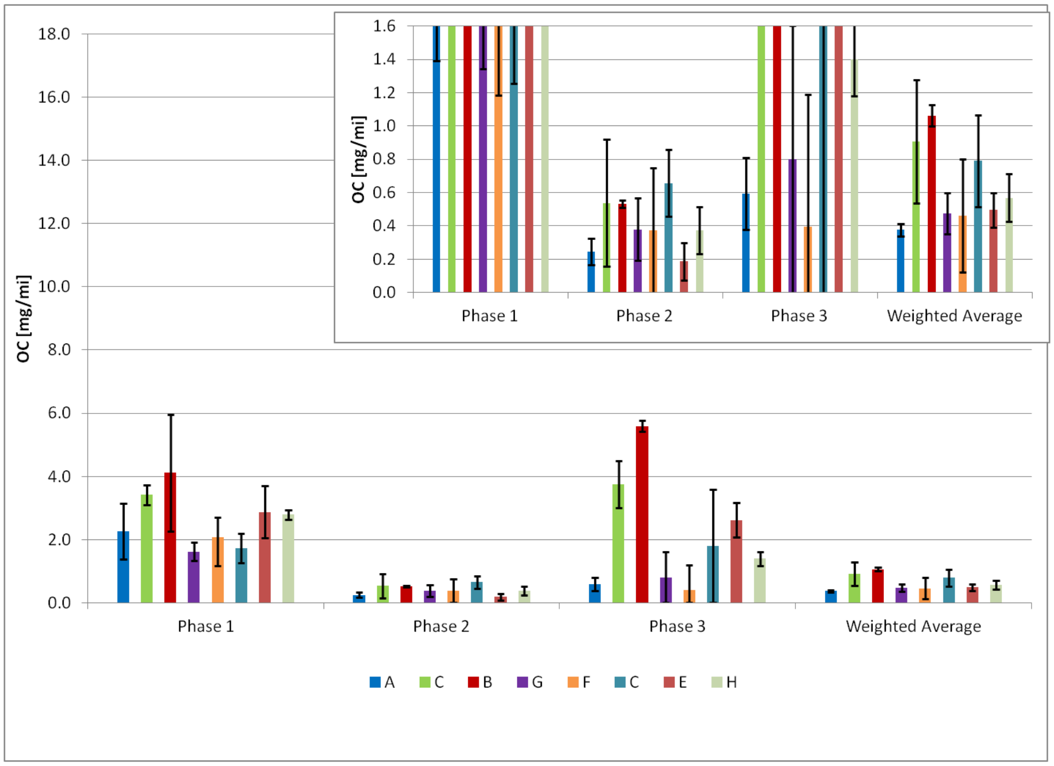


FIGURE E-93. OC EMISSIONS FOR VEHICLE I

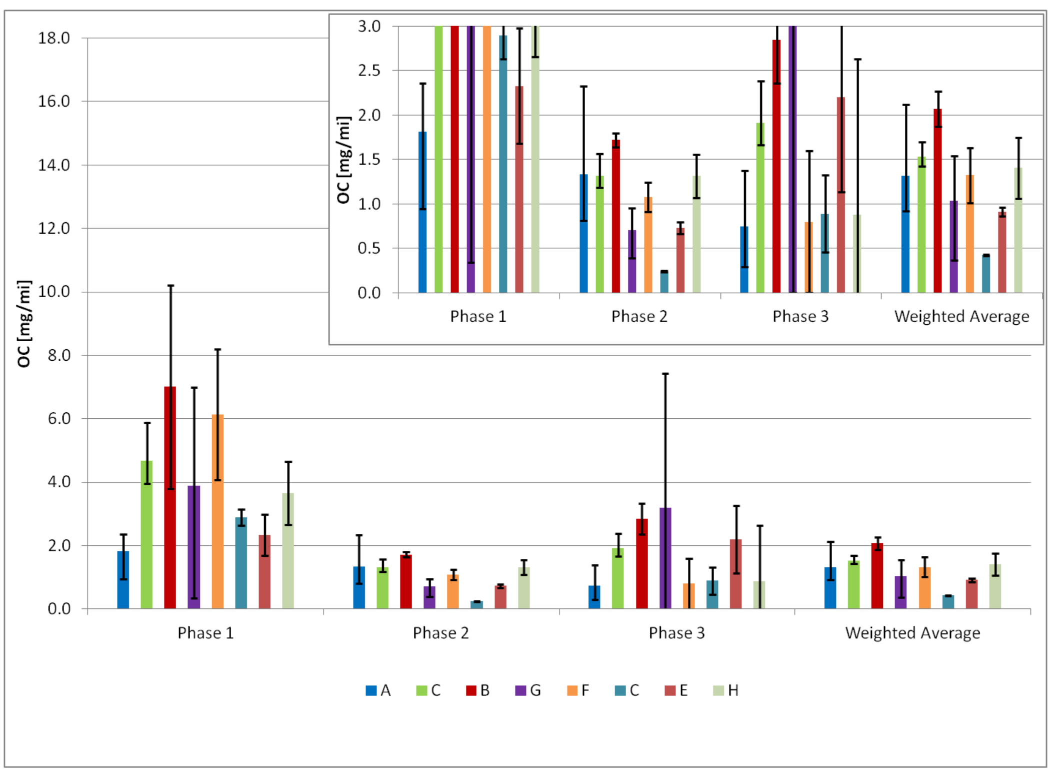


FIGURE E-94. OC EMISSIONS FOR VEHICLE J

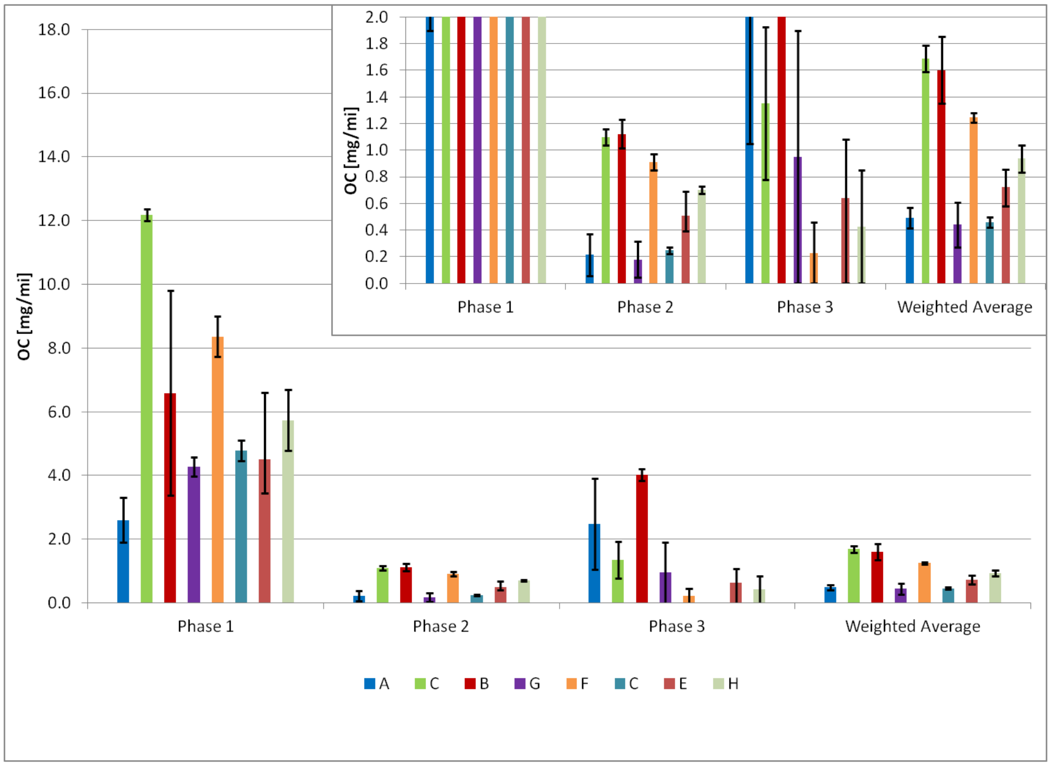


FIGURE E-95. OC EMISSIONS FOR VEHICLE K

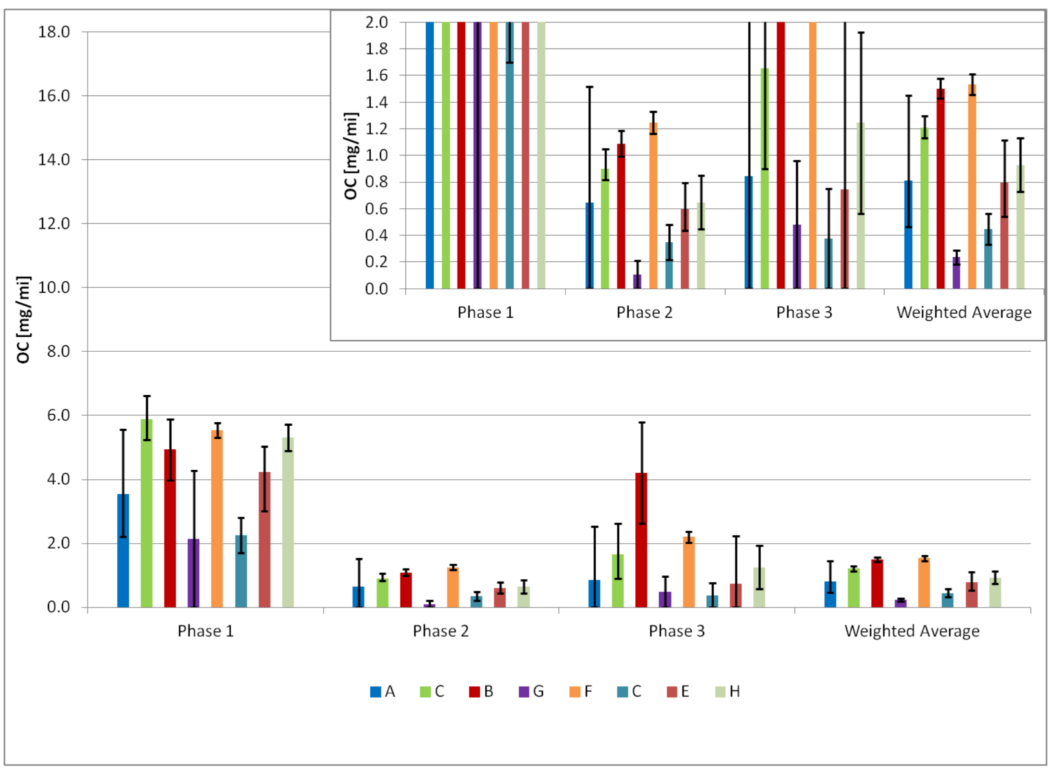


FIGURE E-96. OC EMISSIONS FOR VEHICLE L

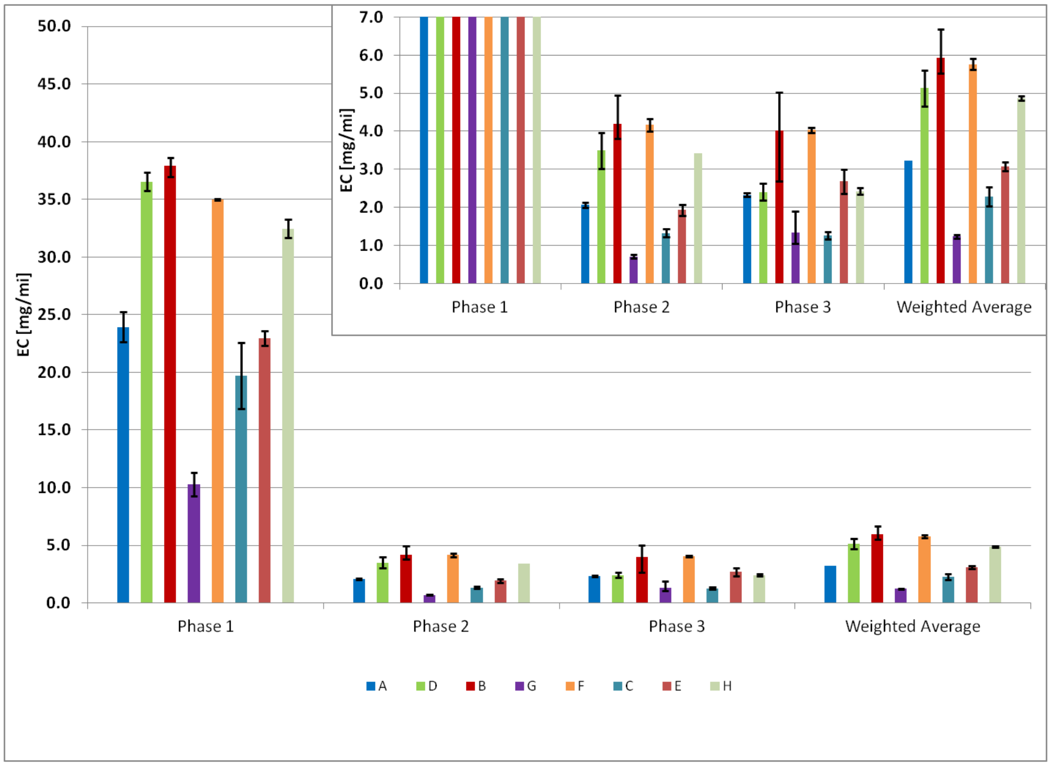


FIGURE E-97. EC EMISSIONS FOR VEHICLE A

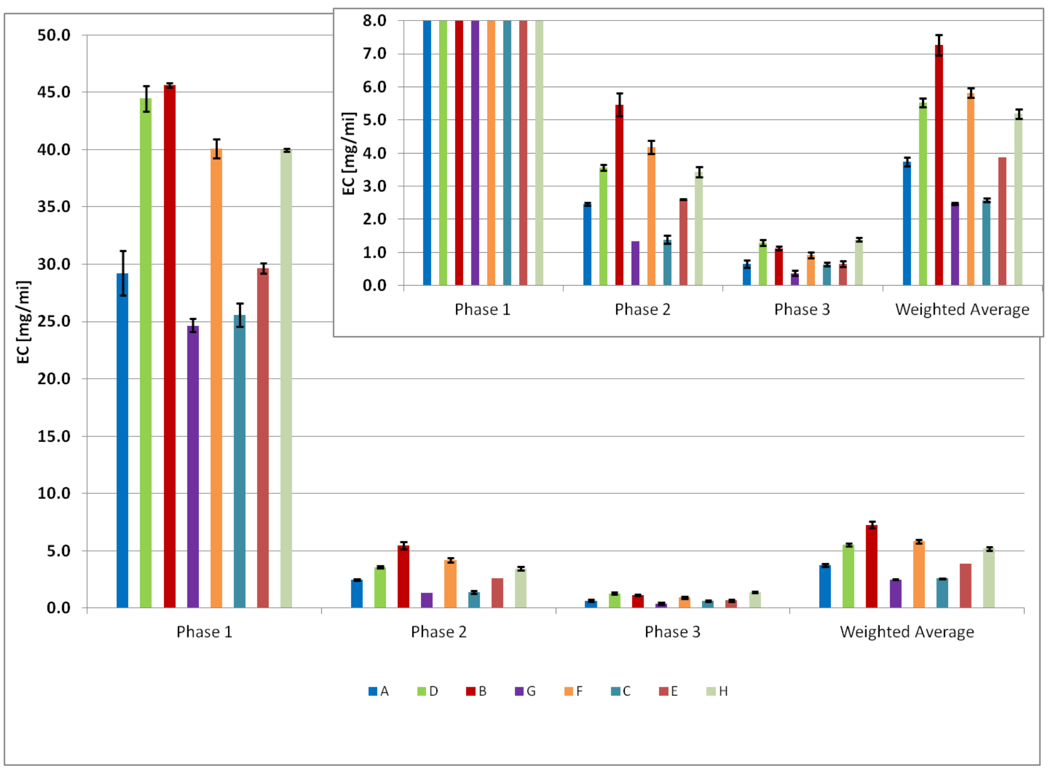


FIGURE E-98. EC EMISSIONS FOR VEHICLE B

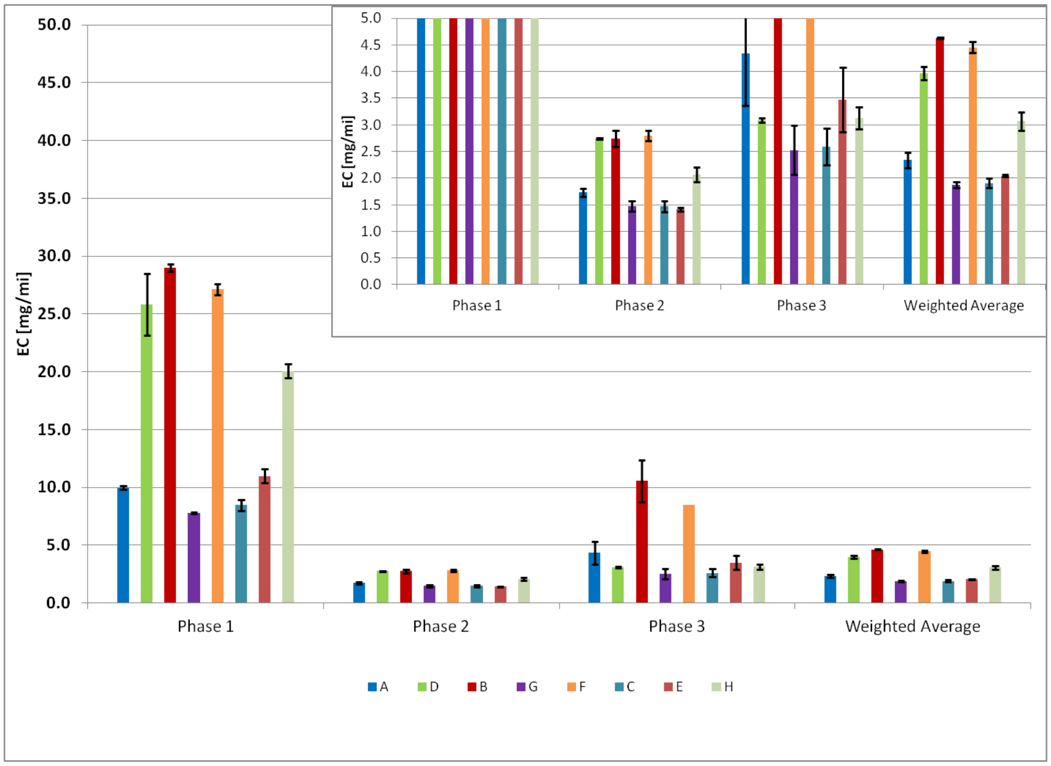


FIGURE E-99. EC EMISSIONS FOR VEHICLE C

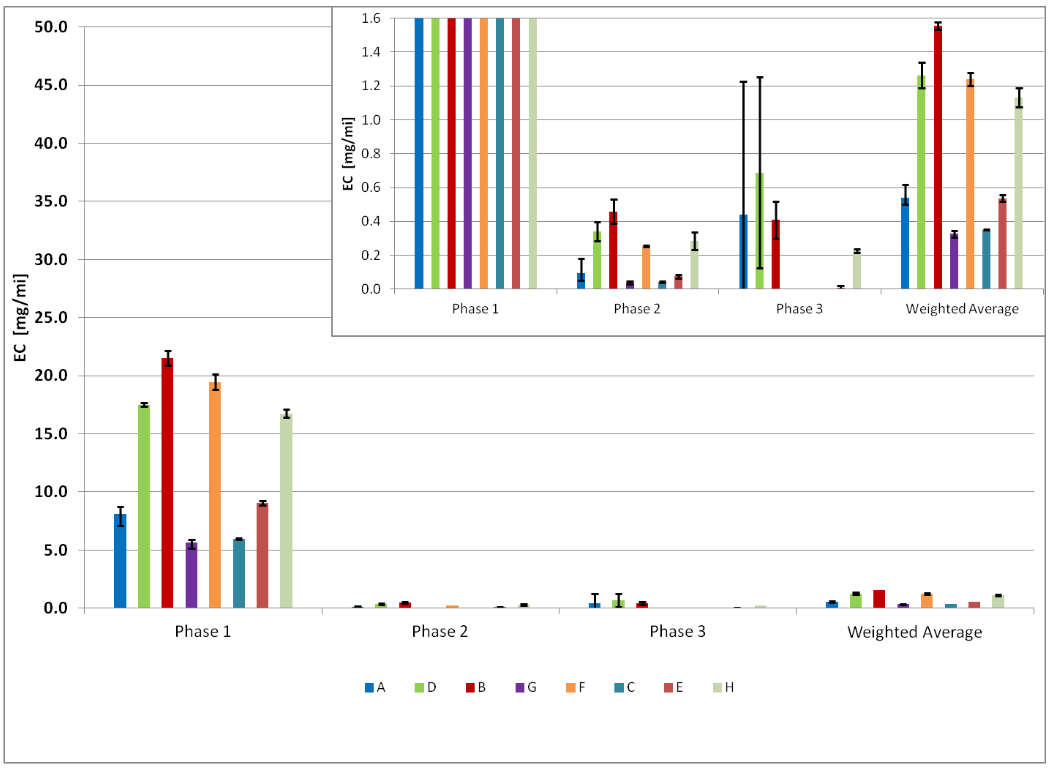


FIGURE E-100. EC EMISSIONS FOR VEHICLE D

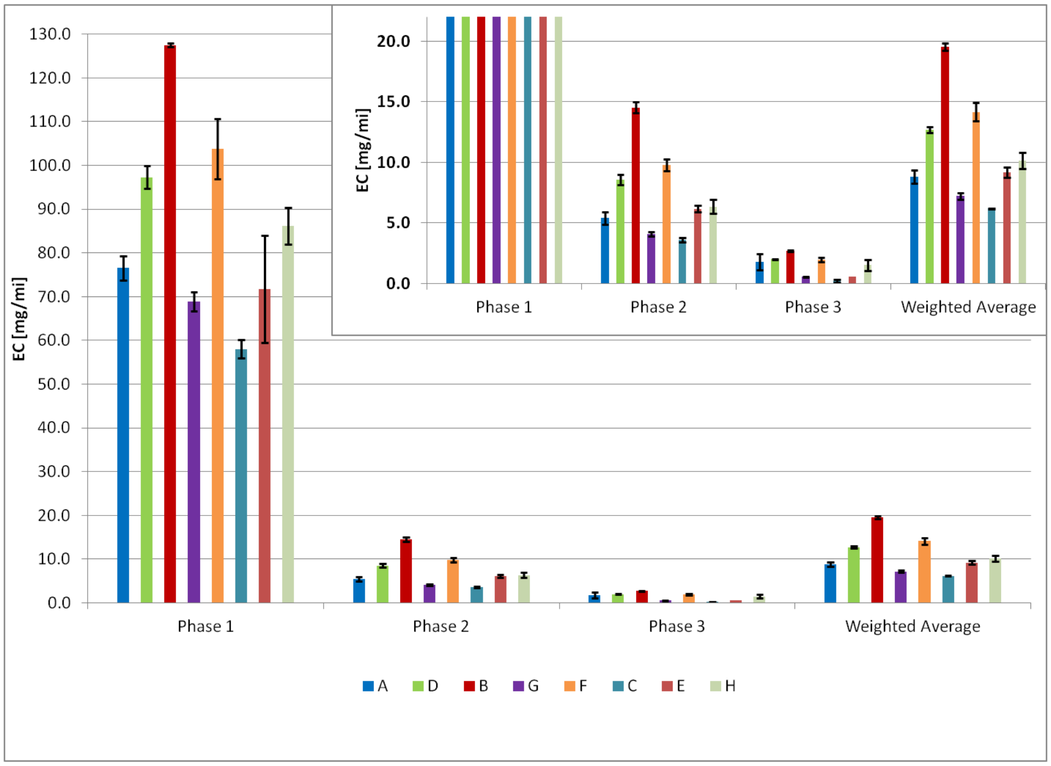


FIGURE E-101. EC EMISSIONS FOR VEHICLE E

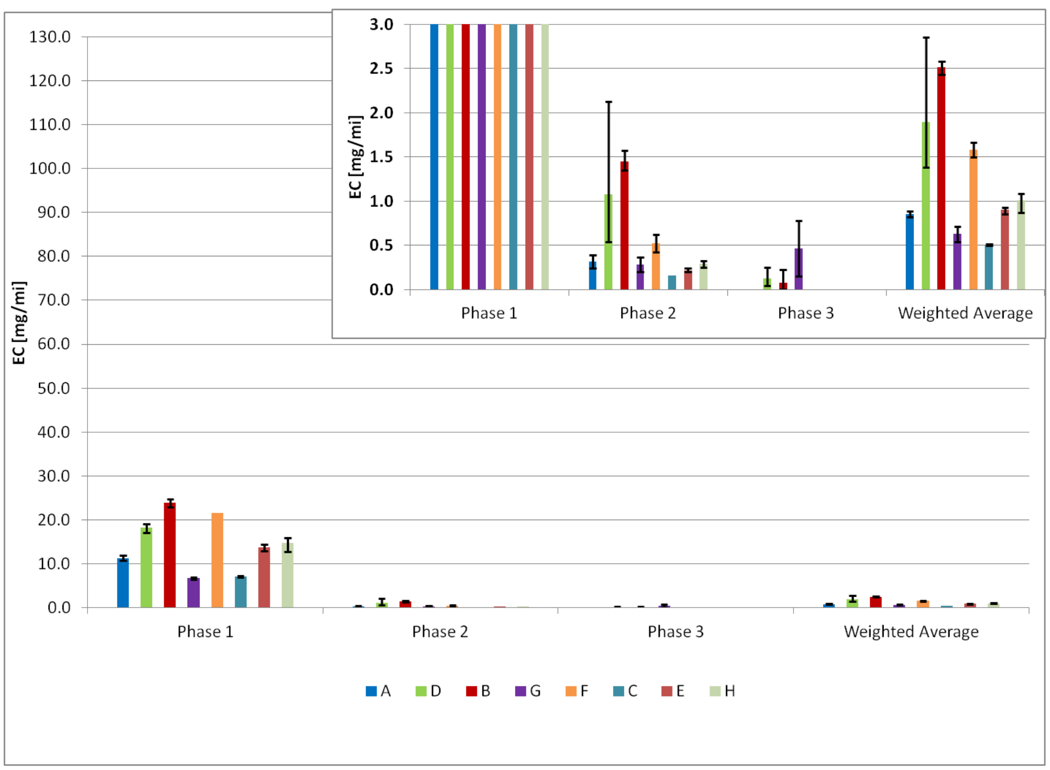


FIGURE E-102. EC EMISSIONS FOR VEHICLE F

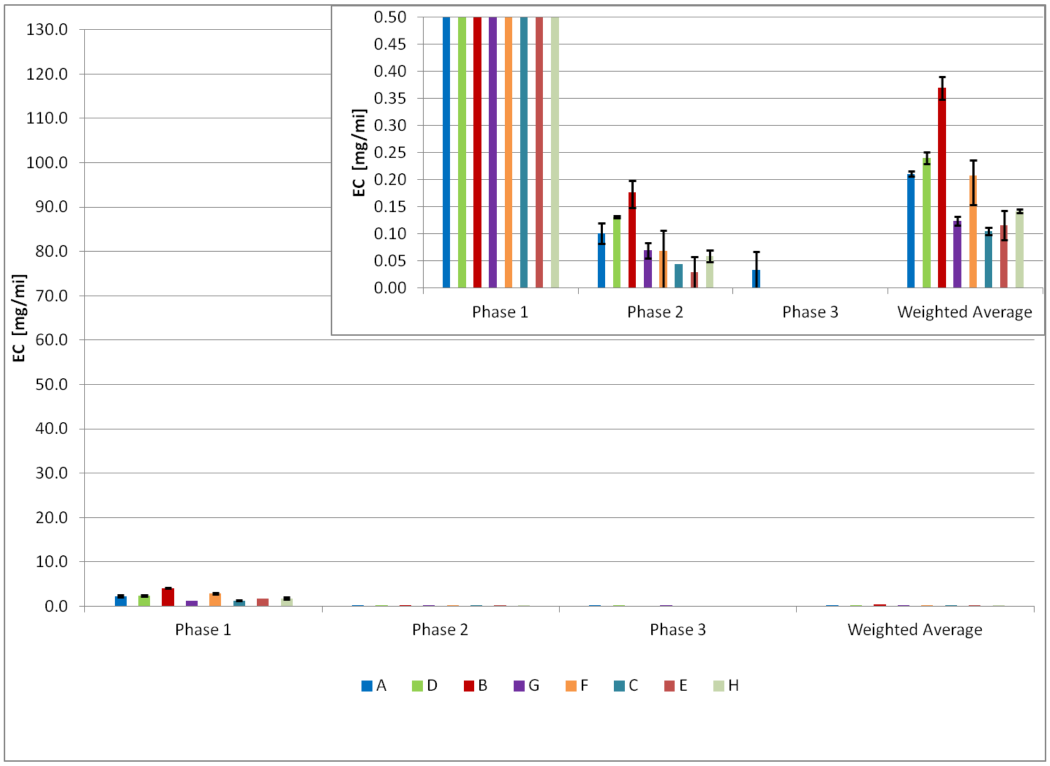


FIGURE E-103. EC EMISSIONS FOR VEHICLE G

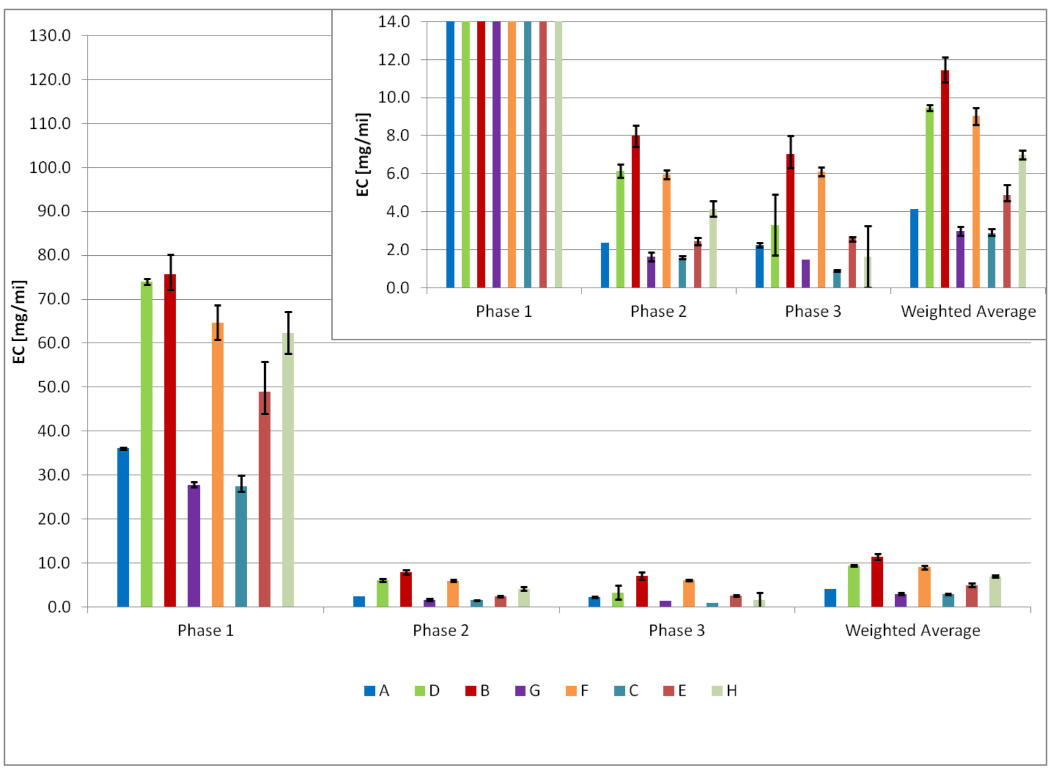


FIGURE E-104. EC EMISSIONS FOR VEHICLE H

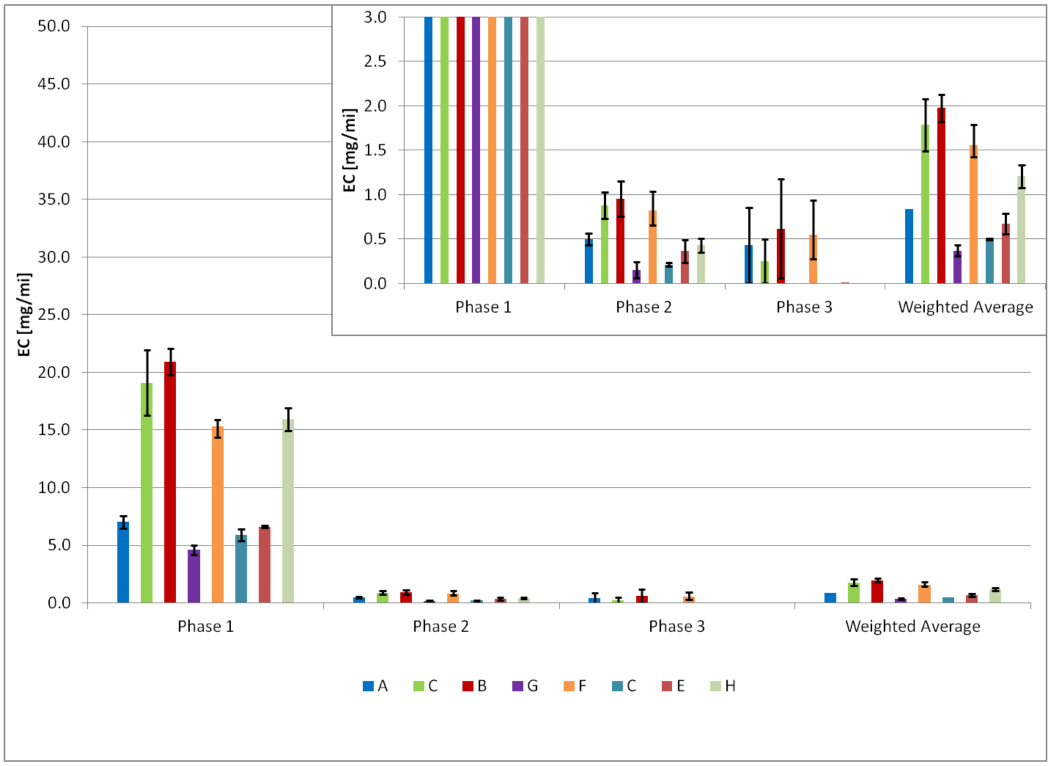


FIGURE E-105. EC EMISSIONS FOR VEHICLE I

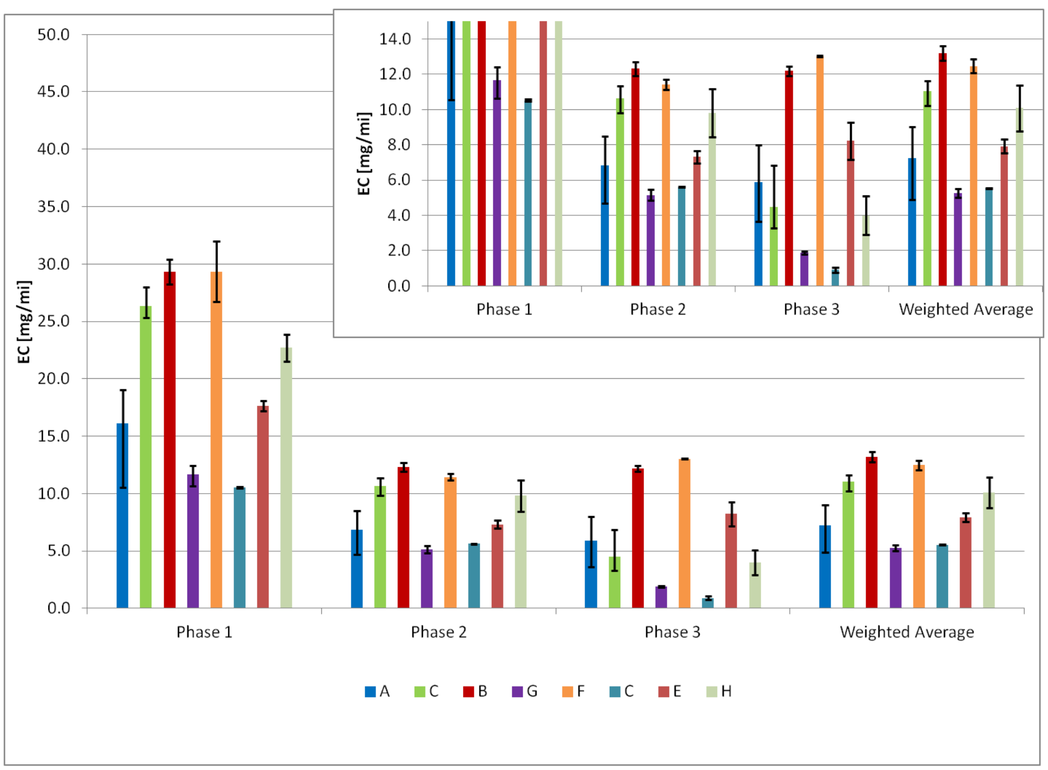


FIGURE E-106. EC EMISSIONS FOR VEHICLE J

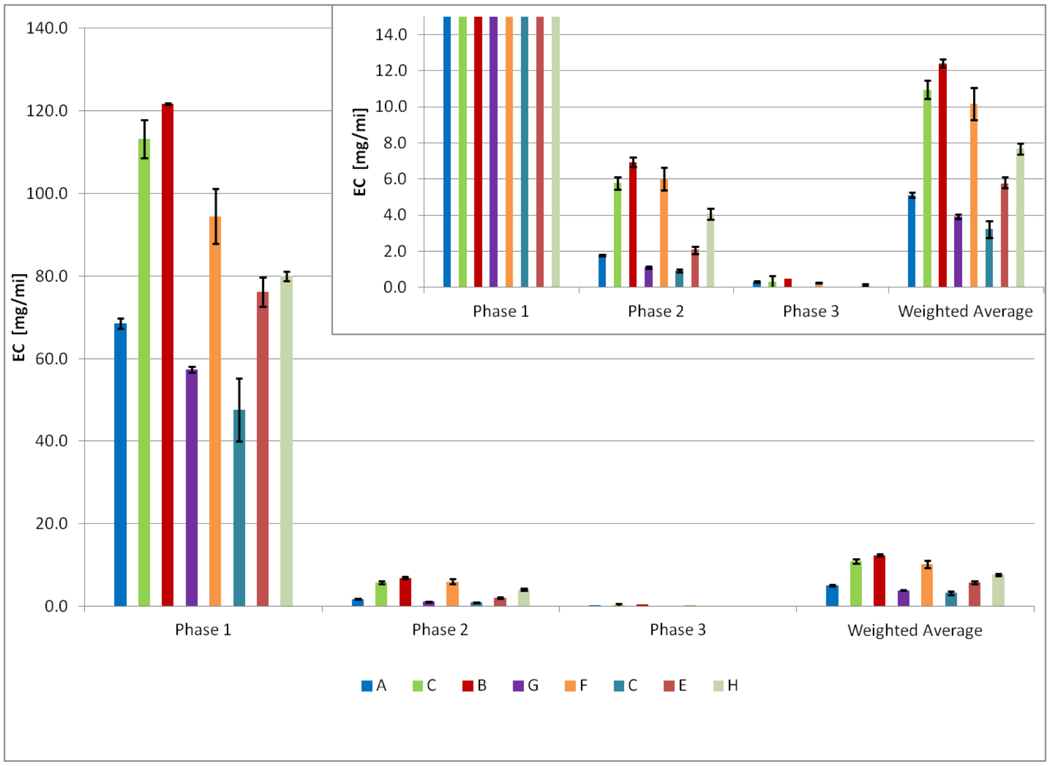


FIGURE E-107. EC EMISSIONS FOR VEHICLE K

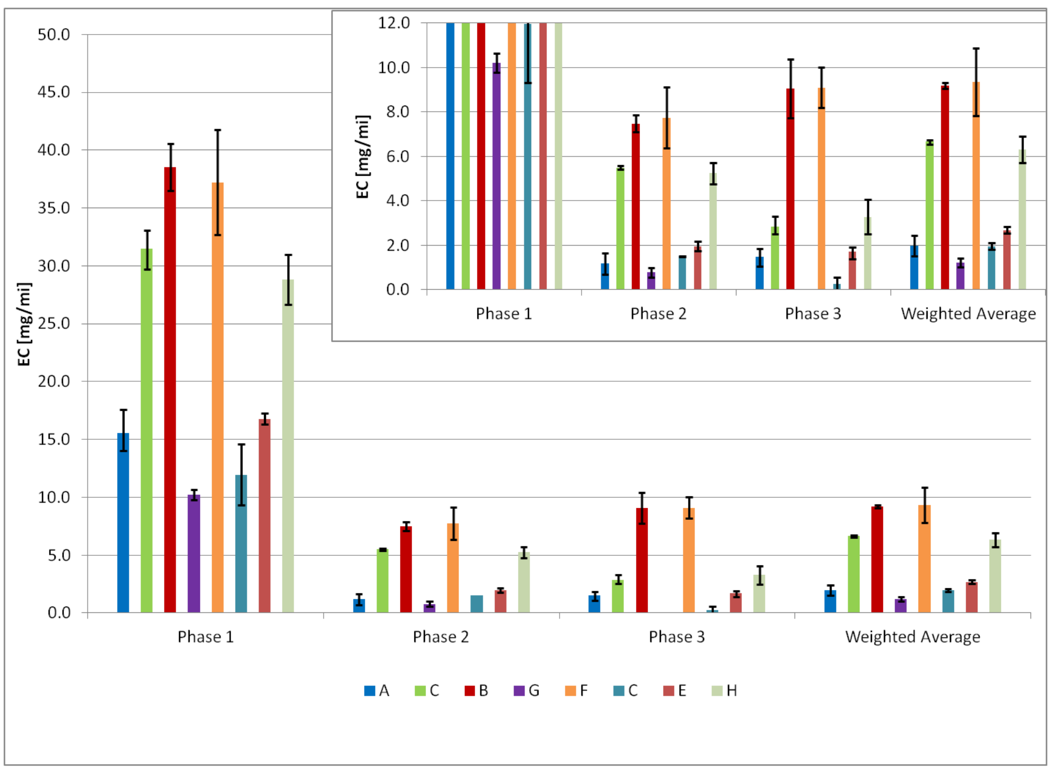


FIGURE E-108. EC EMISSIONS FOR VEHICLE L

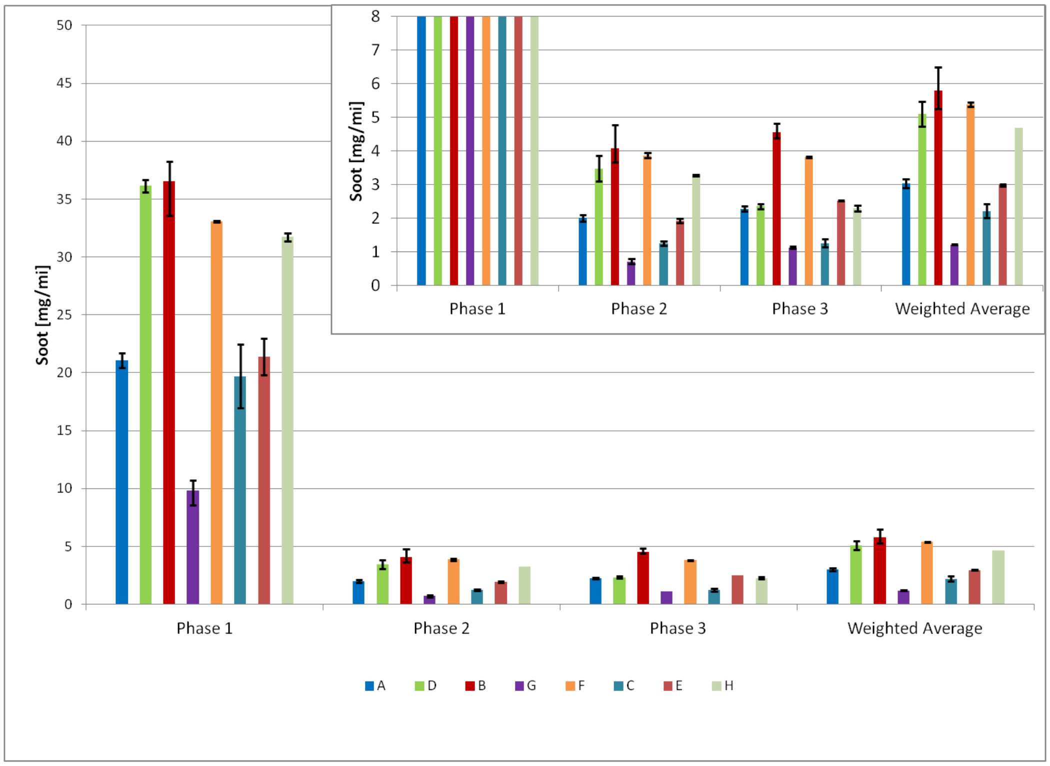


FIGURE E-109. MSS EMISSIONS FOR VEHICLE A

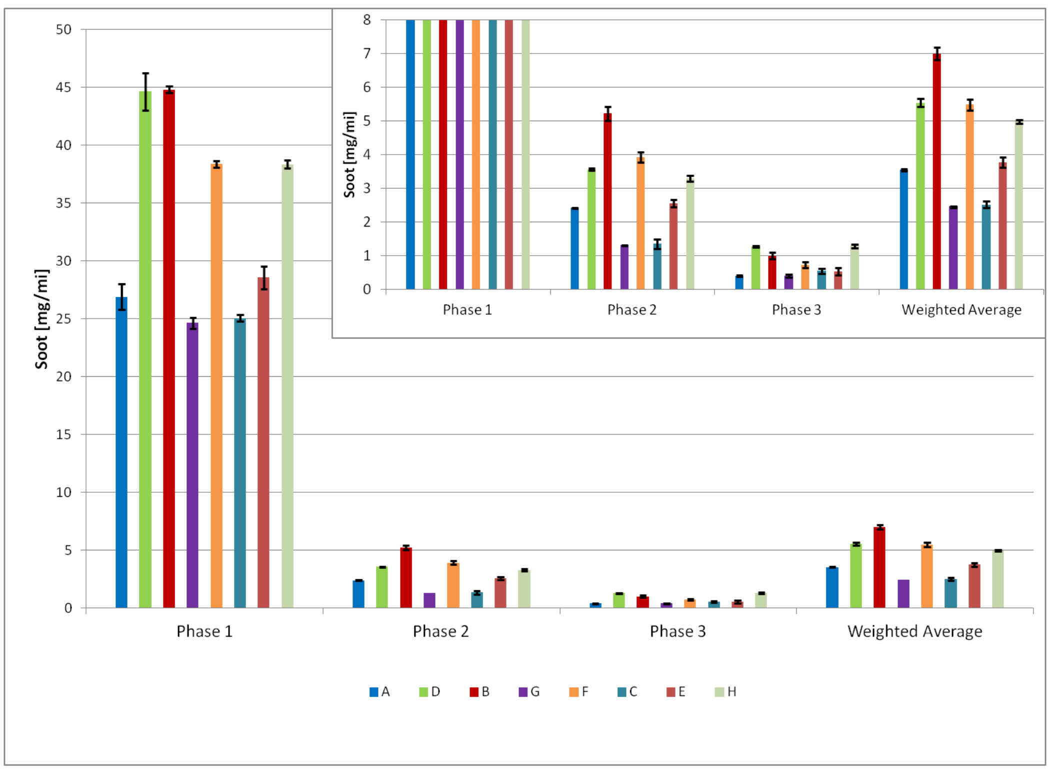


FIGURE E-110. MSS EMISSIONS FOR VEHICLE B

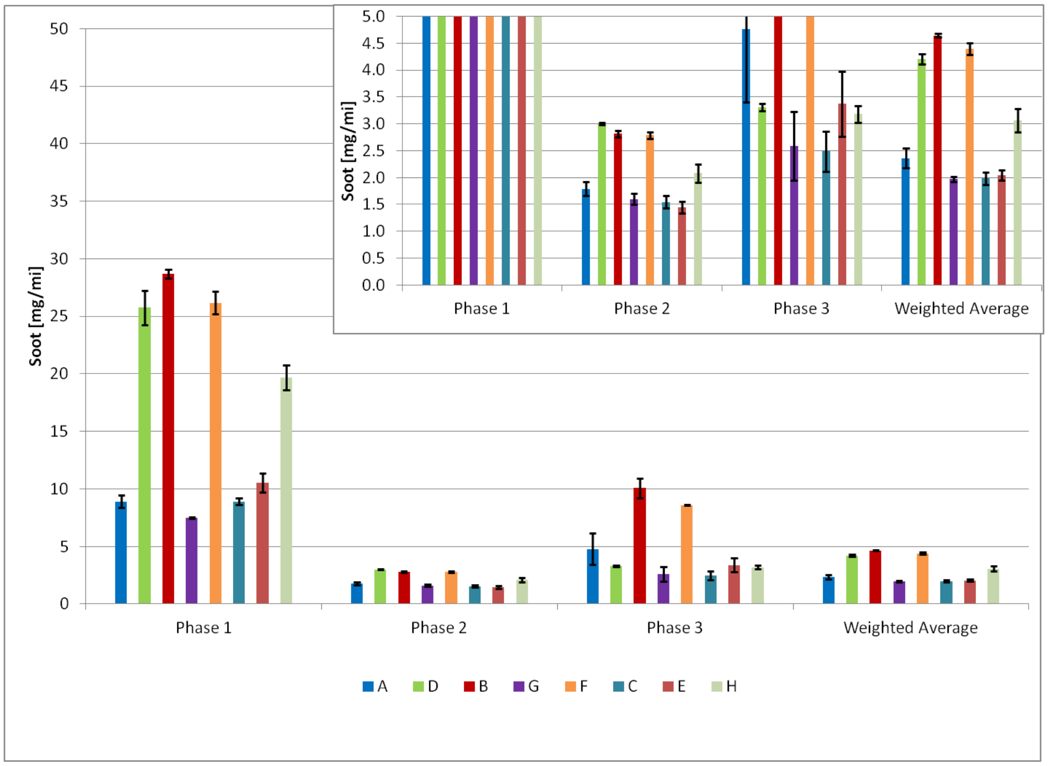


FIGURE E-111. MSS EMISSIONS FOR VEHICLE C

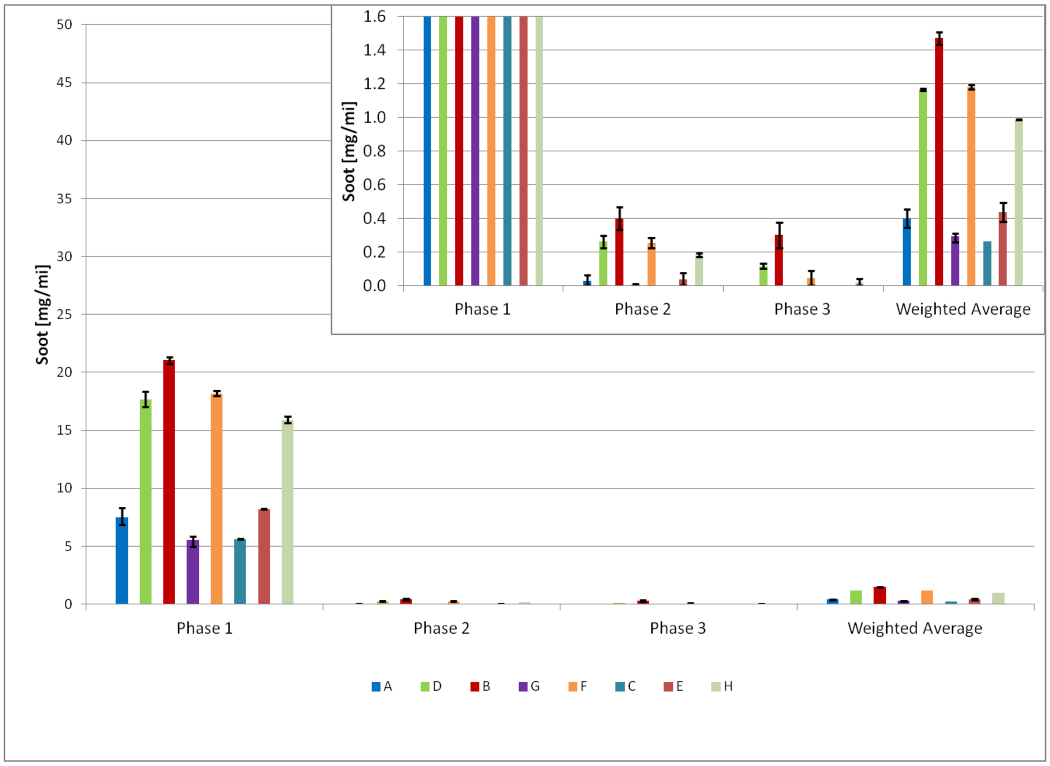


FIGURE E-112. MSS EMISSIONS FOR VEHICLE D

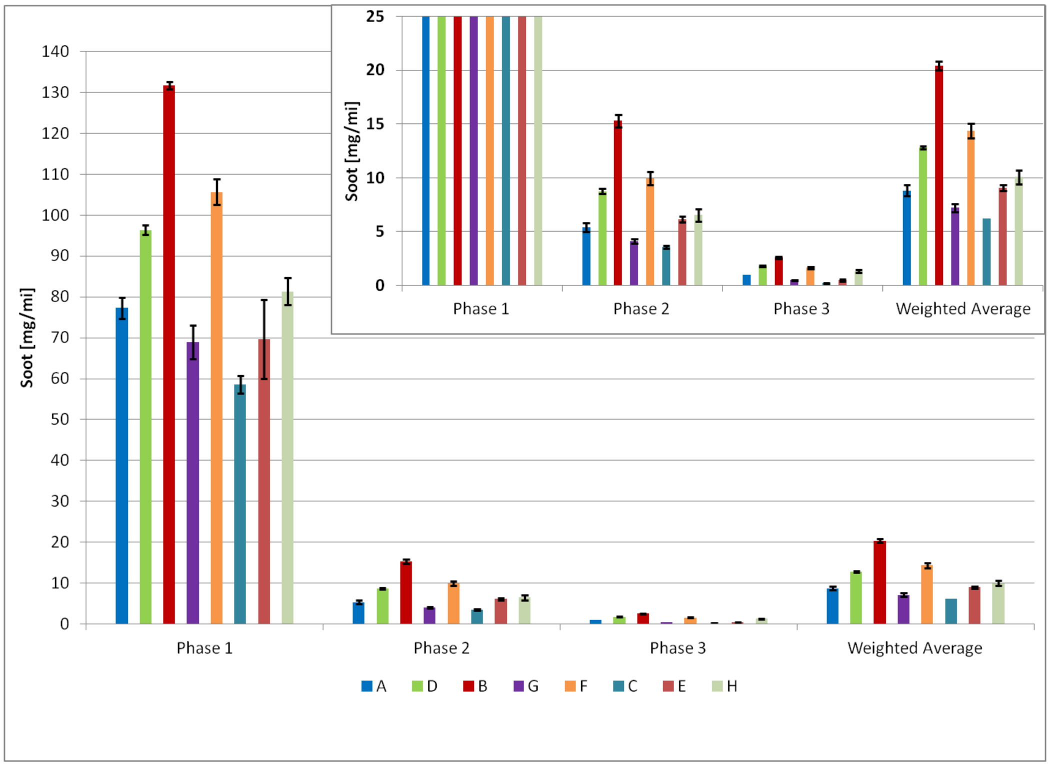


FIGURE E-113. MSS EMISSIONS FOR VEHICLE E

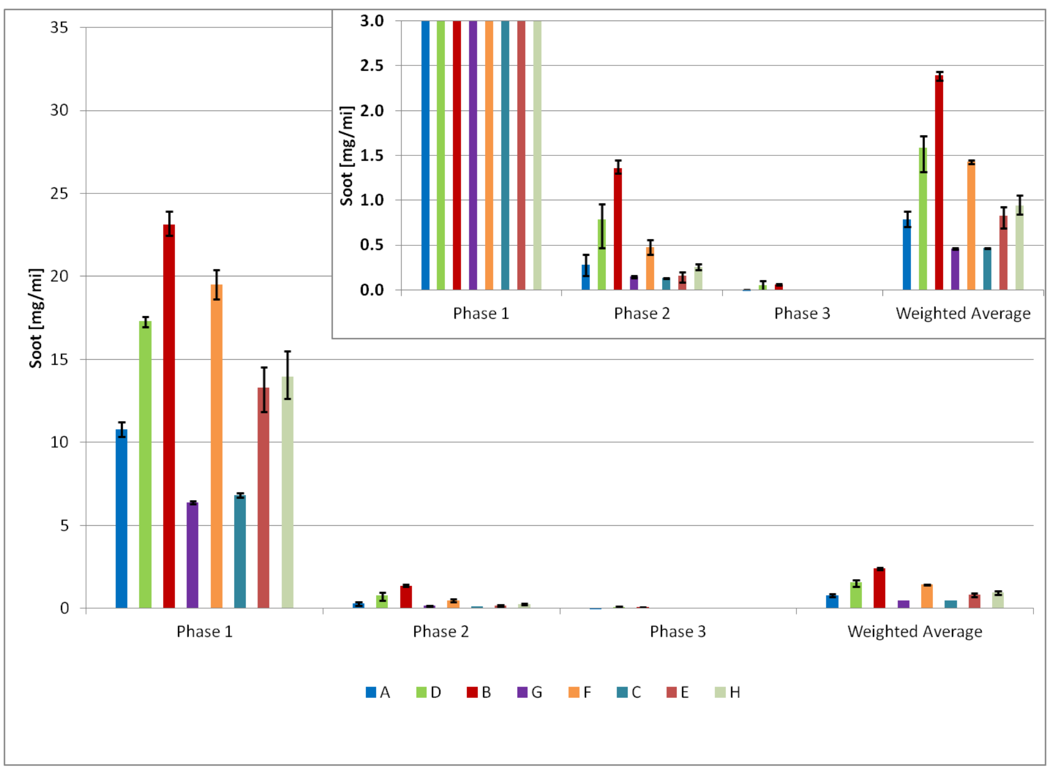


FIGURE E-114. MSS EMISSIONS FOR VEHICLE F

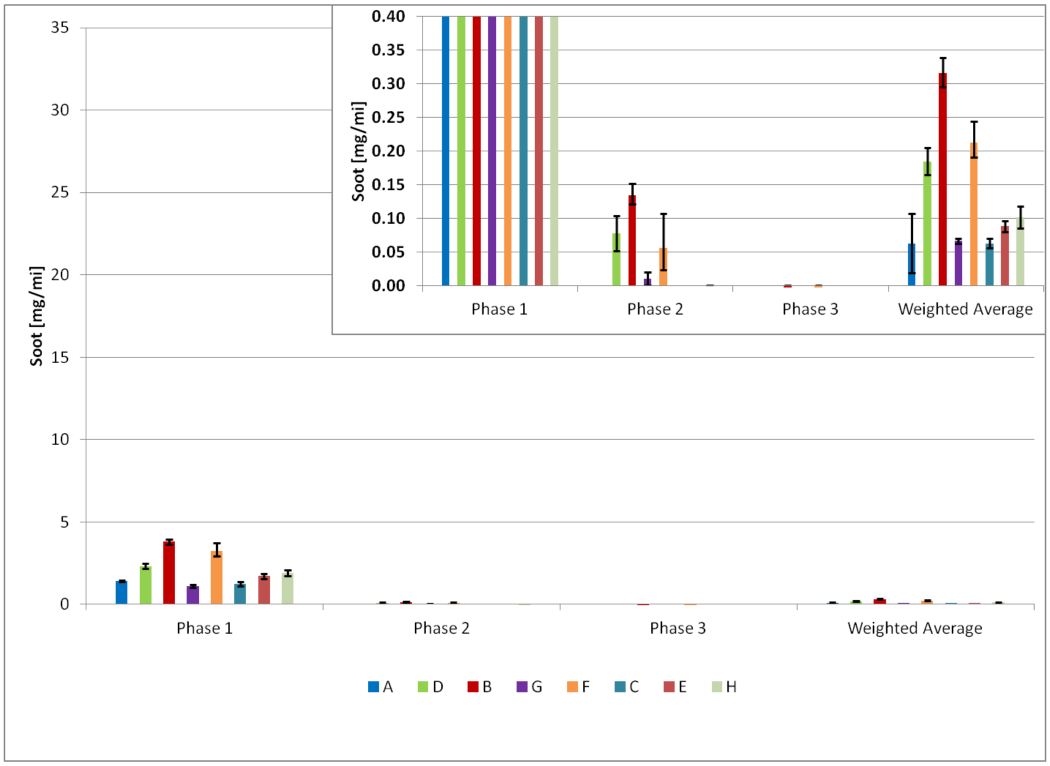


FIGURE E-115. MSS EMISSIONS FOR VEHICLE G

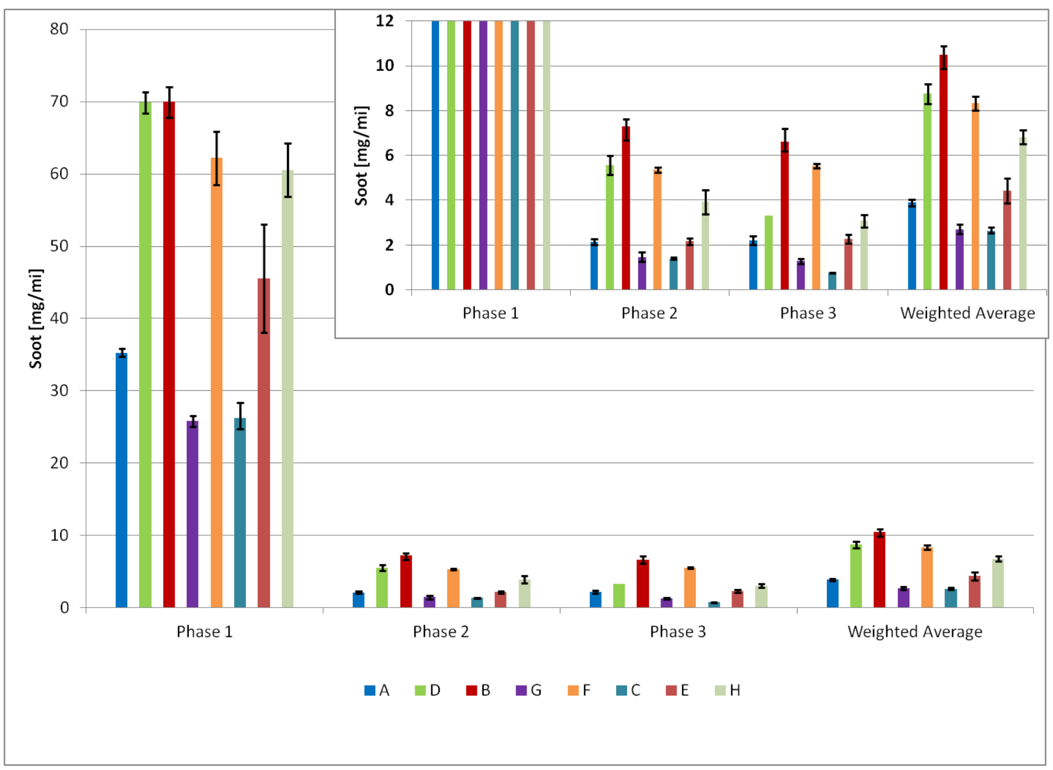


FIGURE E-116. MSS EMISSIONS FOR VEHICLE H

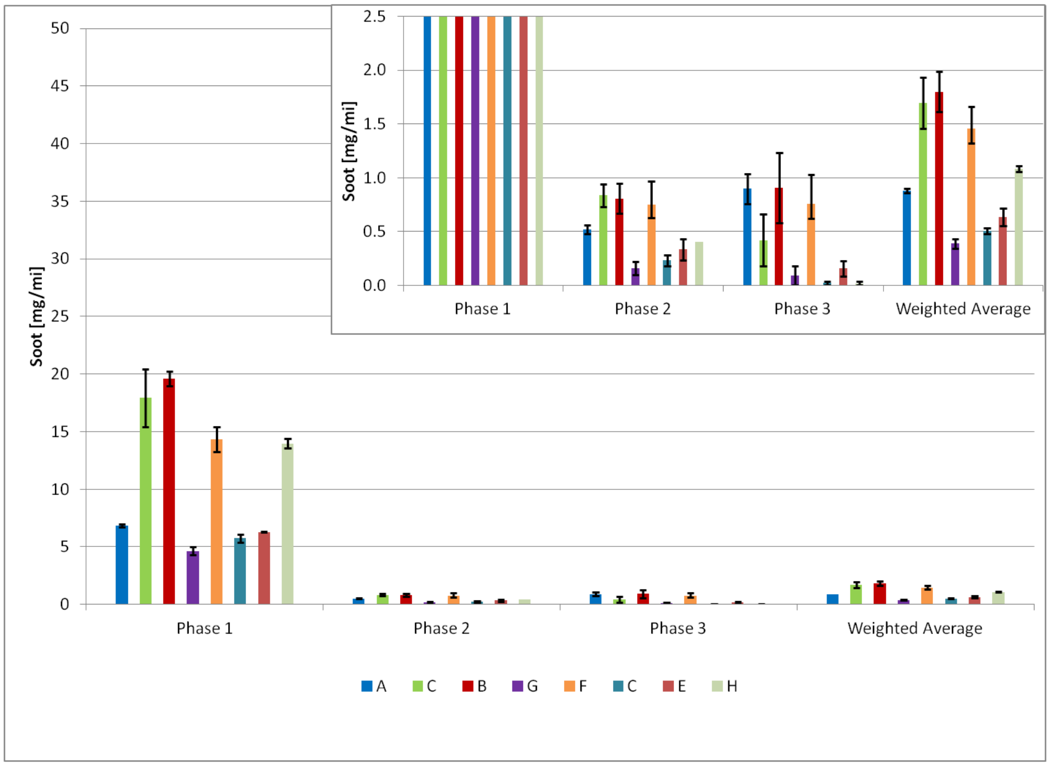


FIGURE E-117. MSS EMISSIONS FOR VEHICLE I

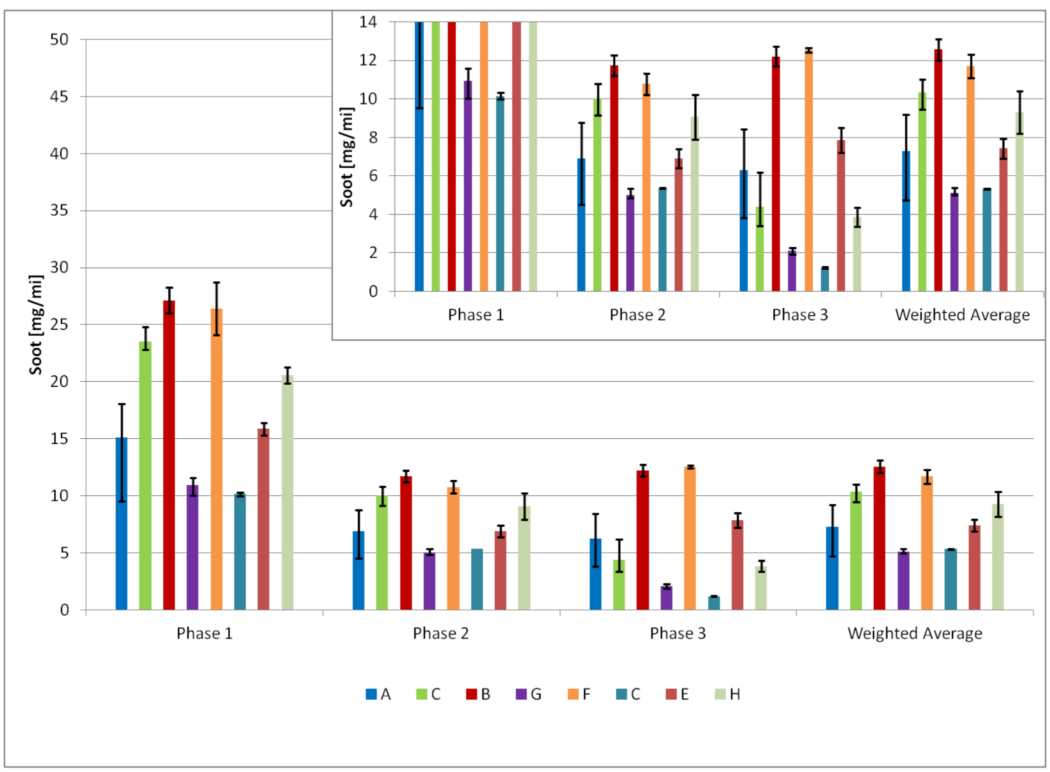


FIGURE E-118. MSS EMISSIONS FOR VEHICLE J

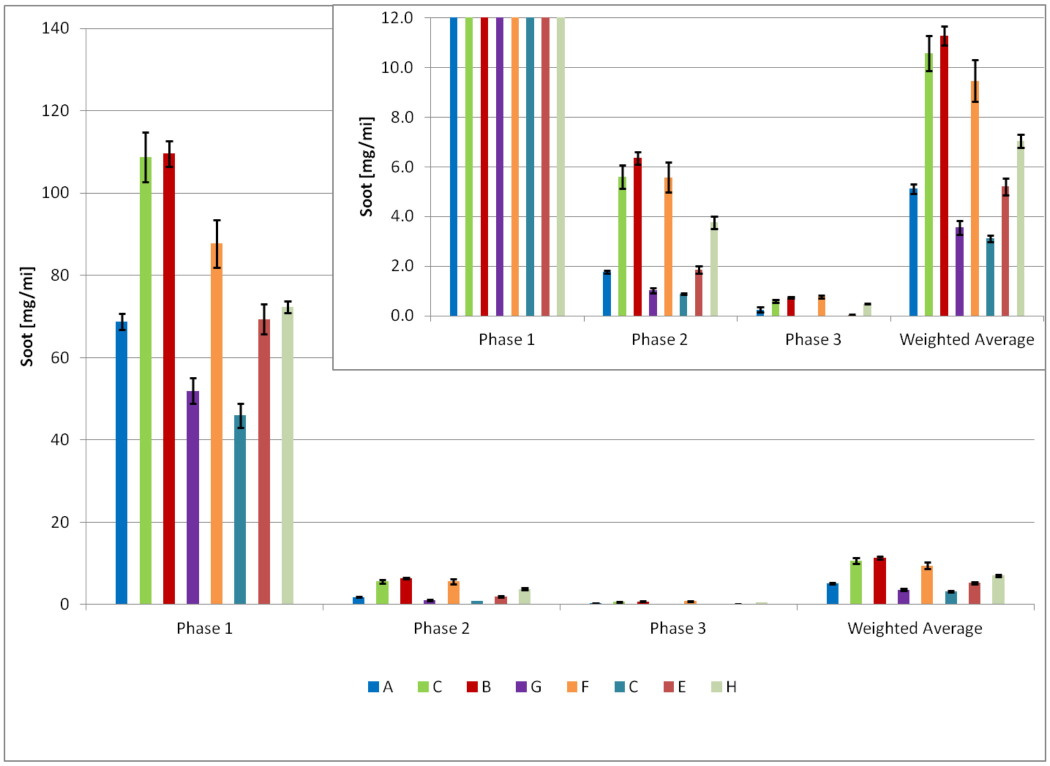


FIGURE E-119. MSS EMISSIONS FOR VEHICLE K

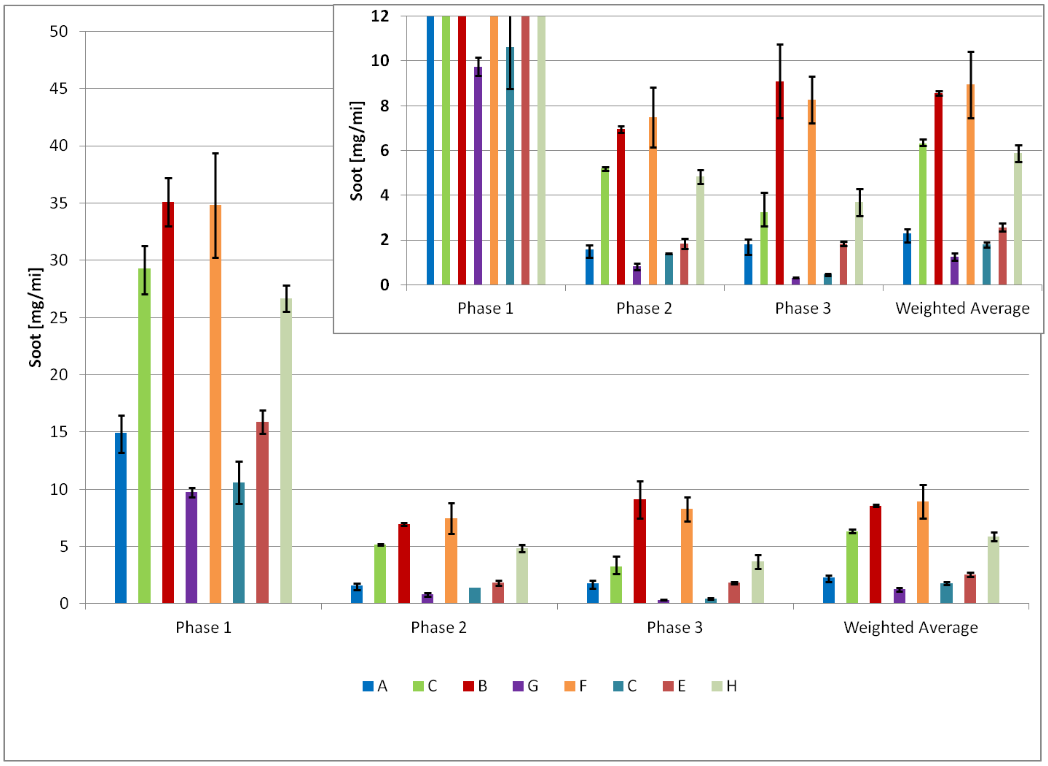


FIGURE E-120. MSS EMISSIONS FOR VEHICLE L

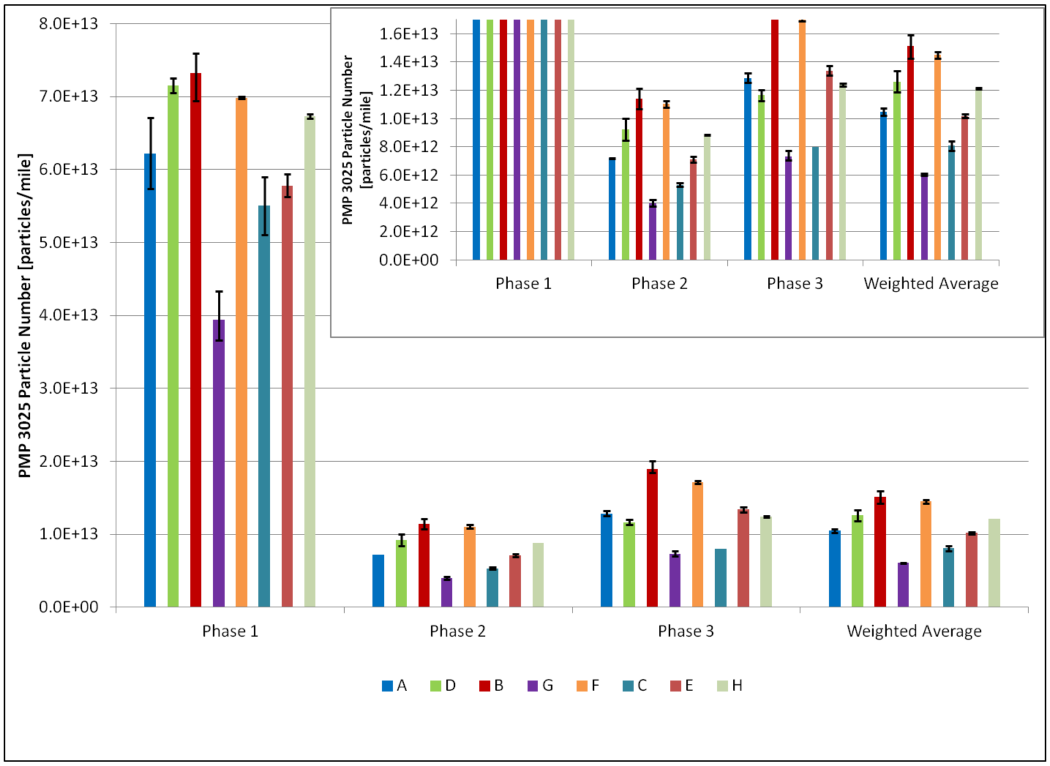


FIGURE E-121. CPC 3025 EMISSIONS FOR VEHICLE A

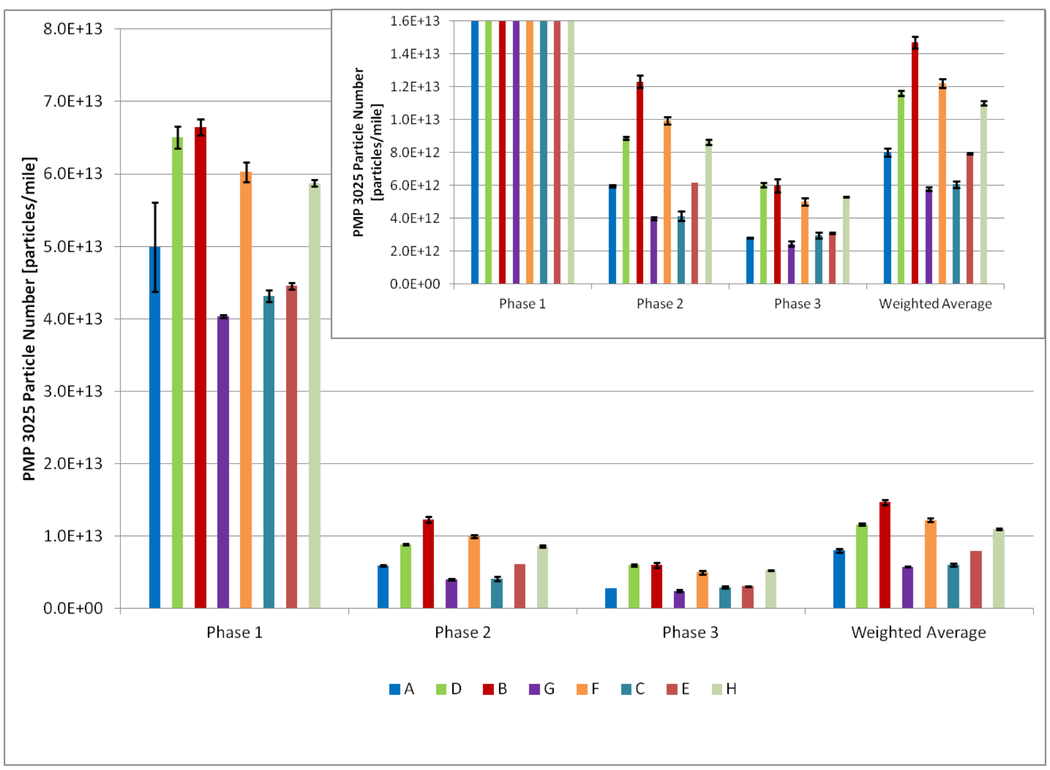


FIGURE E-122. CPC 3025 EMISSIONS FOR VEHICLE B

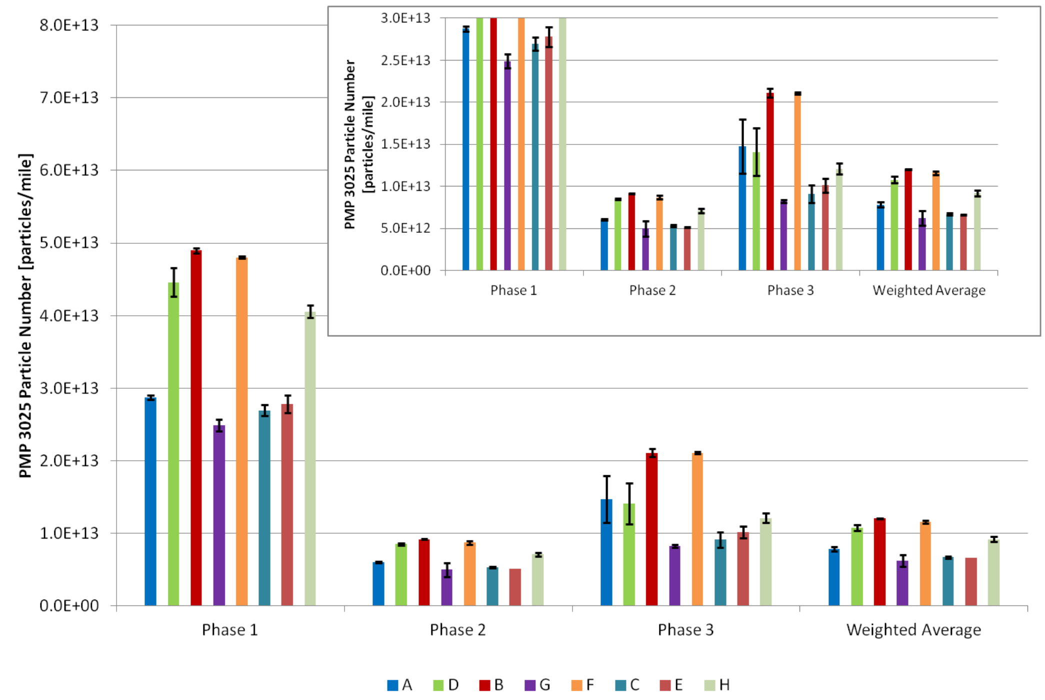


FIGURE E-123. CPC 3025 EMISSIONS FOR VEHICLE C

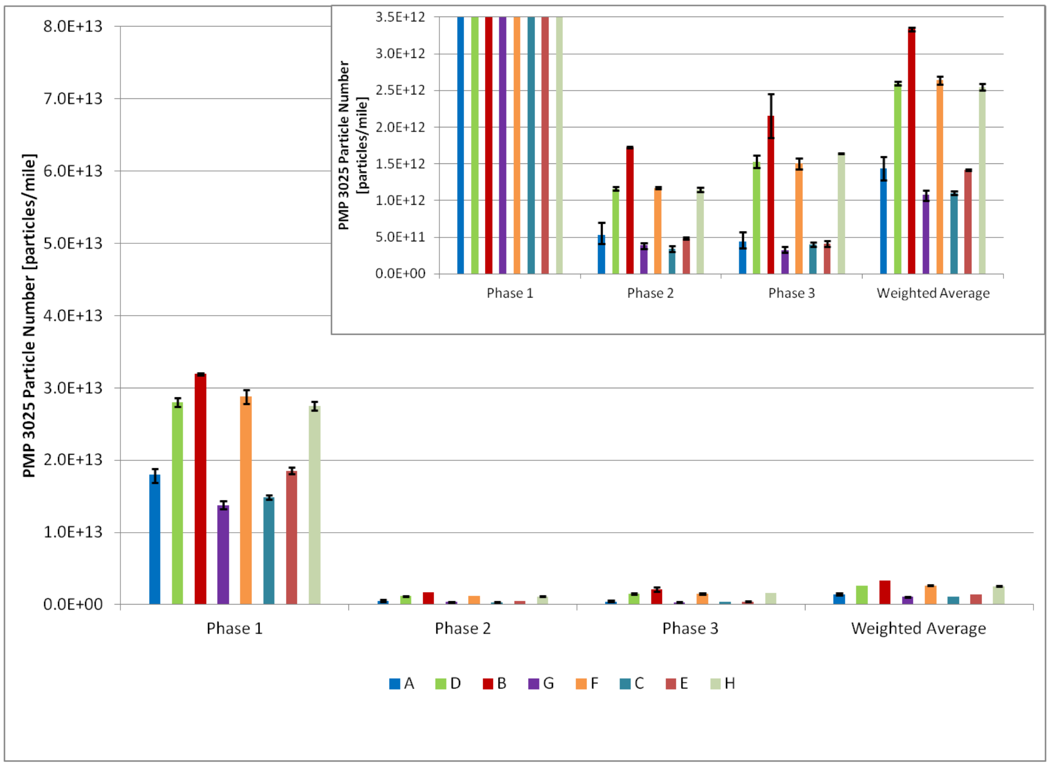


FIGURE E-124. CPC 3025 EMISSIONS FOR VEHICLE D

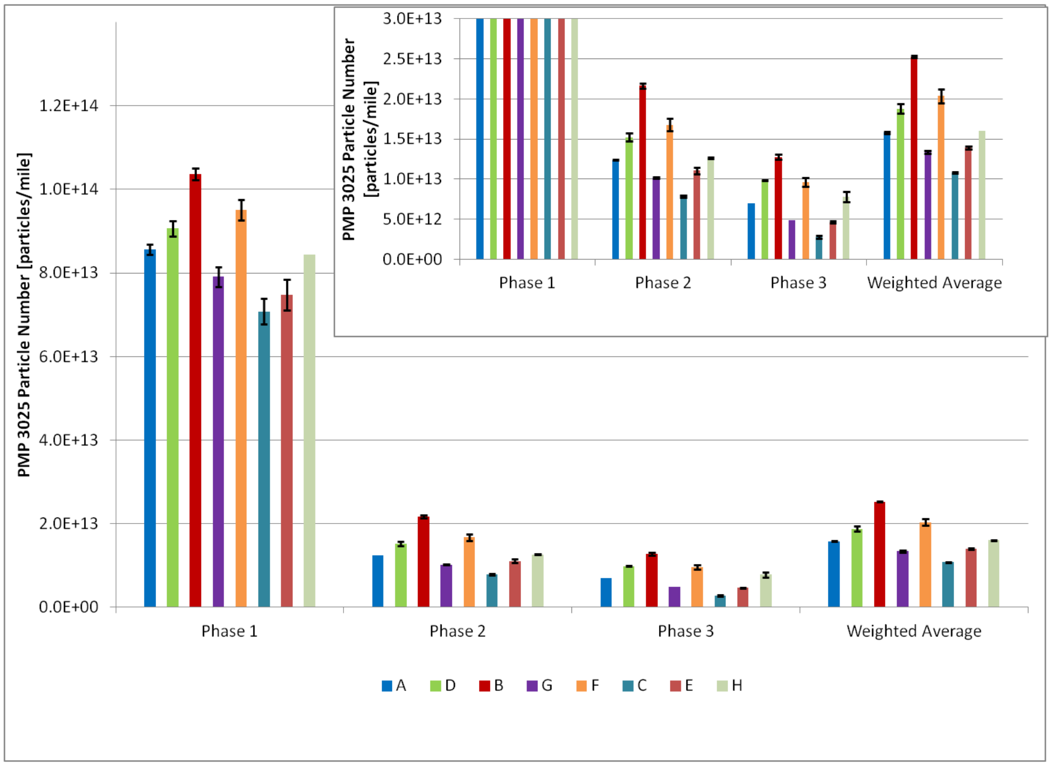


FIGURE E-125. CPC 3025 EMISSIONS FOR VEHICLE E

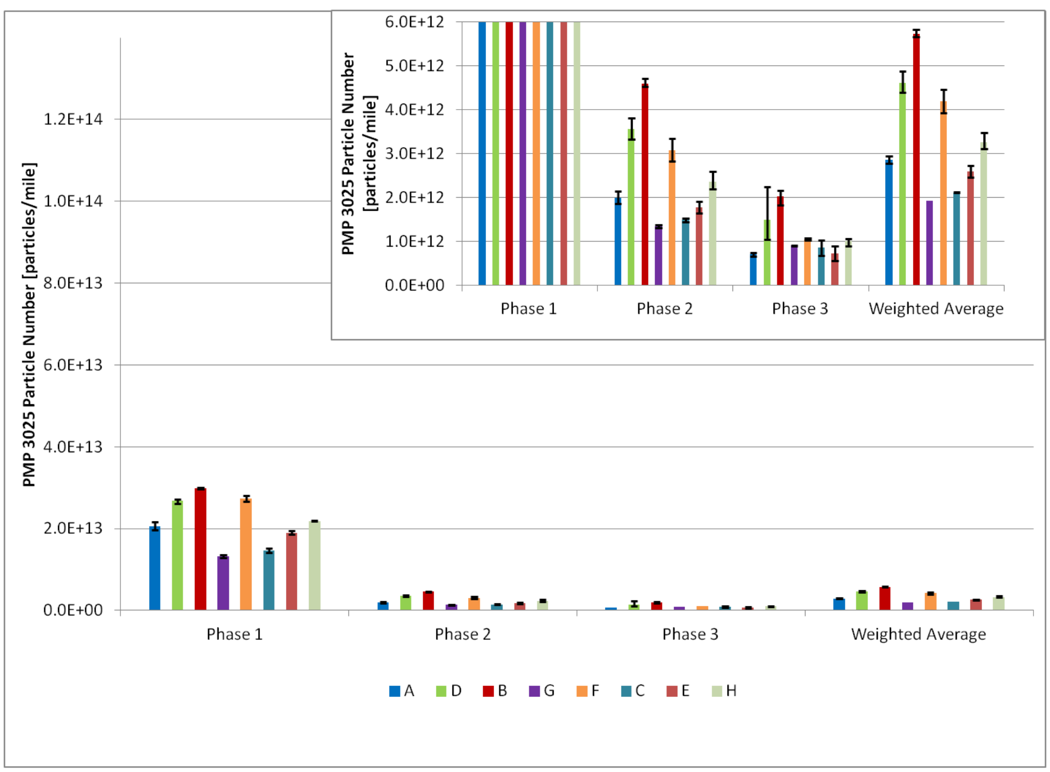


FIGURE E-126. CPC 3025 EMISSIONS FOR VEHICLE F

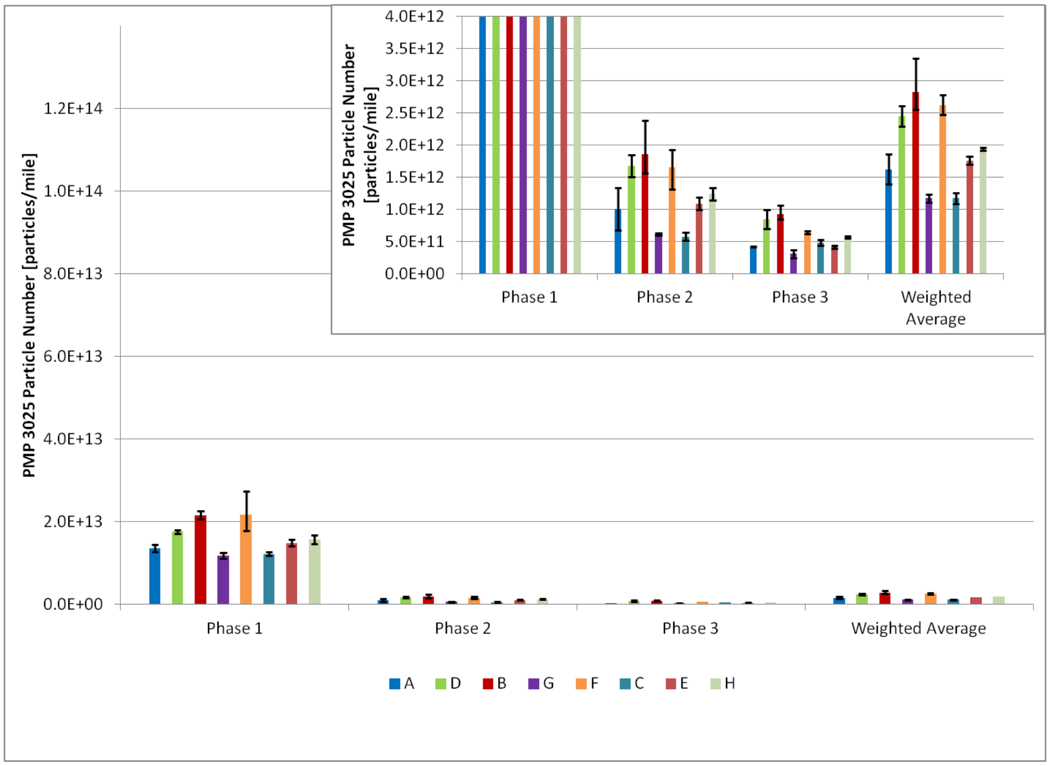


FIGURE E-127. CPC 3025 EMISSIONS FOR VEHICLE G

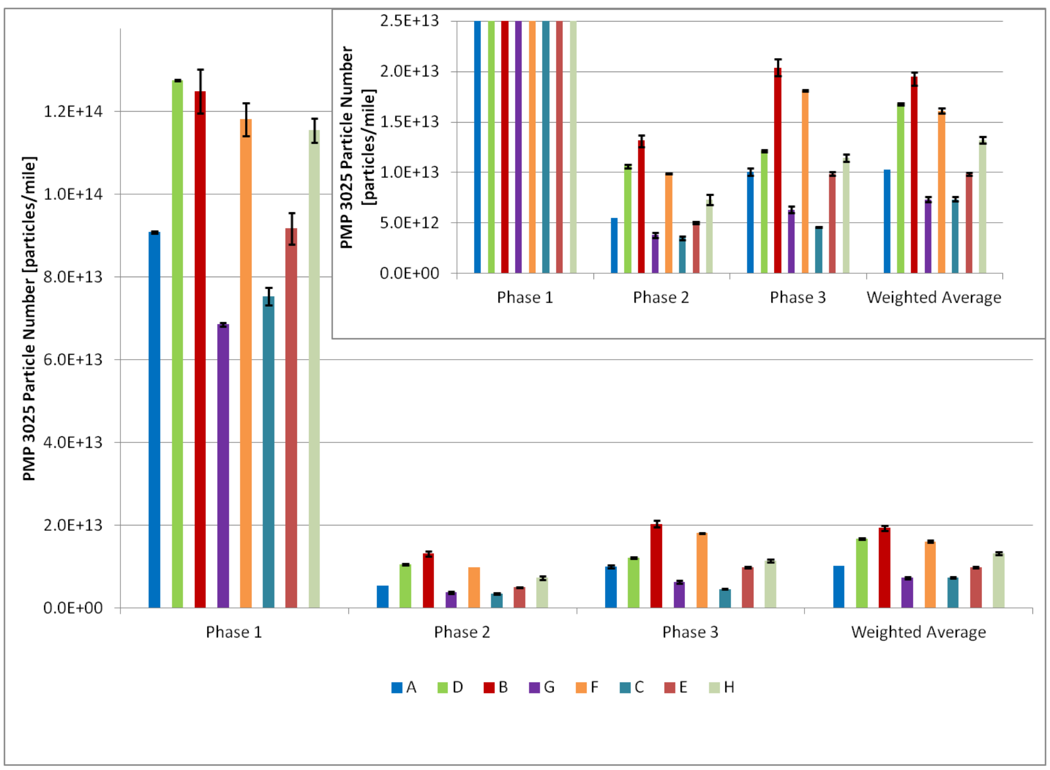


FIGURE E-128. CPC 3025 EMISSIONS FOR VEHICLE H

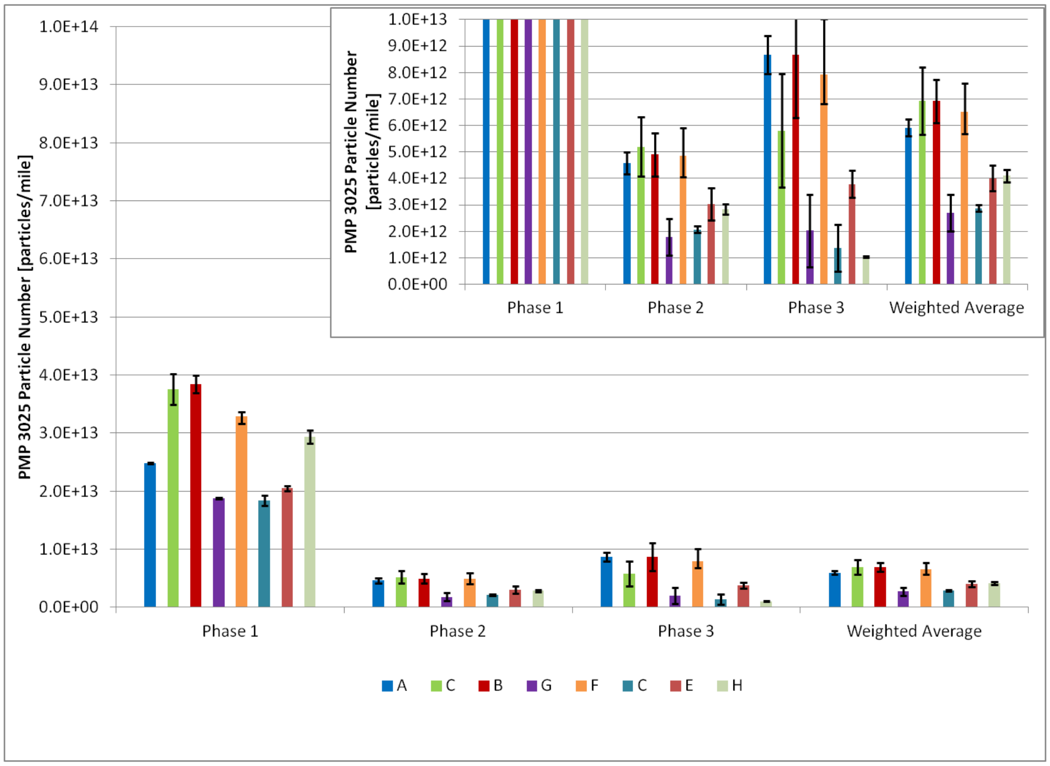


FIGURE E-129. CPC 3025 EMISSIONS FOR VEHICLE I

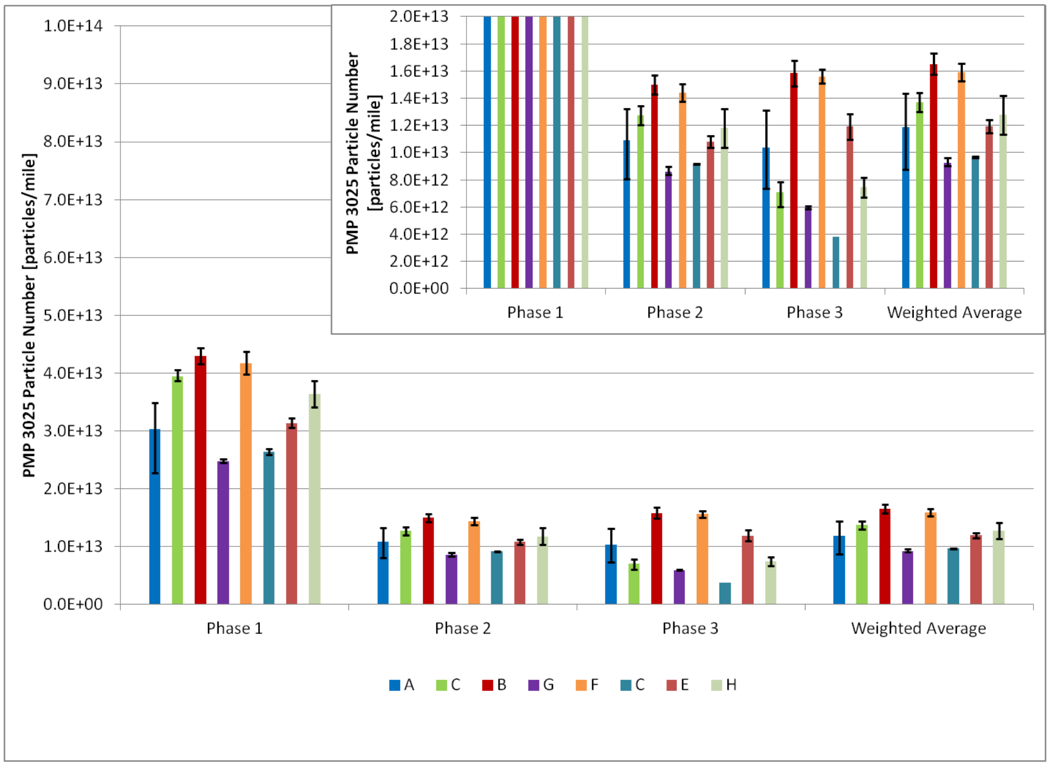


FIGURE E-130. CPC 3025 EMISSIONS FOR VEHICLE J

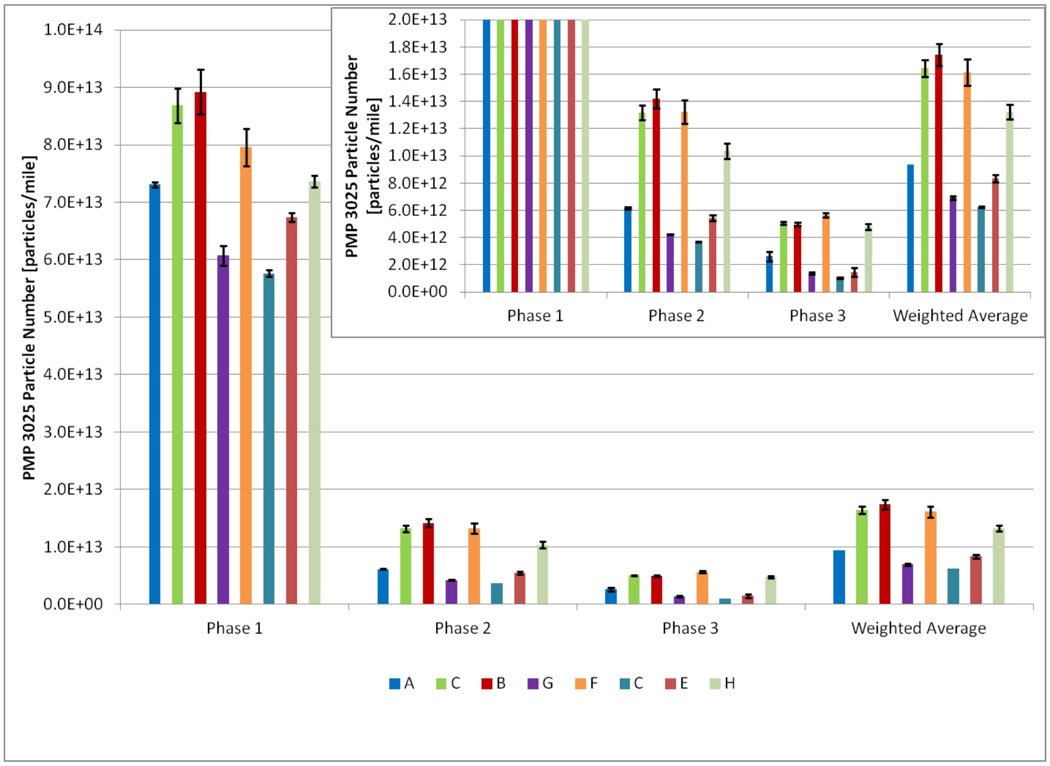


FIGURE E-131. CPC 3025 EMISSIONS FOR VEHICLE K

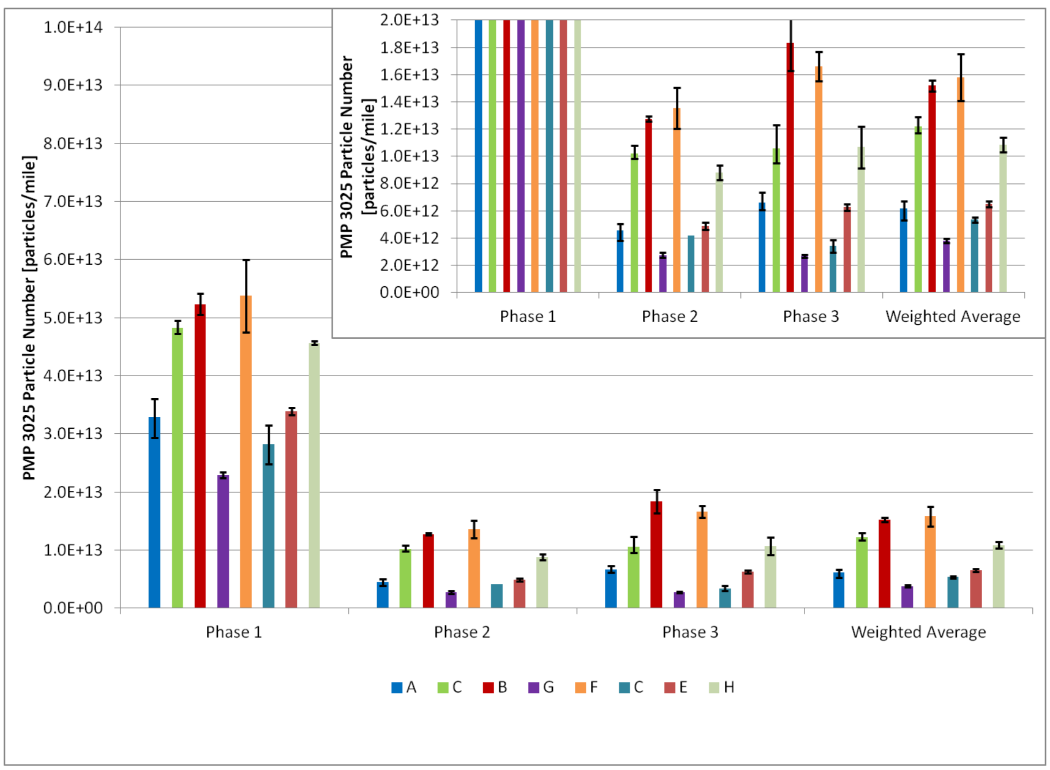


FIGURE E-132. CPC 3025 EMISSIONS FOR VEHICLE L

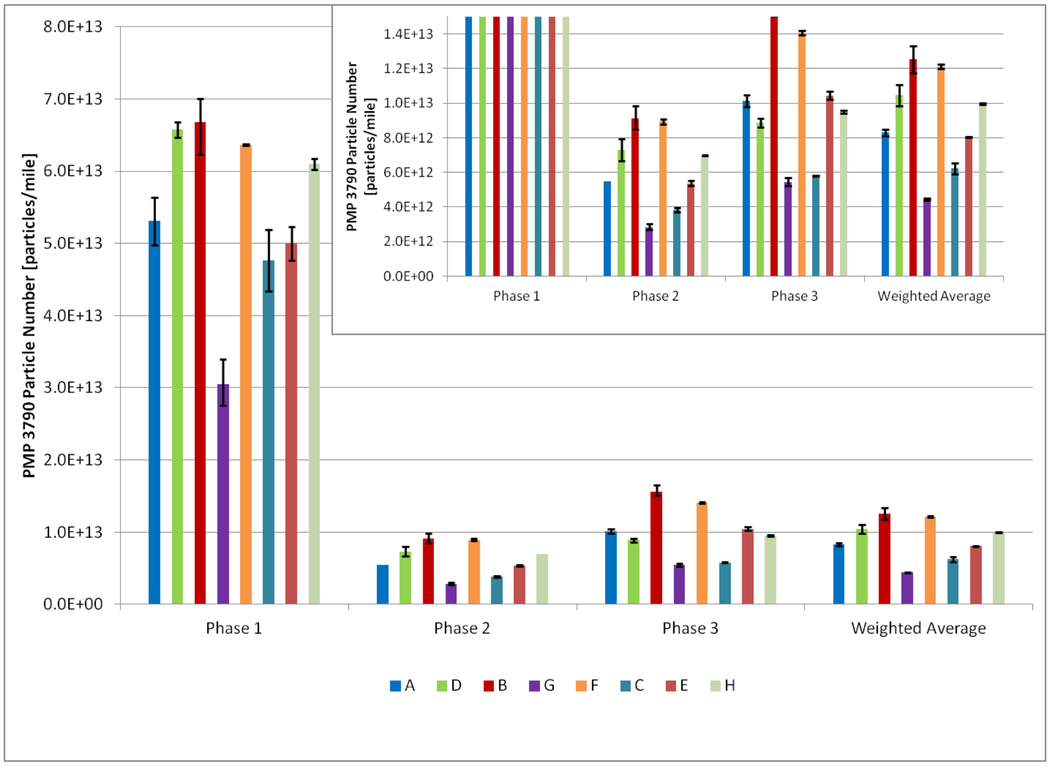


FIGURE E-133. CPC 3790 EMISSIONS FOR VEHICLE A

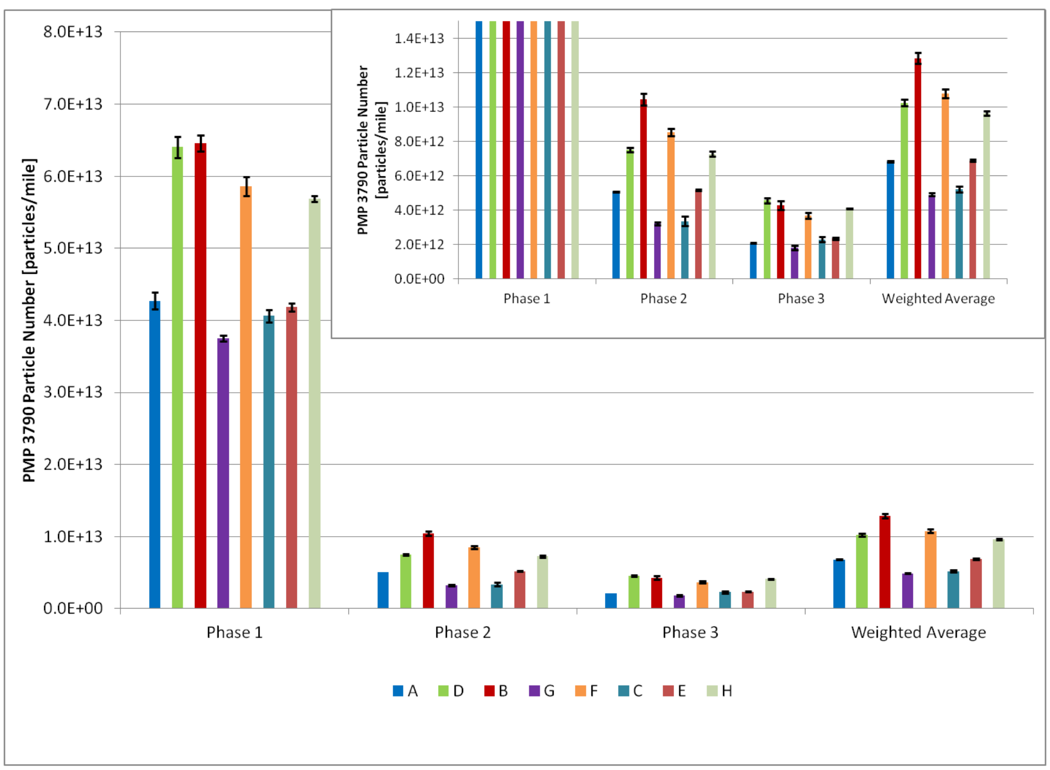


FIGURE E-134. CPC 3790 EMISSIONS FOR VEHICLE B

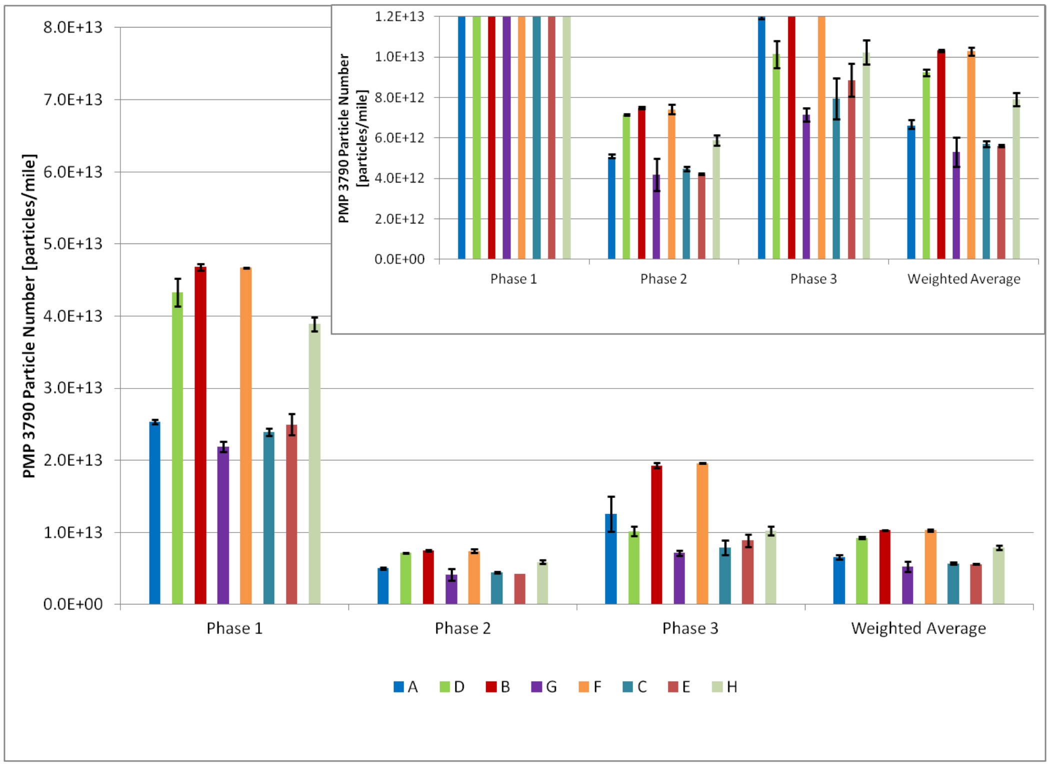


FIGURE E-135. CPC 3790 EMISSIONS FOR VEHICLE C

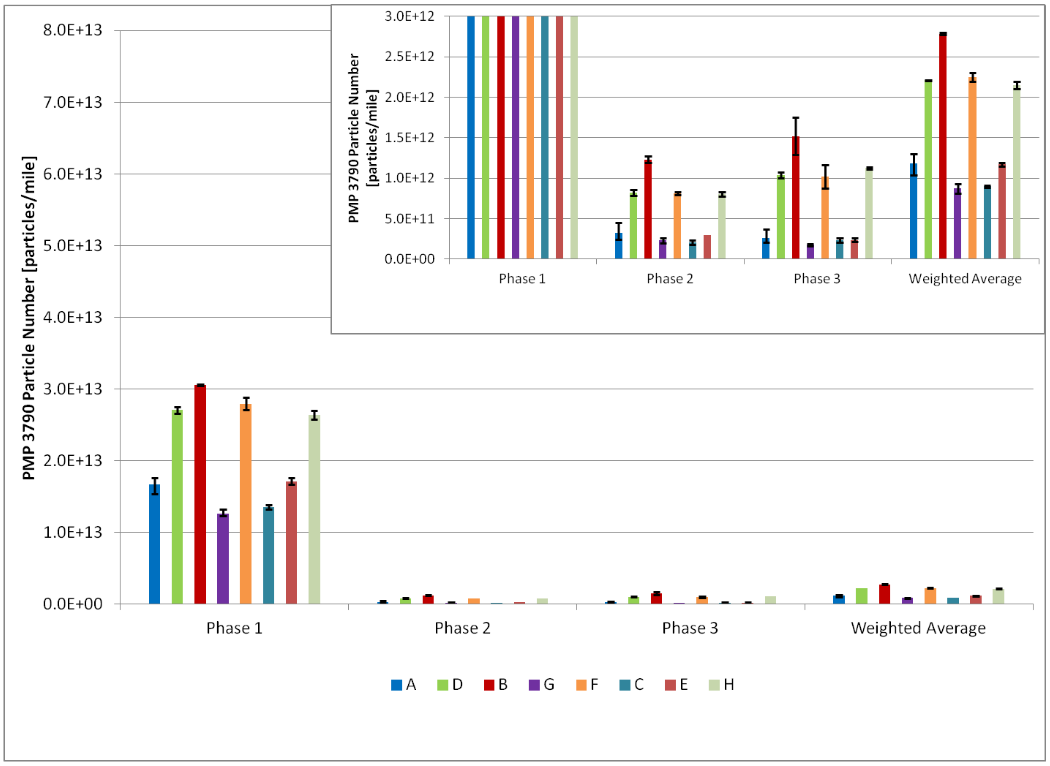


FIGURE E-136. CPC 3790 EMISSIONS FOR VEHICLE D

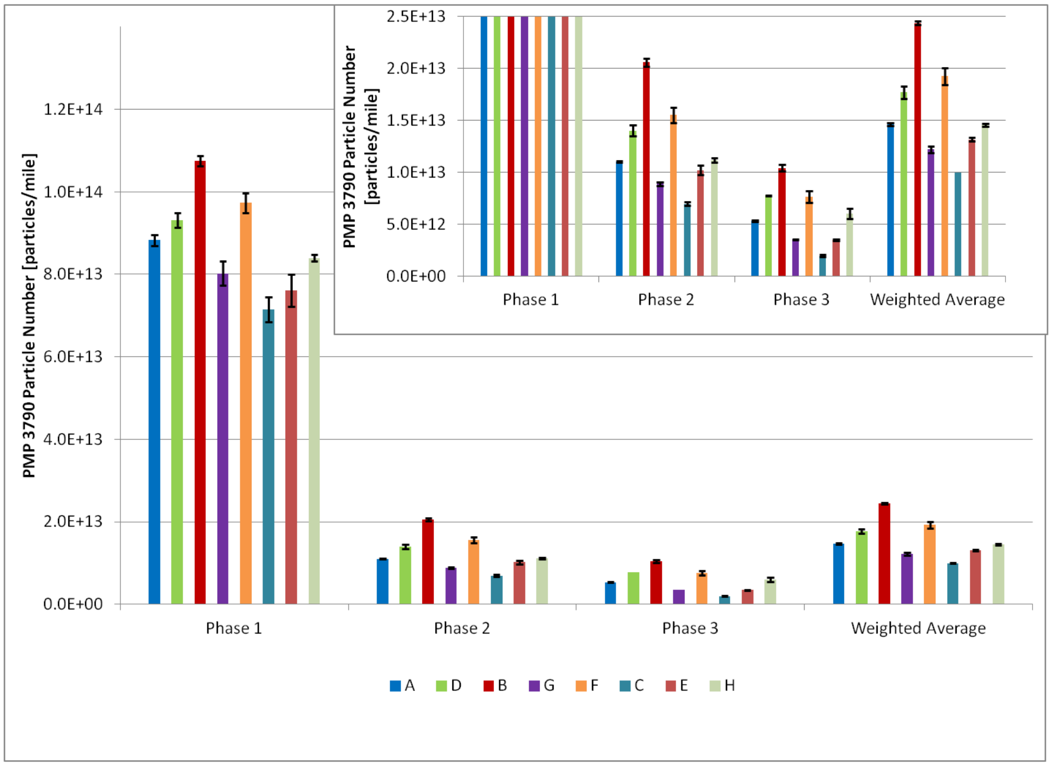


FIGURE E-137. CPC 3790 EMISSIONS FOR VEHICLE E

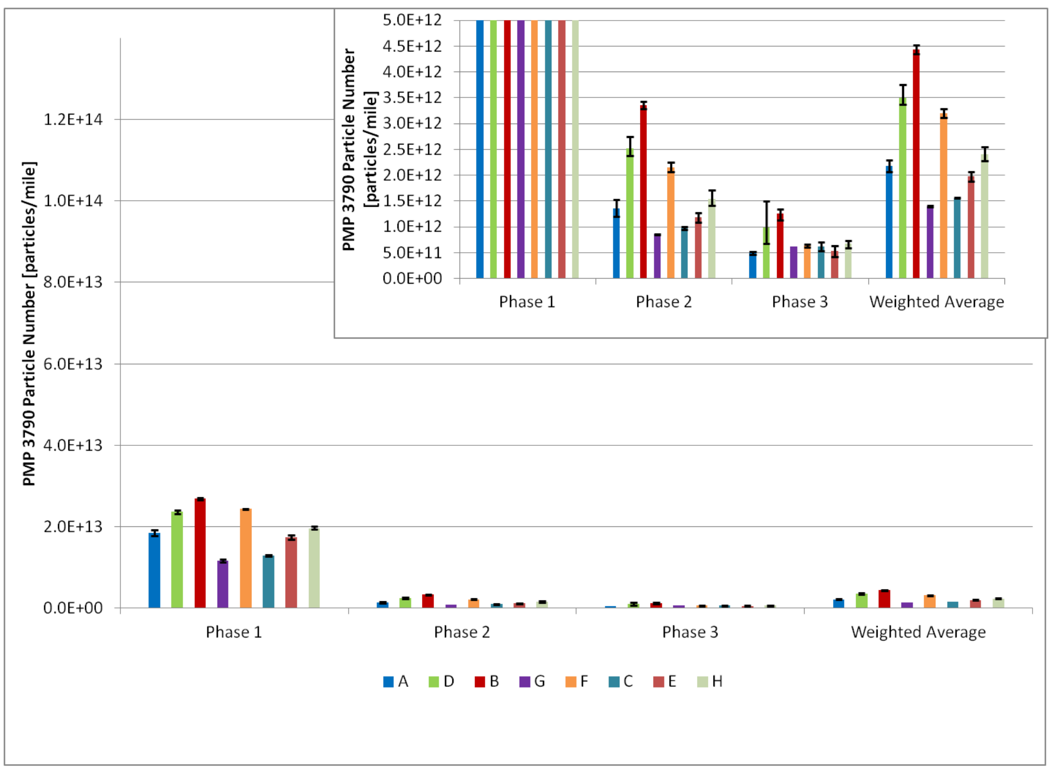


FIGURE E-138. CPC 3790 EMISSIONS FOR VEHICLE F

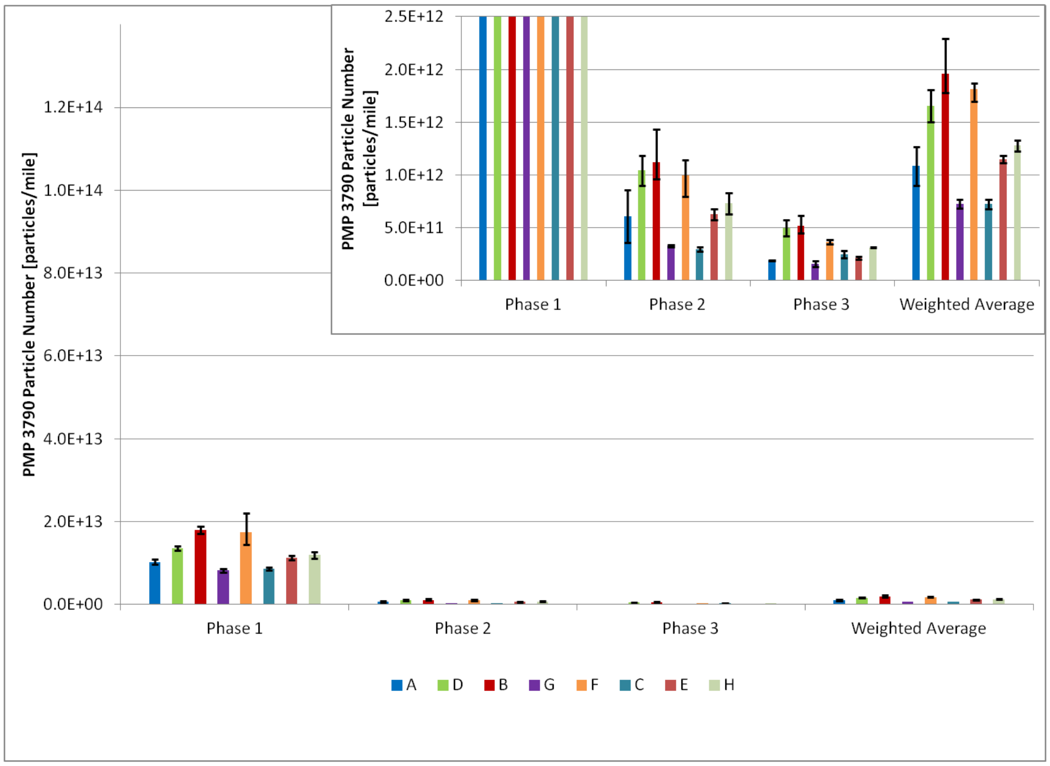


FIGURE E-139. CPC 3790 EMISSIONS FOR VEHICLE G

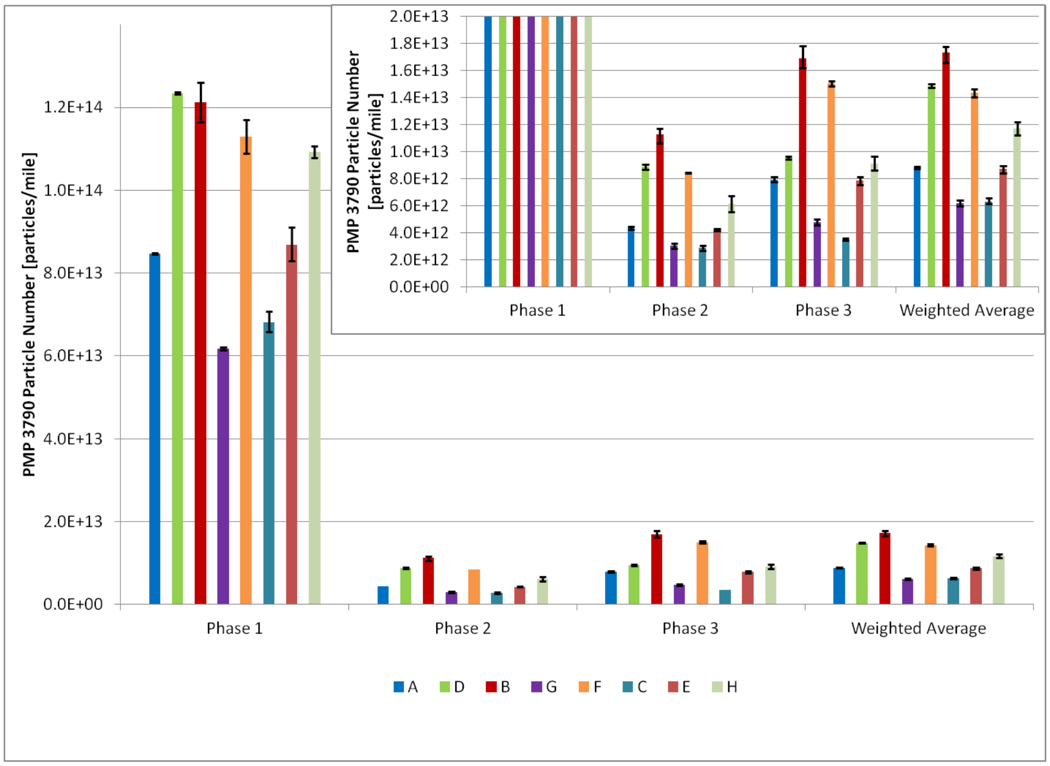


FIGURE E-140. CPC 3790 EMISSIONS FOR VEHICLE H

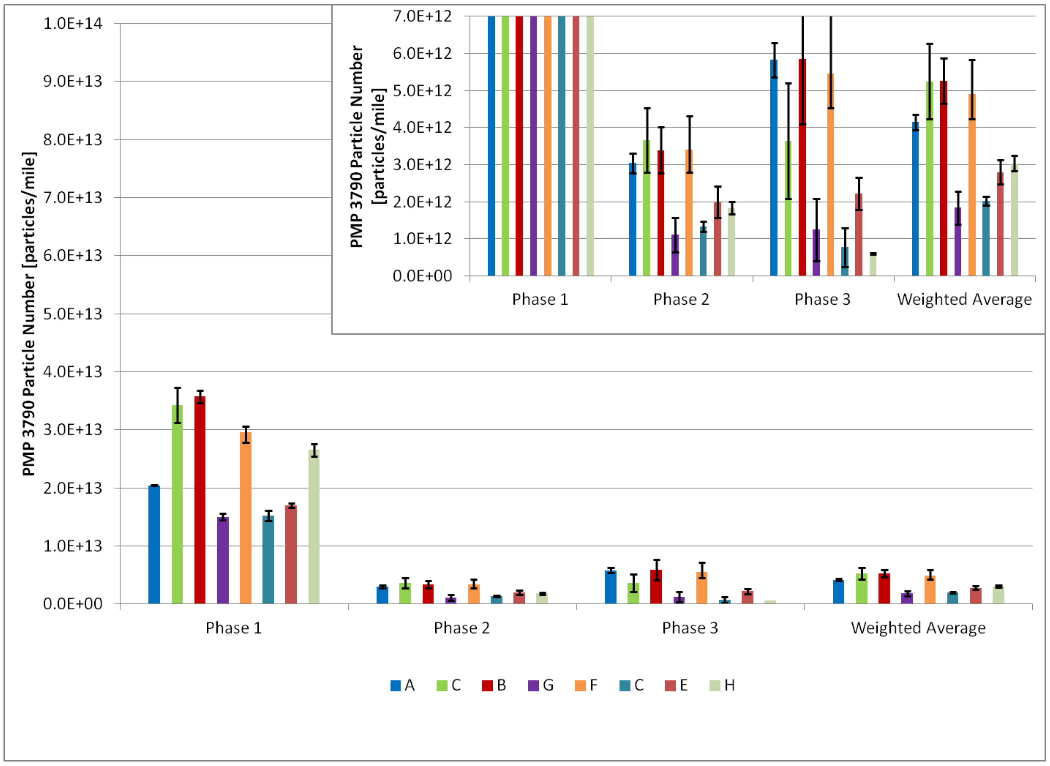


FIGURE E-141. CPC 3790 EMISSIONS FOR VEHICLE I

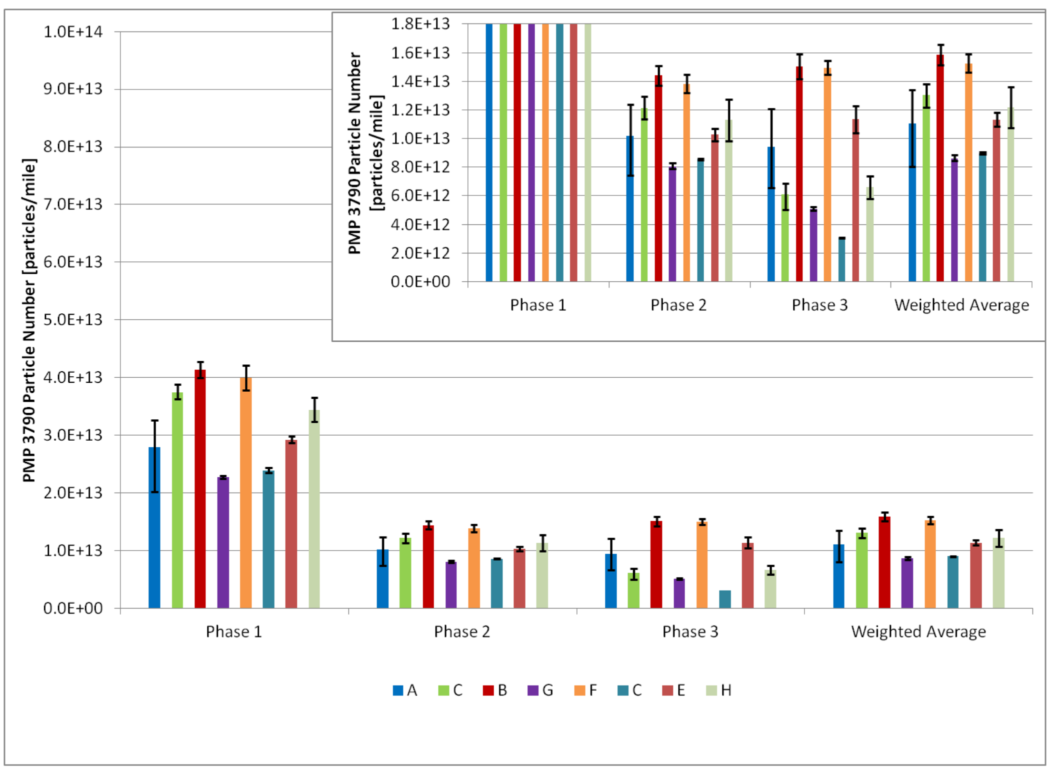


FIGURE E-142. CPC 3790 EMISSIONS FOR VEHICLE J

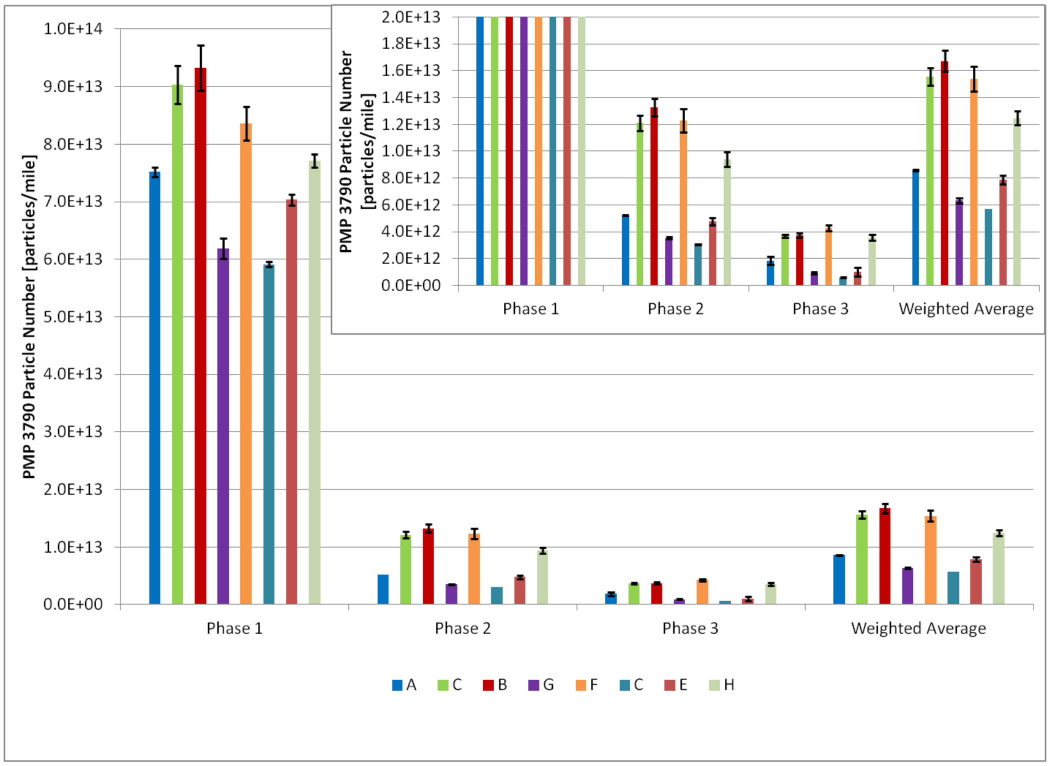


FIGURE E-143. CPC 3790 EMISSIONS FOR VEHICLE K

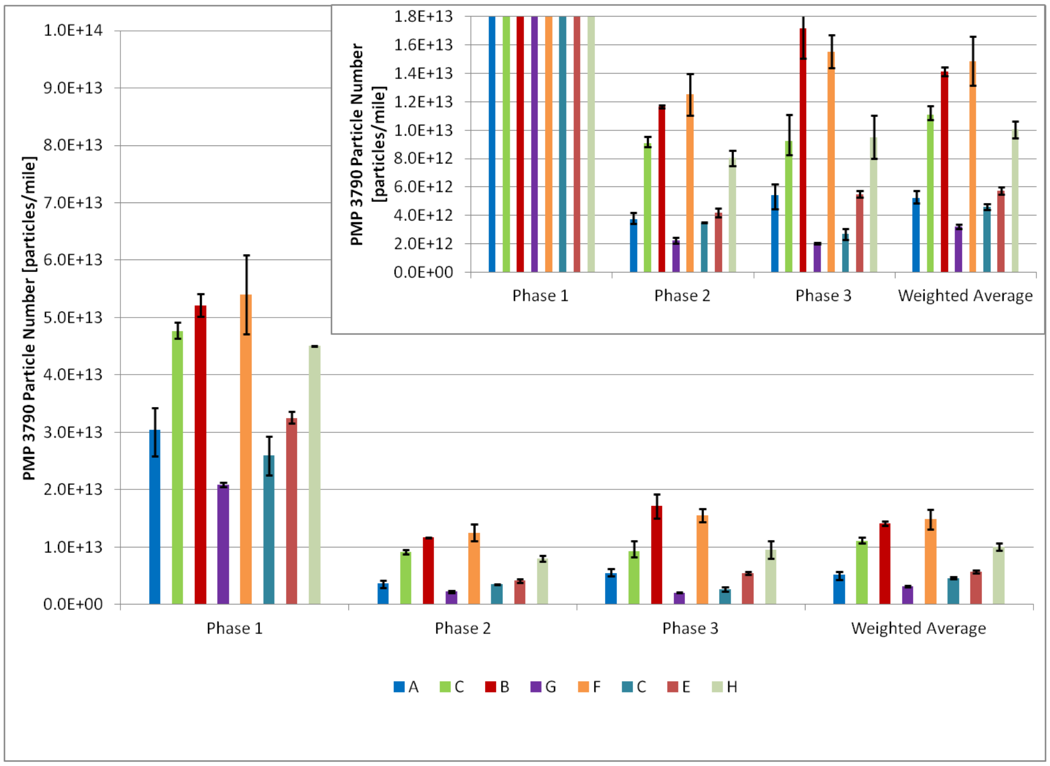


FIGURE E-144. CPC 3790 EMISSIONS FOR VEHICLE L

FIGURE F

PMI, ETHANOL CONTENT, AND OCTANE EFFECTS ON PM EMISSIONS

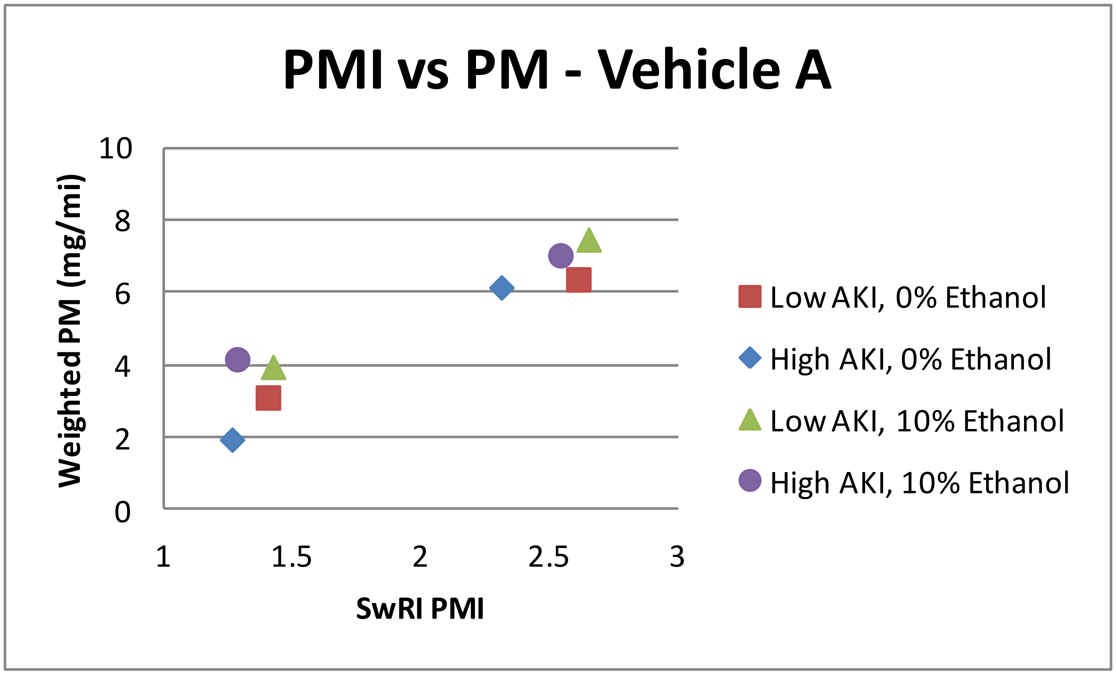


FIGURE F-1. VEHICLE A PM EMISSIONS VERSUS PMI

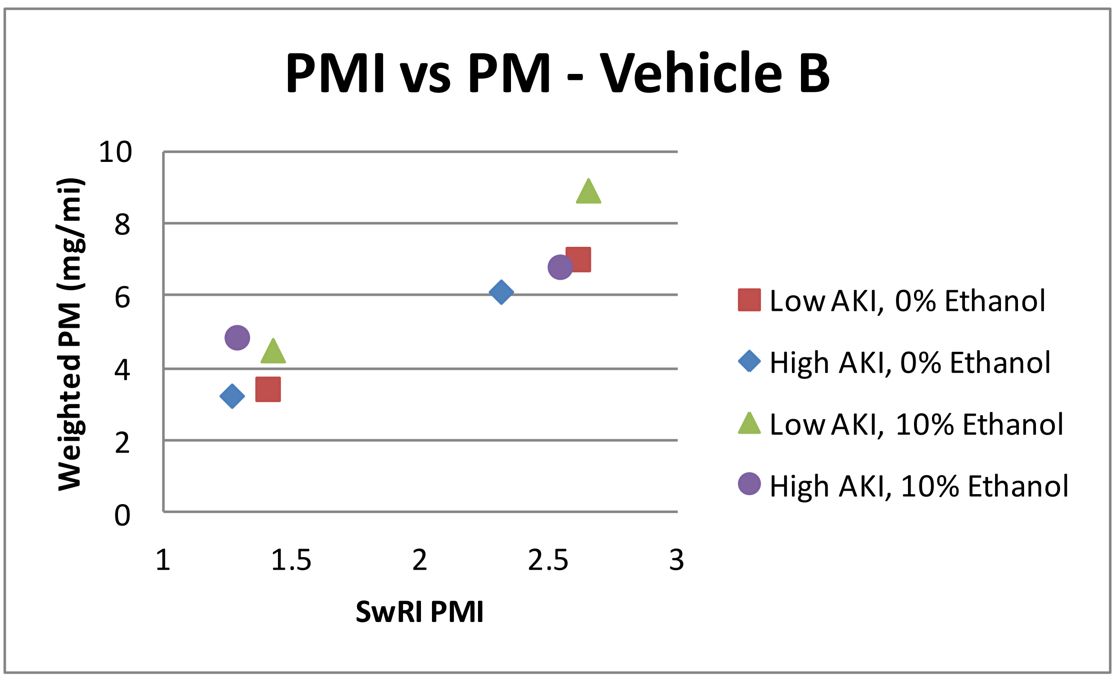


FIGURE F-2. VEHICLE B PM EMISSIONS VERSUS PMI

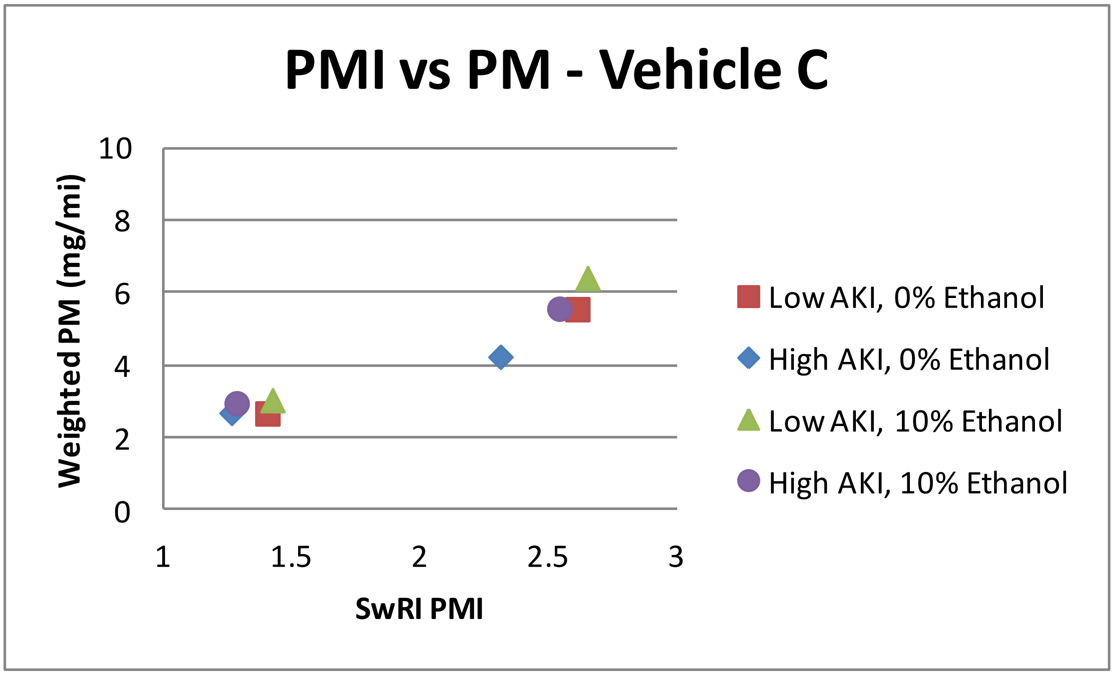


FIGURE F-3. VEHICLE C PM EMISSIONS VERSUS PMI

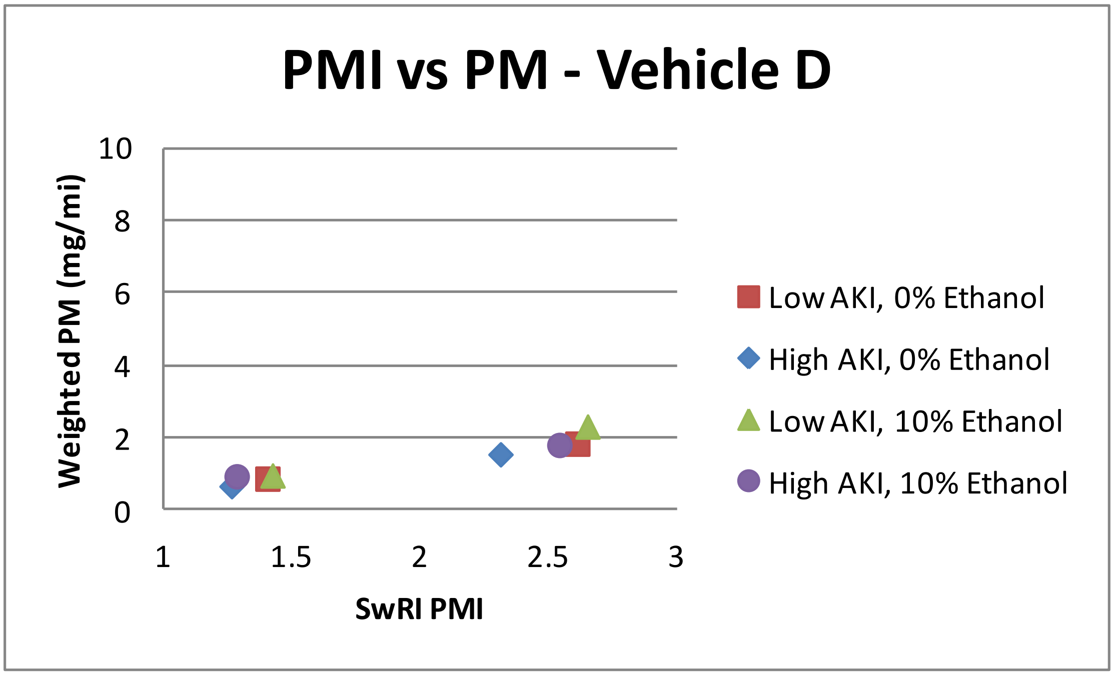


FIGURE F-4. VEHICLE D PM EMISSIONS VERSUS PMI

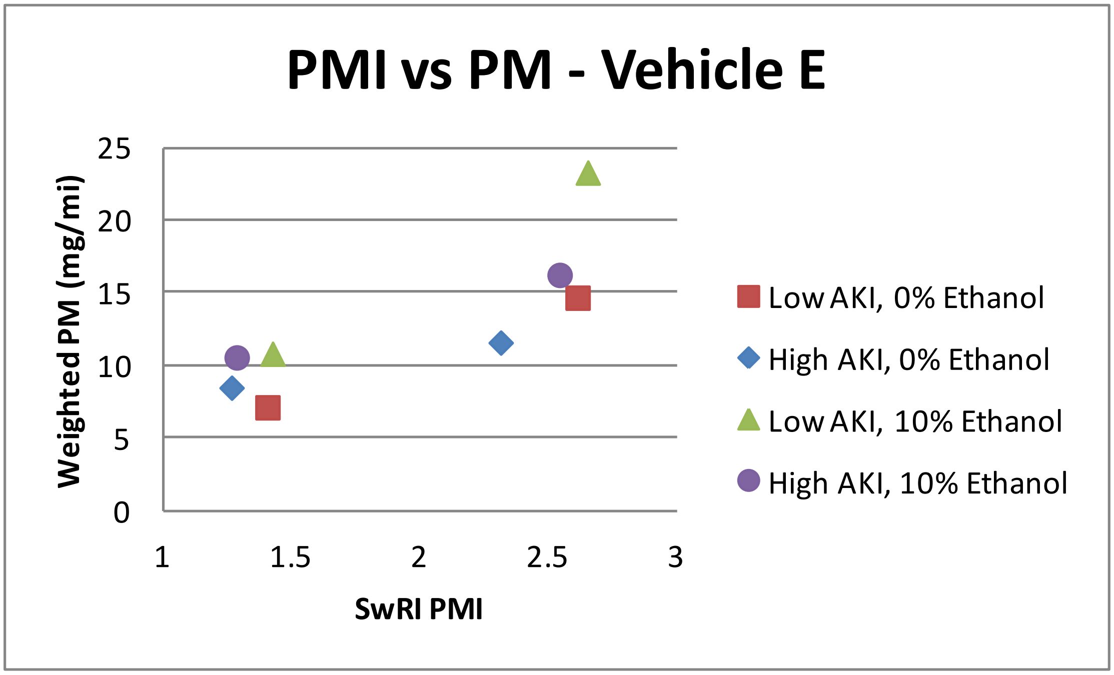


FIGURE F-5. VEHICLE E PM EMISSIONS VERSUS PMI

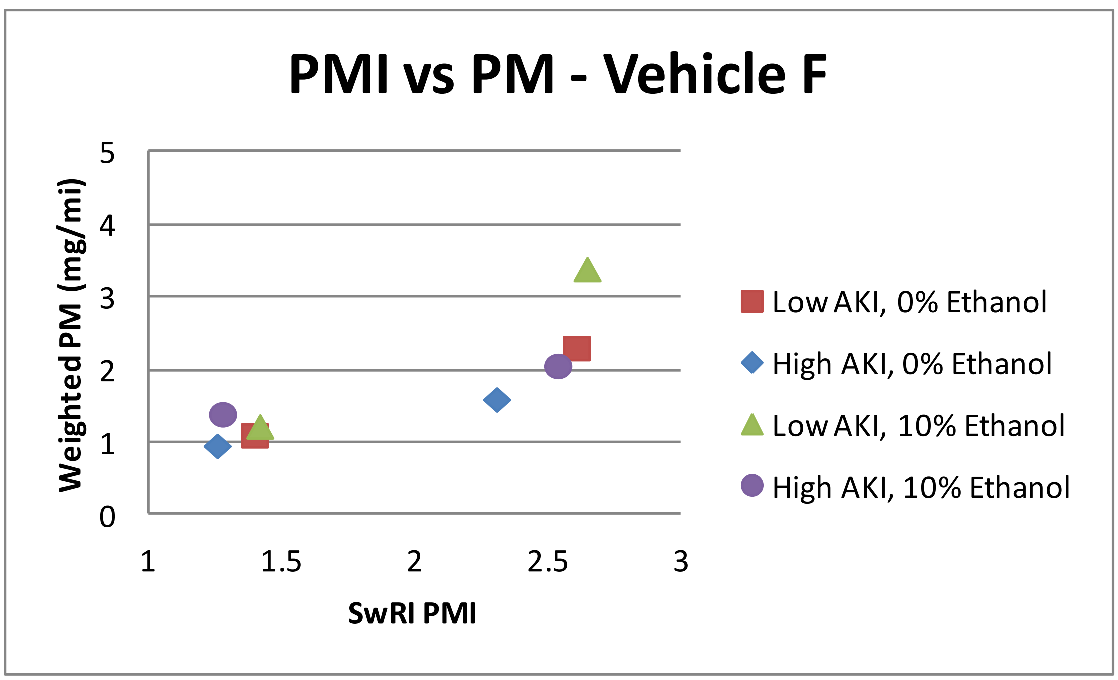


FIGURE F-6. VEHICLE F PM EMISSIONS VERSUS PMI

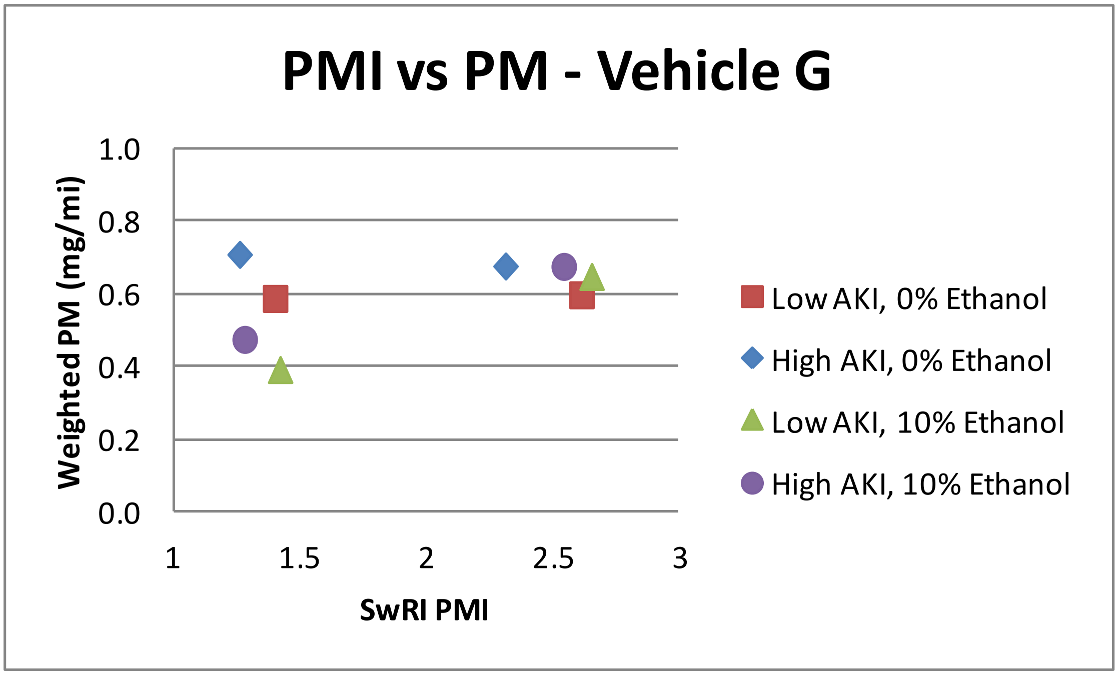


FIGURE F-7. VEHICLE G PM EMISSIONS VERSUS PMI

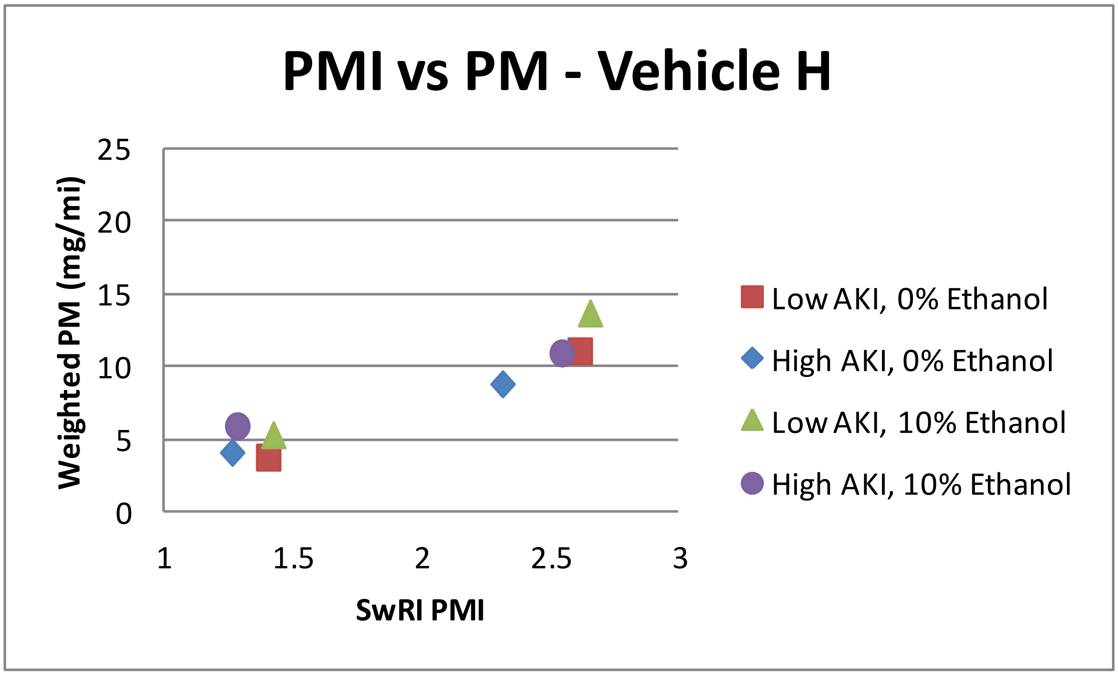


FIGURE F-8. VEHICLE H PM EMISSIONS VERSUS PMI

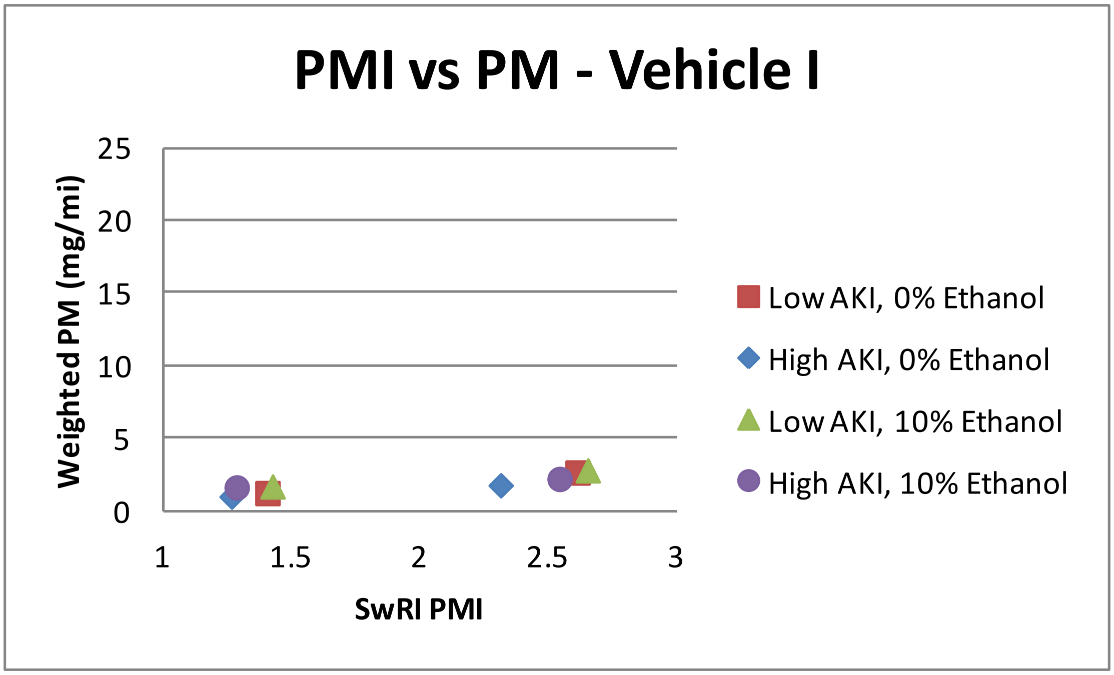


FIGURE F-9. VEHICLE I PM EMISSIONS VERSUS PMI

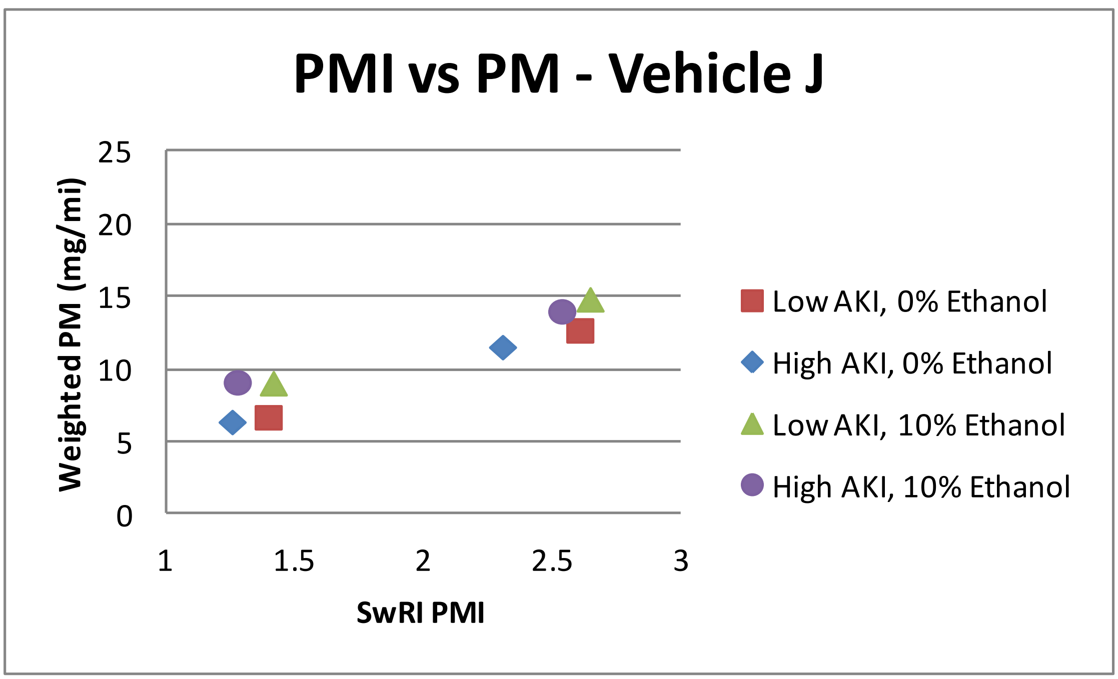


FIGURE F-10. VEHICLE J PM EMISSIONS VERSUS PMI

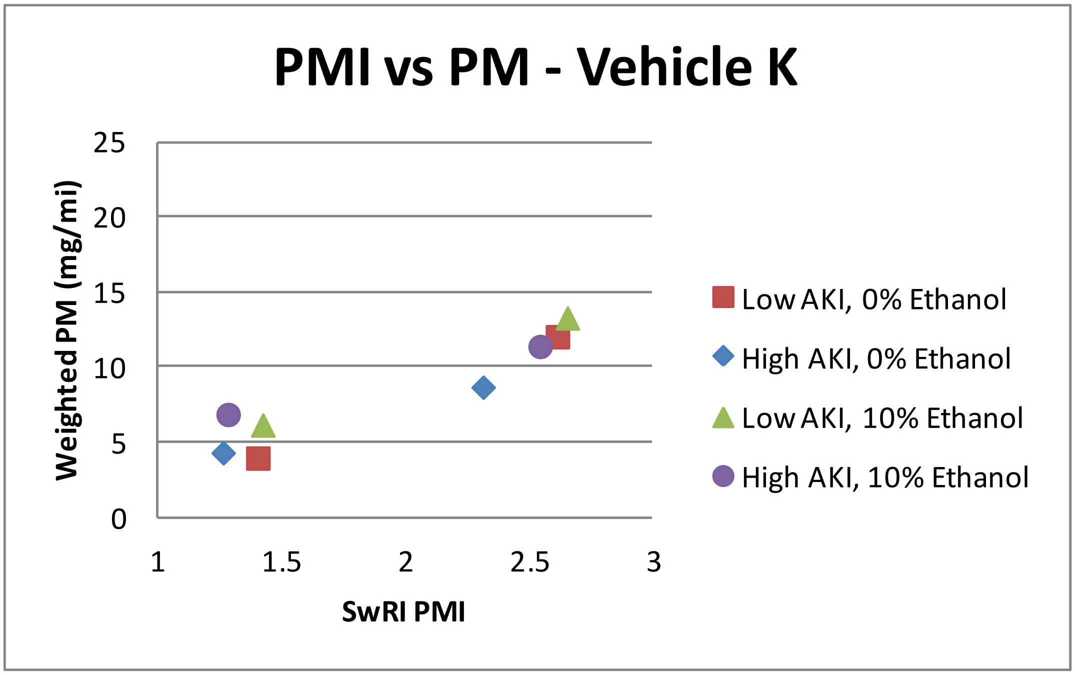


FIGURE F-11. VEHICLE K PM EMISSIONS VERSUS PMI

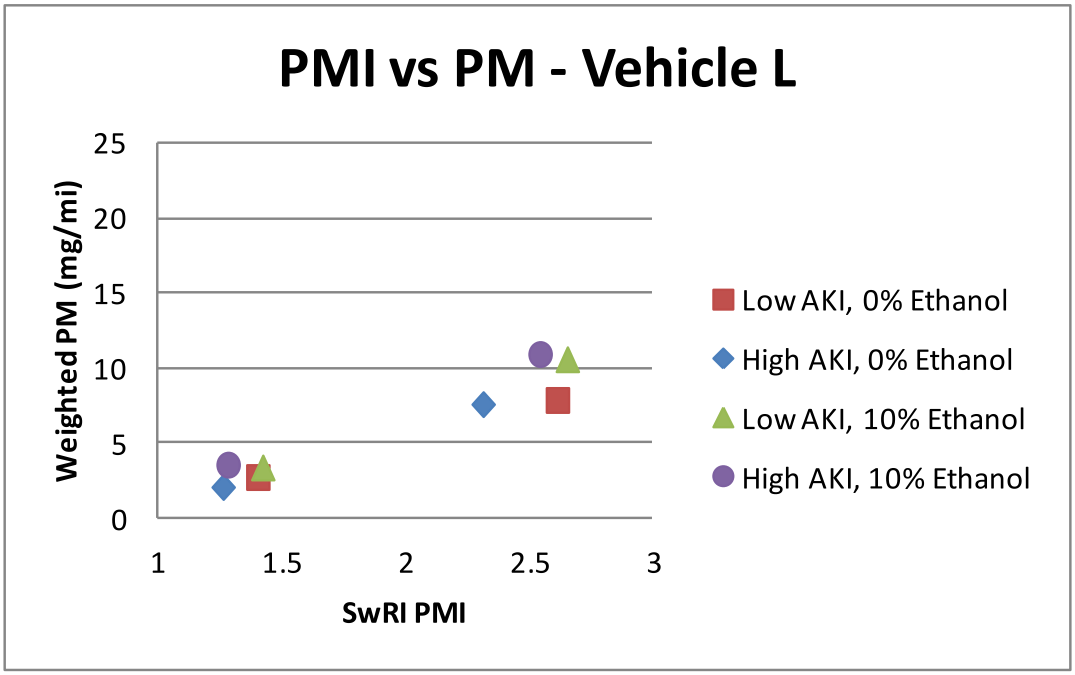


FIGURE F-12. VEHICLE L PM EMISSIONS VERSUS PMI

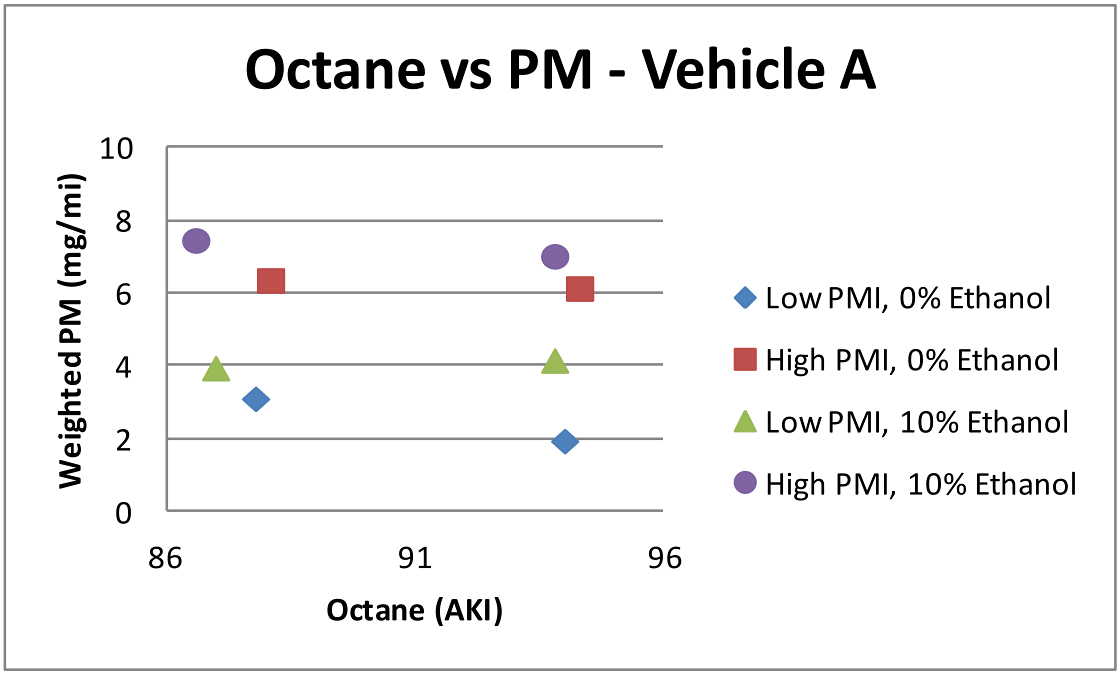


FIGURE F-13. VEHICLE A PM EMISSIONS VERSUS OCTANE (AKI)

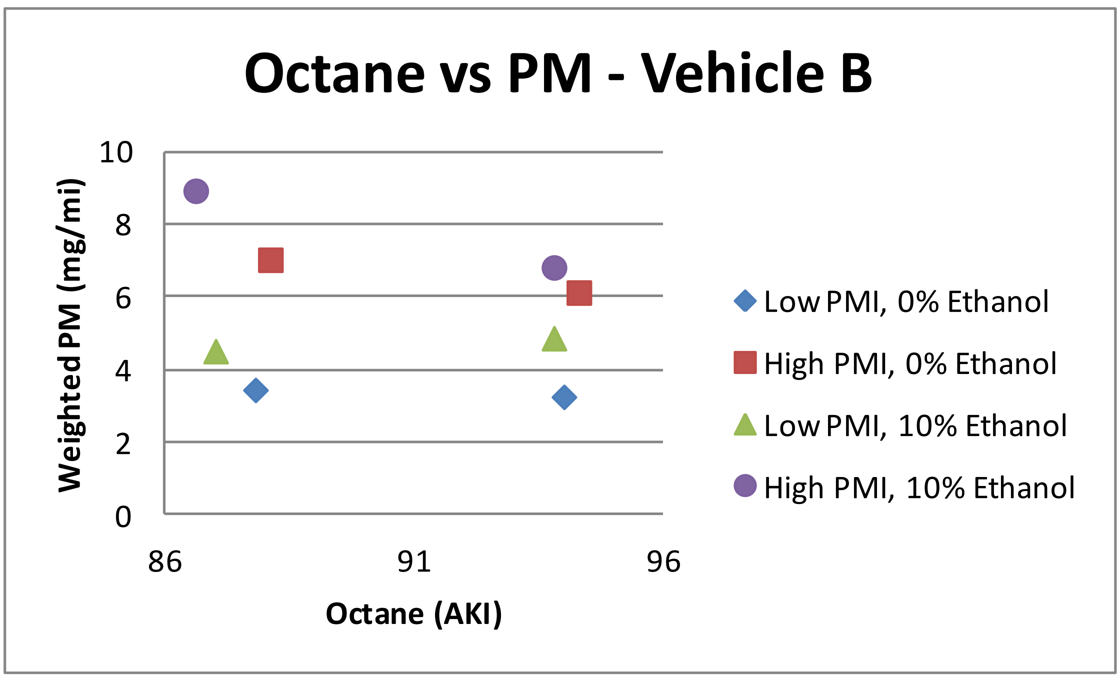


FIGURE F-14. VEHICLE B PM EMISSIONS VERSUS OCTANE (AKI)

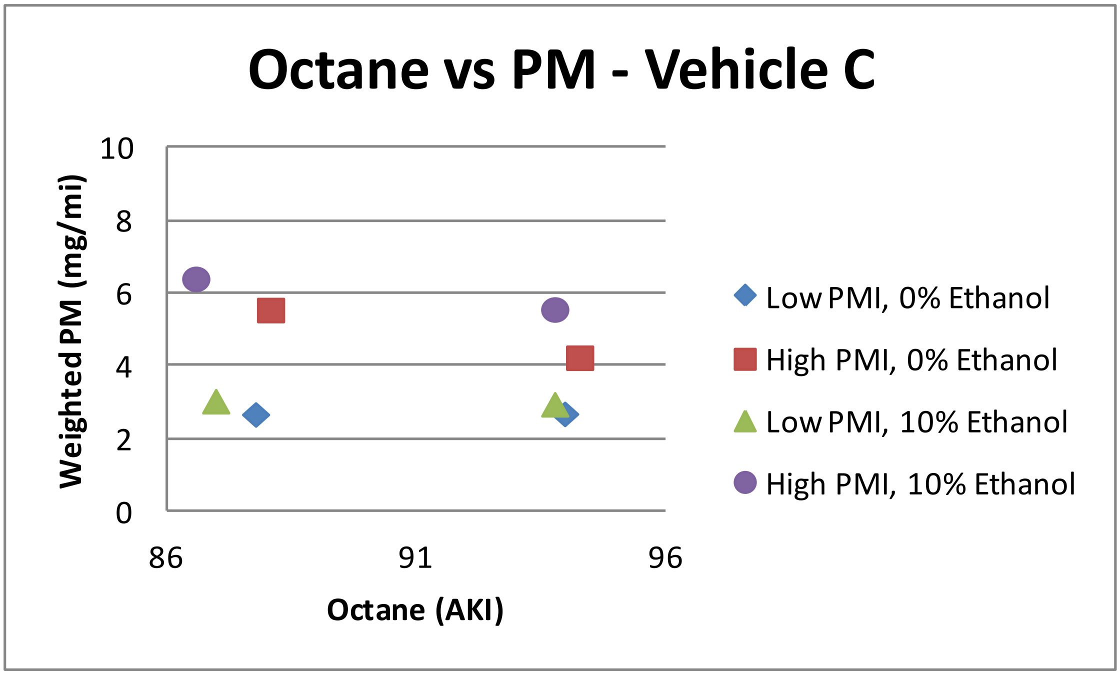


FIGURE F-15. VEHICLE C PM EMISSIONS VERSUS OCTANE (AKI)

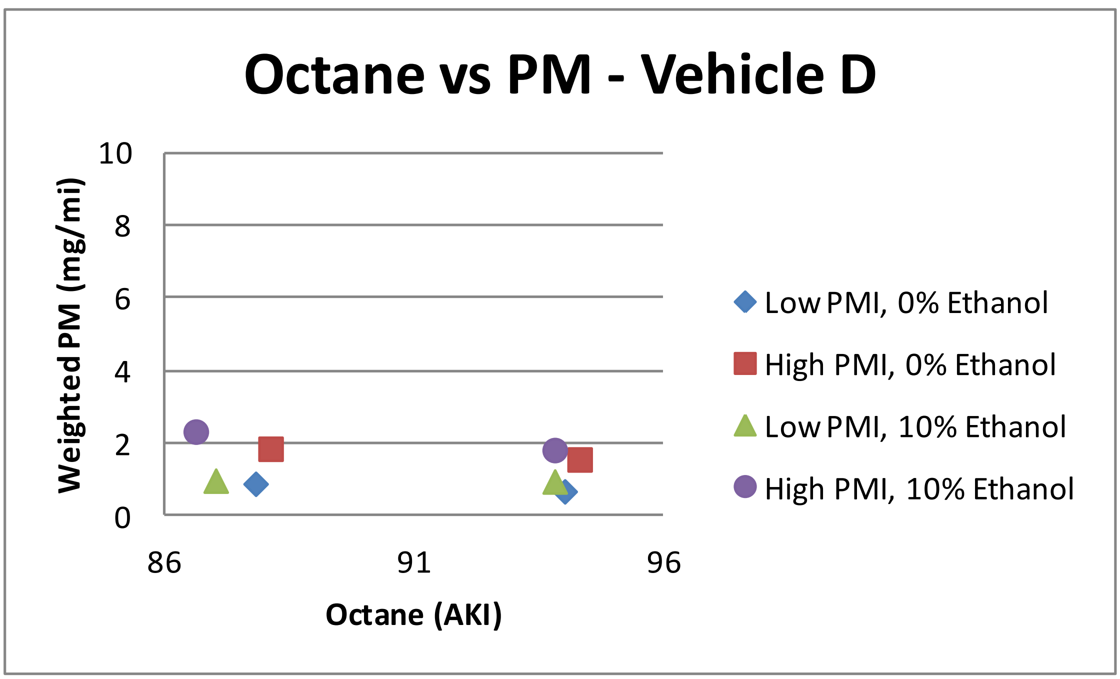


FIGURE F-16. VEHICLE D PM EMISSIONS VERSUS OCTANE (AKI)

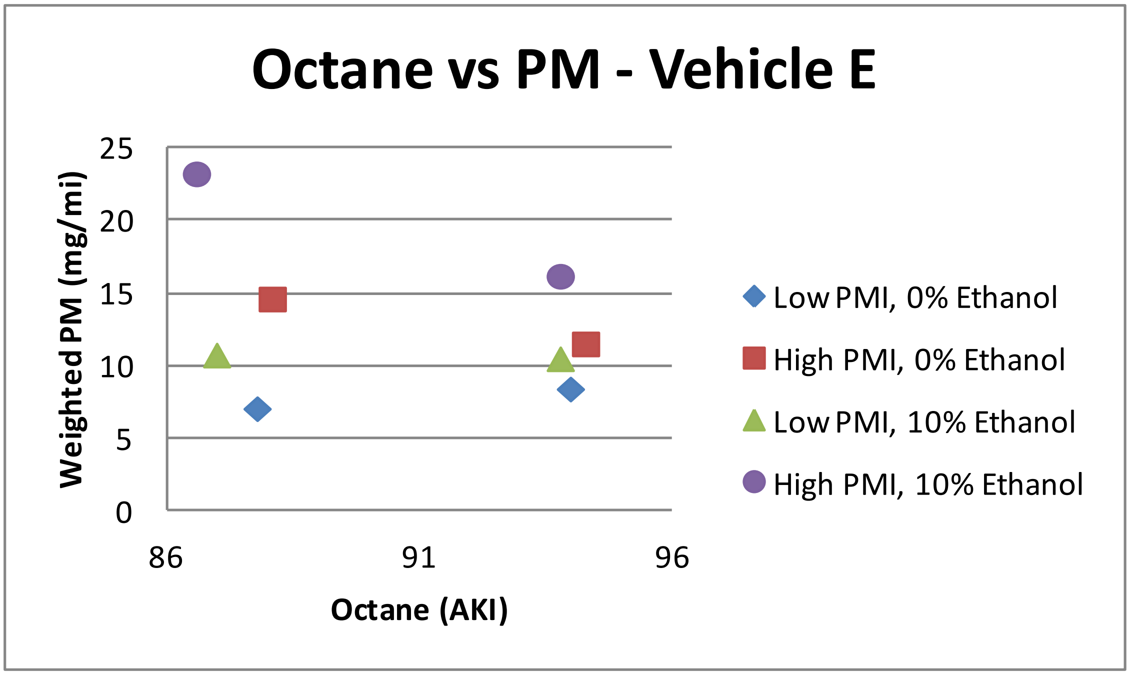


FIGURE F-17. VEHICLE E PM EMISSIONS VERSUS OCTANE (AKI)

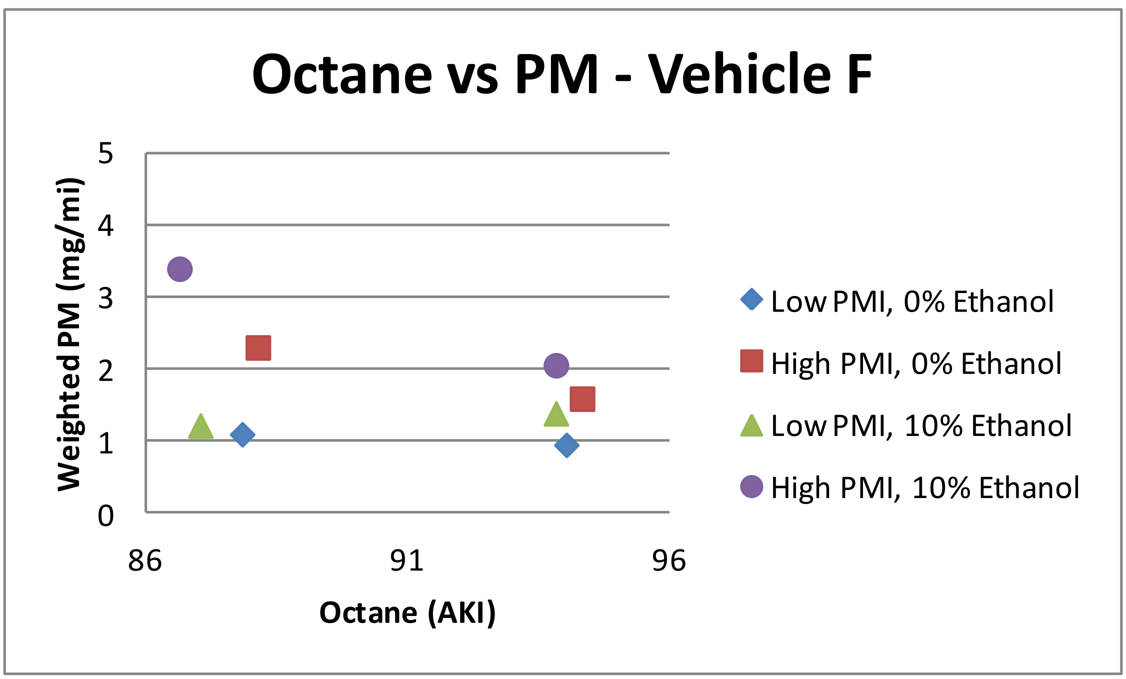


FIGURE F-18. VEHICLE F PM EMISSIONS VERSUS OCTANE (AKI)

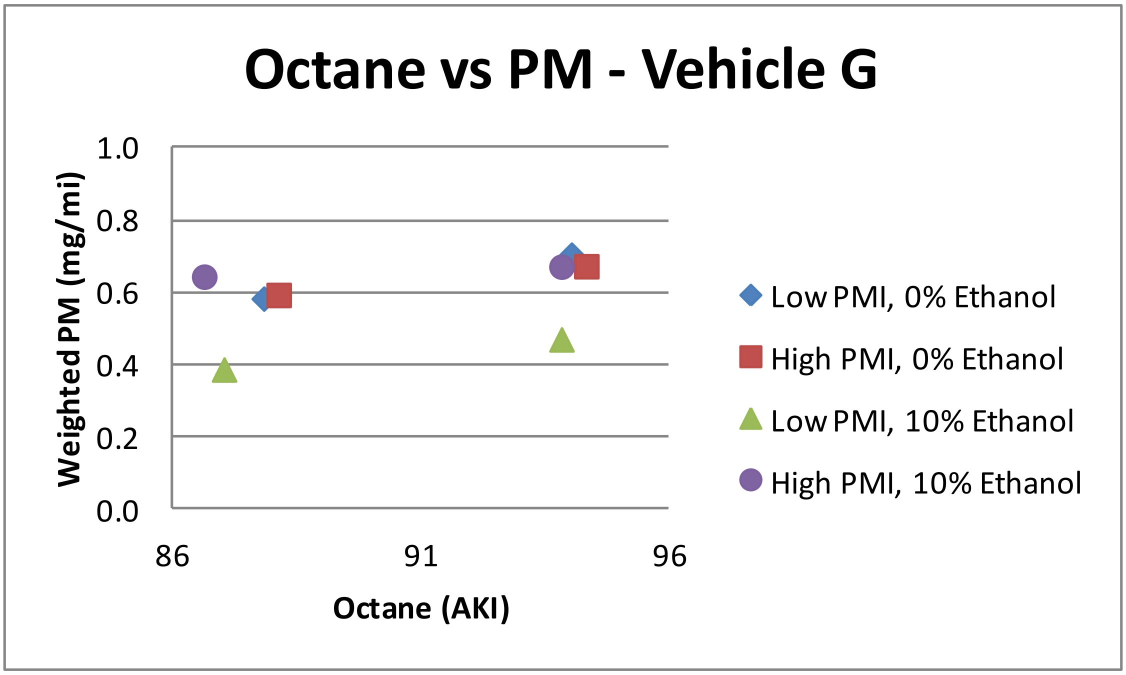


FIGURE F-19. VEHICLE G PM EMISSIONS VERSUS OCTANE (AKI)

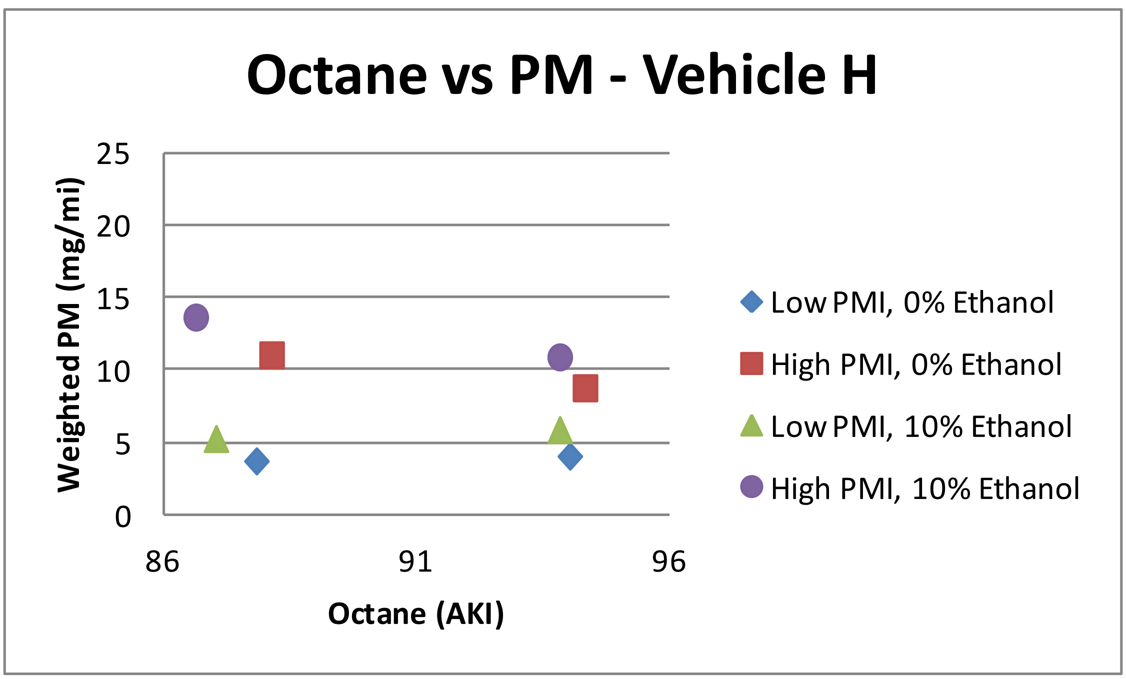


FIGURE F-20. VEHICLE H PM EMISSIONS VERSUS OCTANE (AKI)

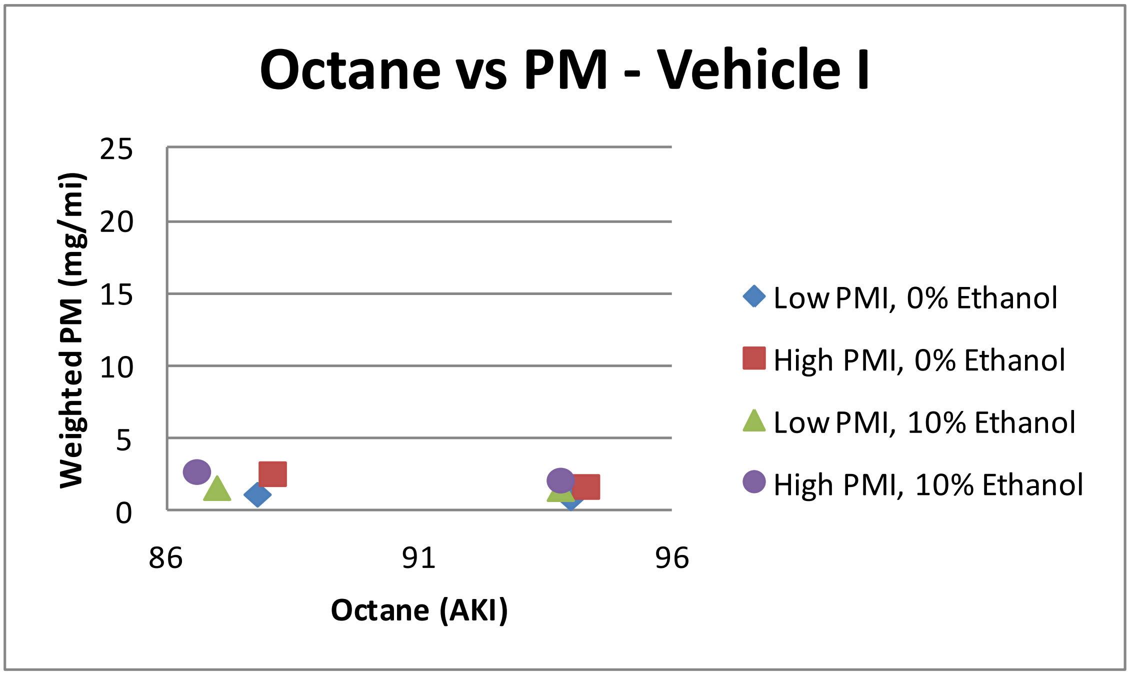


FIGURE F-21. VEHICLE I PM EMISSIONS VERSUS OCTANE (AKI)

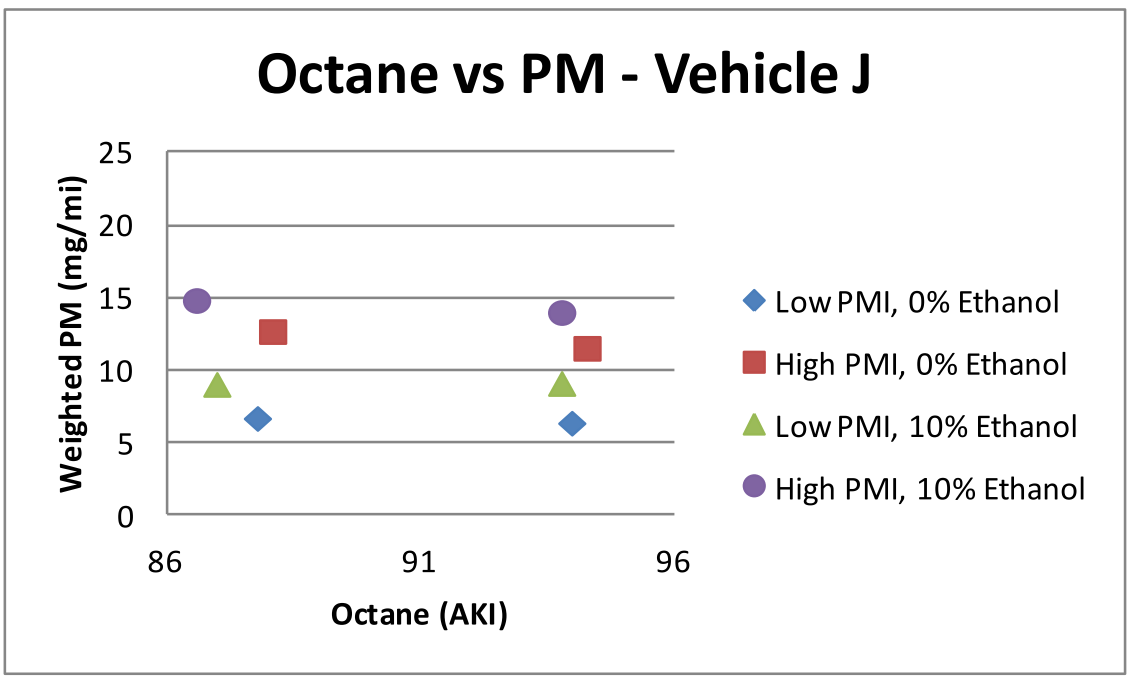


FIGURE F-22. VEHICLE J PM EMISSIONS VERSUS OCTANE (AKI)

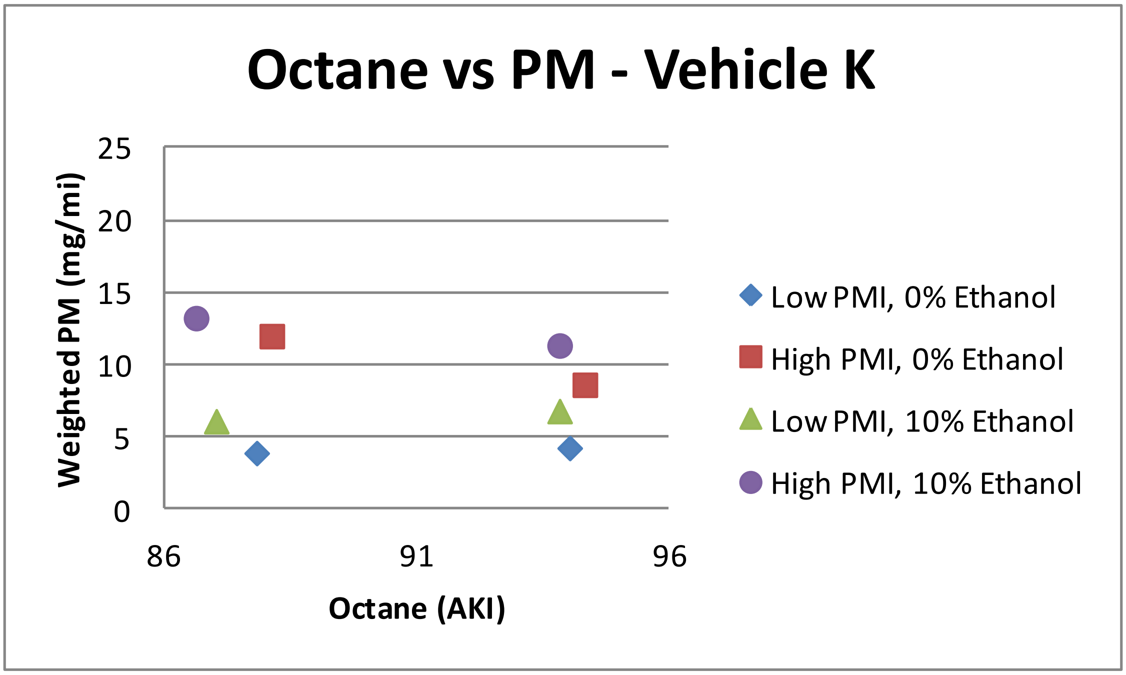


FIGURE F-23. VEHICLE K PM EMISSIONS VERSUS OCTANE (AKI)

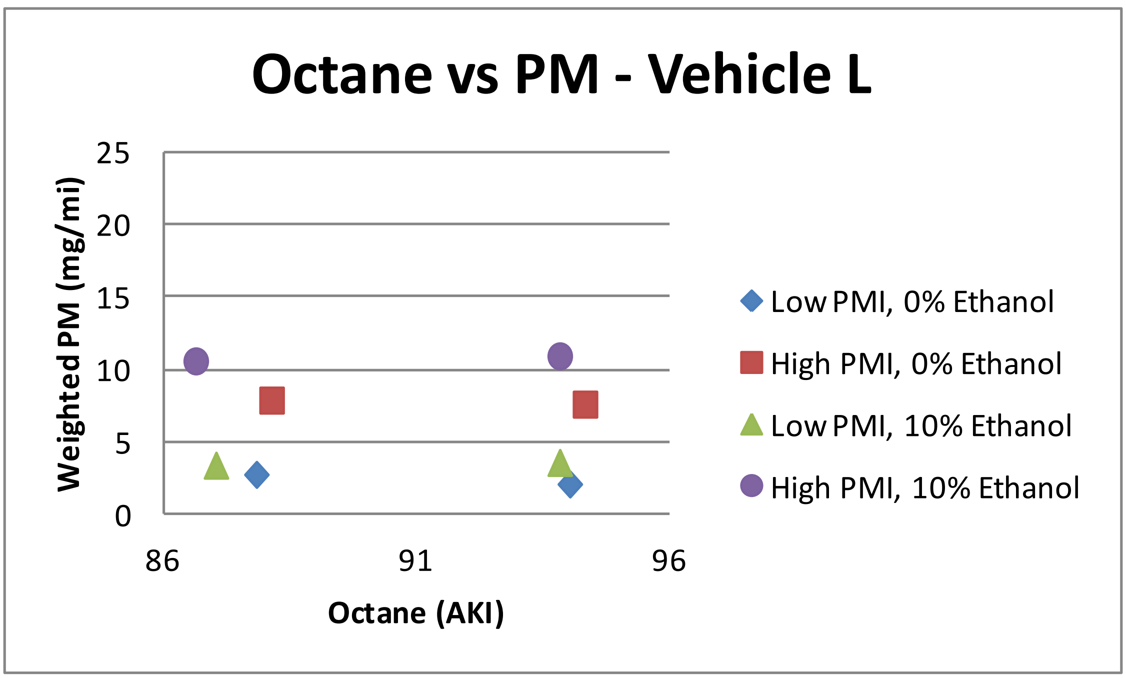


FIGURE F-24. VEHICLE L PM EMISSIONS VERSUS OCTANE (AKI)

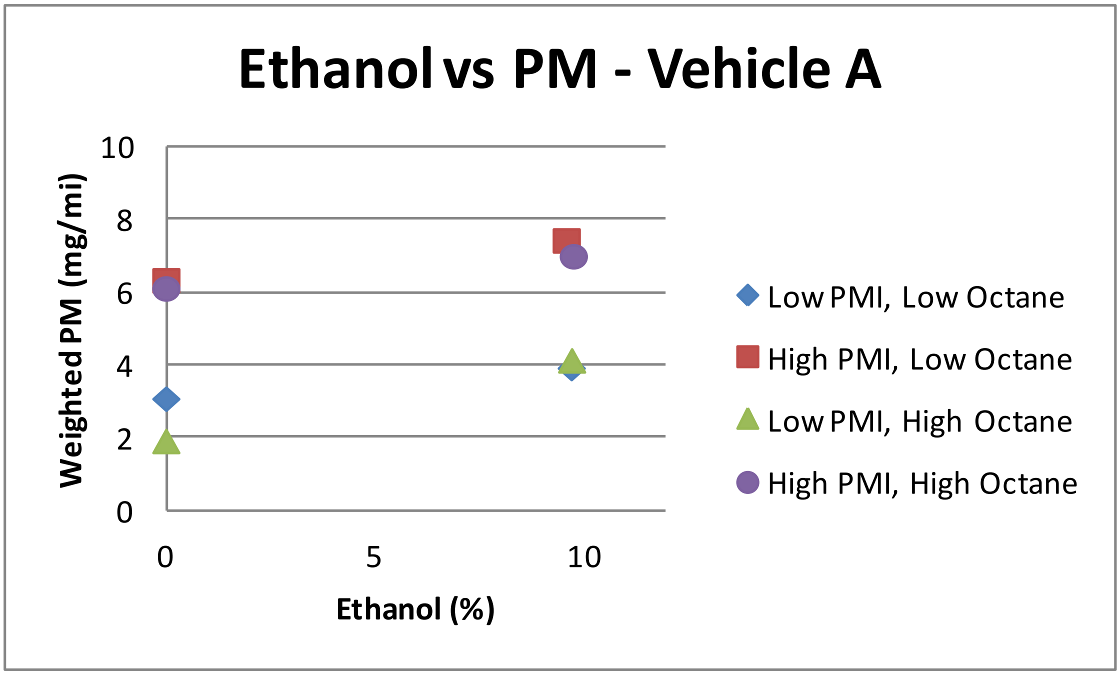


FIGURE F-25. VEHICLE A PM EMISSIONS VERSUS ETHANOL CONTENT

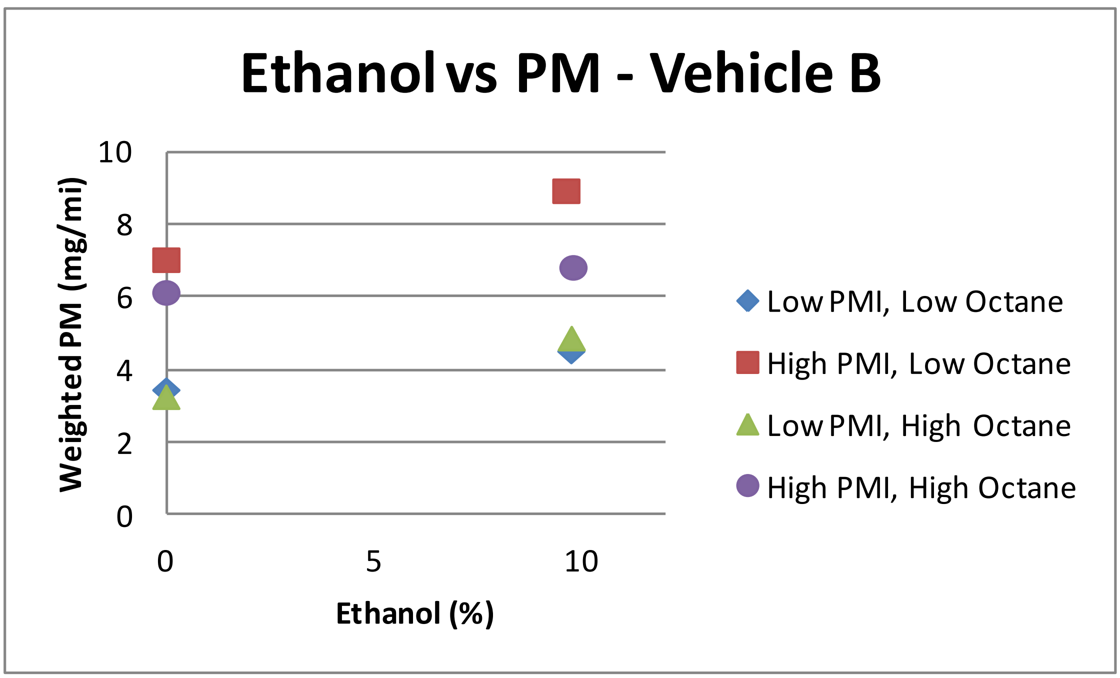


FIGURE F-26. VEHICLE B PM EMISSIONS VERSUS ETHANOL CONTENT

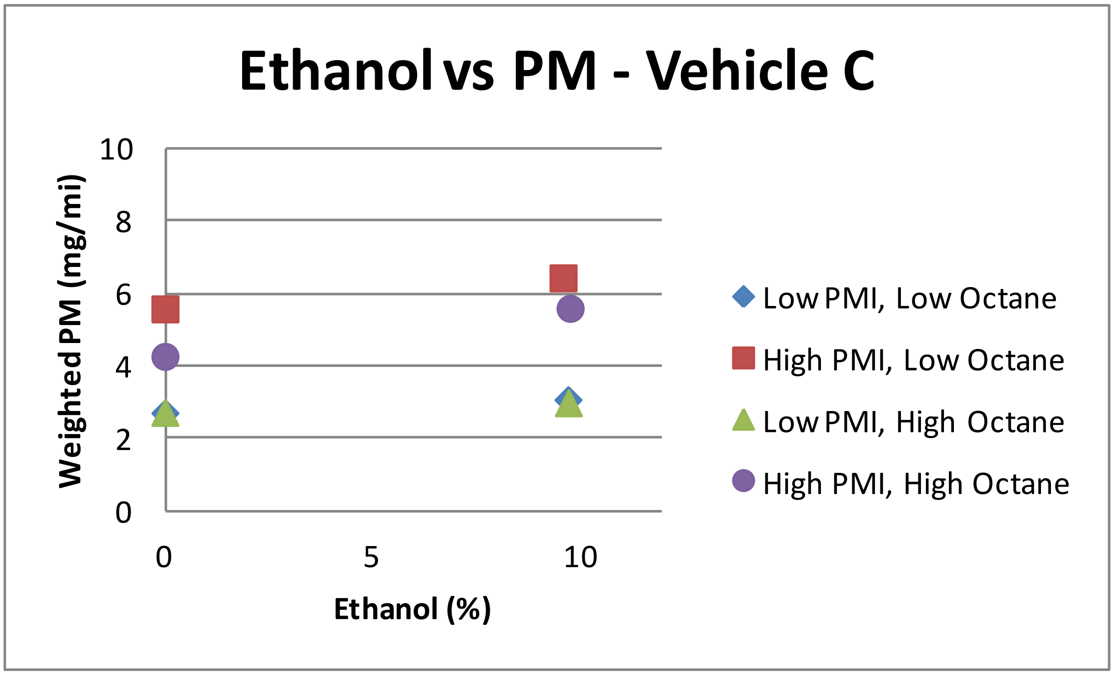


FIGURE F-27. VEHICLE C PM EMISSIONS VERSUS ETHANOL CONTENT

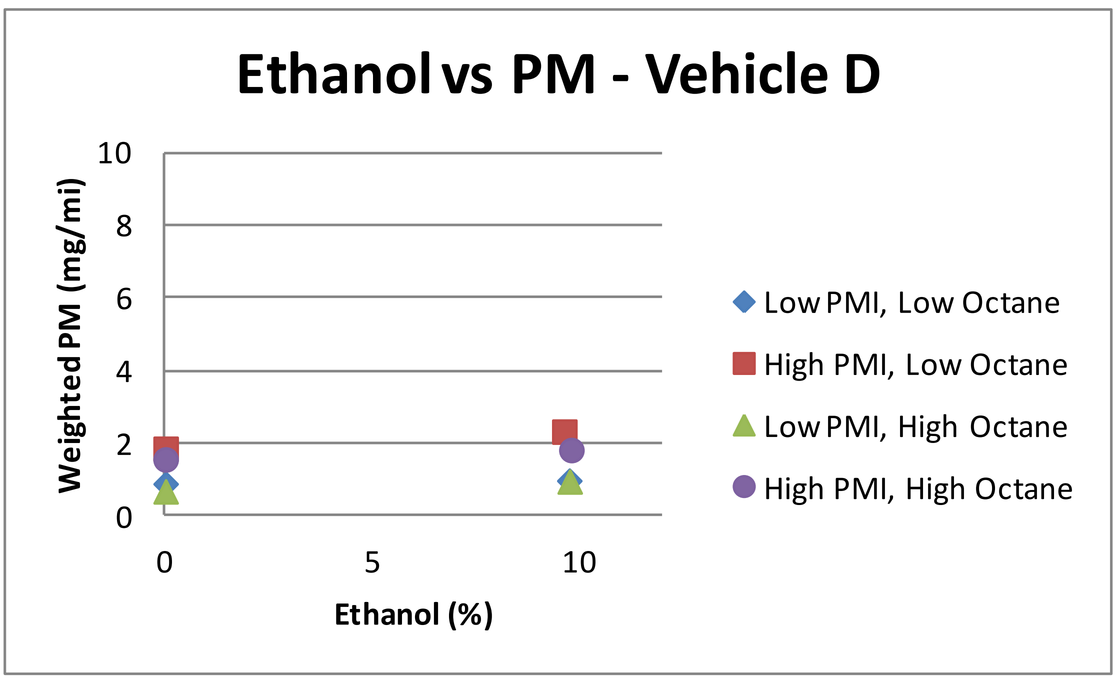


FIGURE F-28. VEHICLE D PM EMISSIONS VERSUS ETHANOL CONTENT

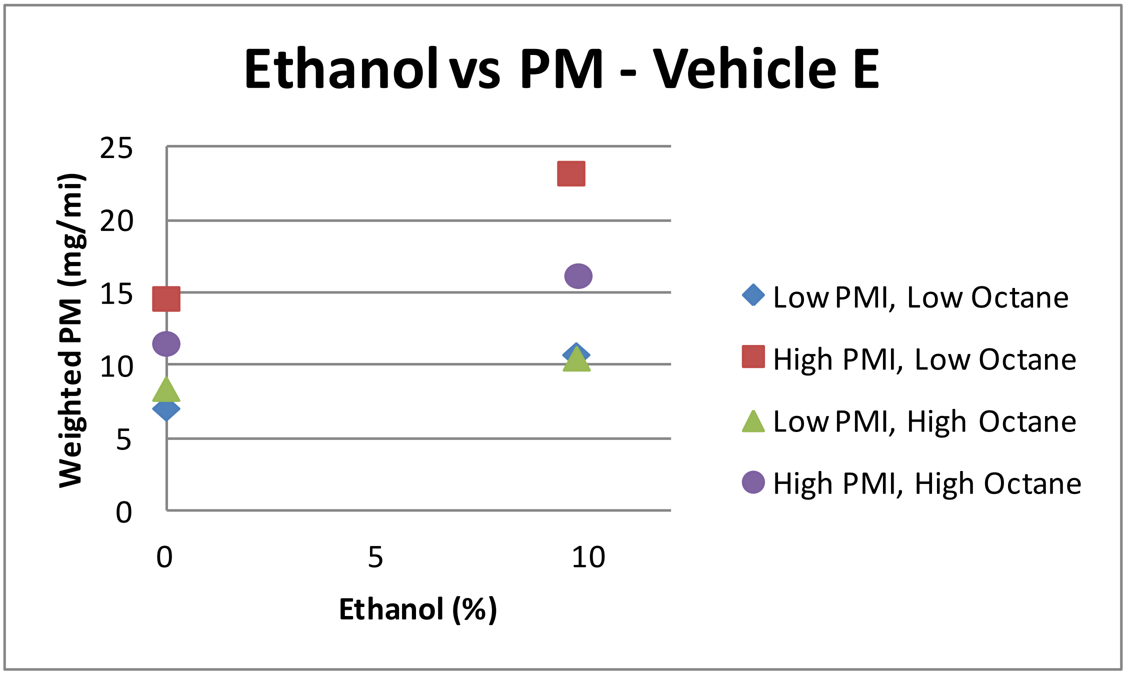


FIGURE F-29. VEHICLE E PM EMISSIONS VERSUS ETHANOL CONTENT

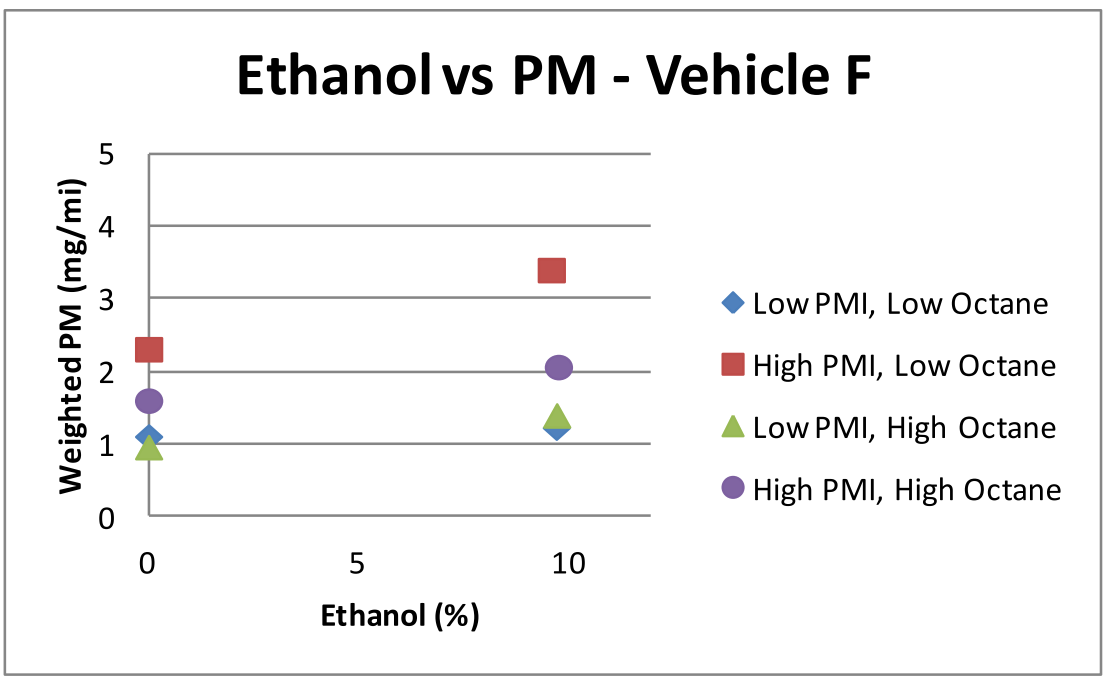


FIGURE F-30. VEHICLE F PM EMISSIONS VERSUS ETHANOL CONTENT

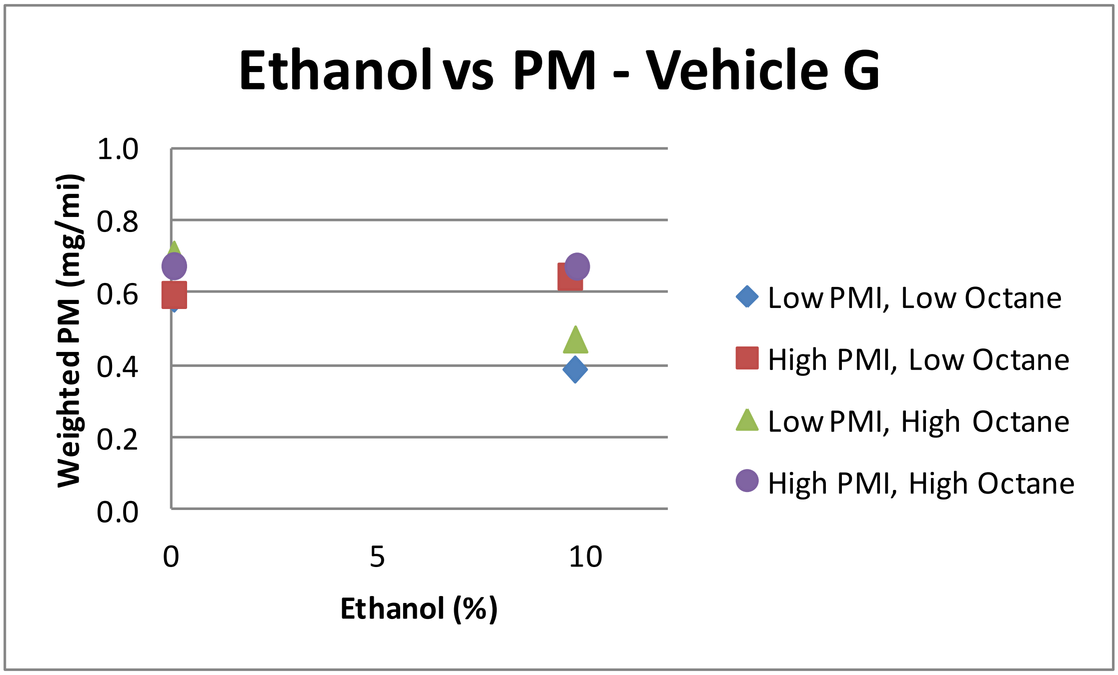


FIGURE F-31. VEHICLE G PM EMISSIONS VERSUS ETHANOL CONTENT

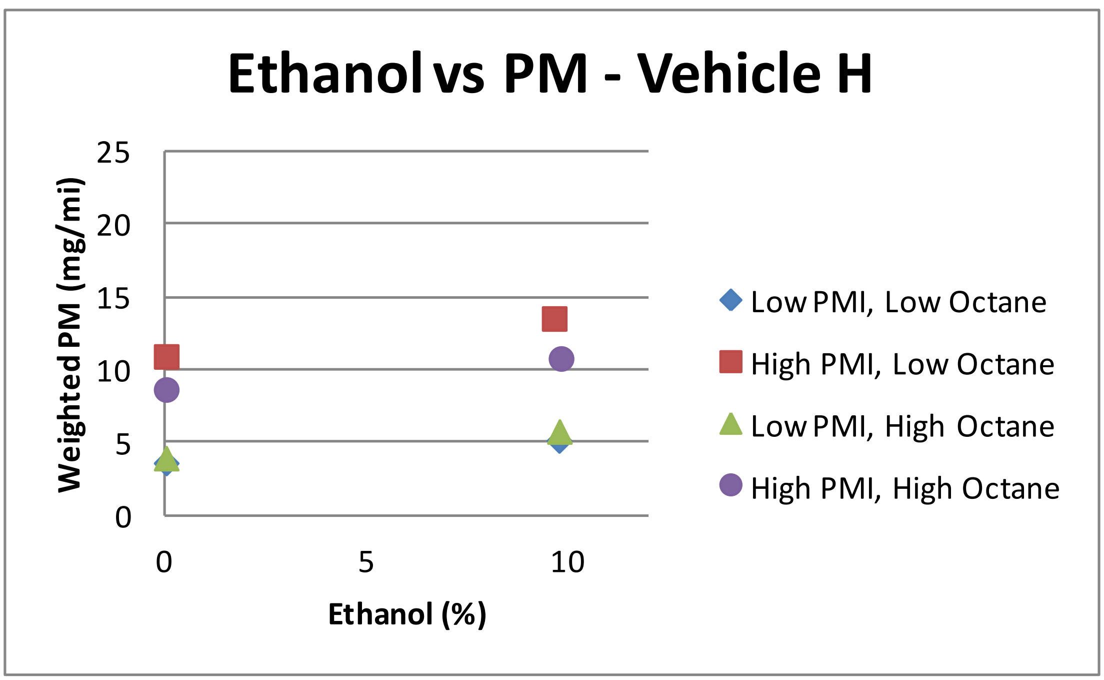


FIGURE F-32. VEHICLE H PM EMISSIONS VERSUS ETHANOL CONTENT

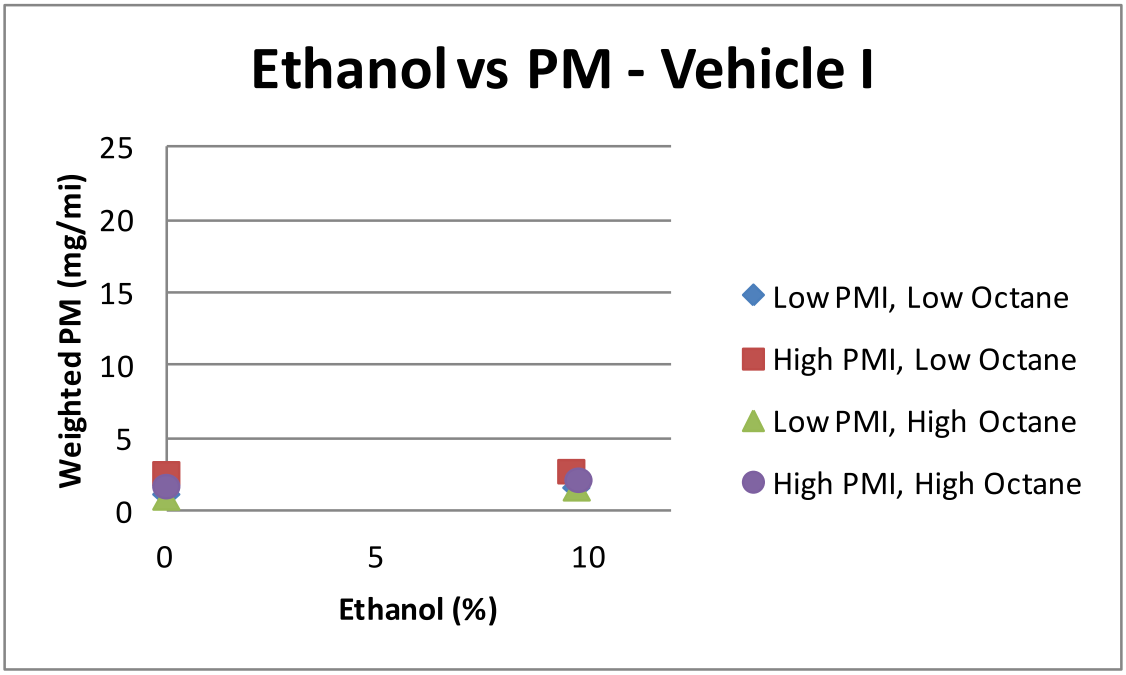


FIGURE F-33. VEHICLE I PM EMISSIONS VERSUS ETHANOL CONTENT

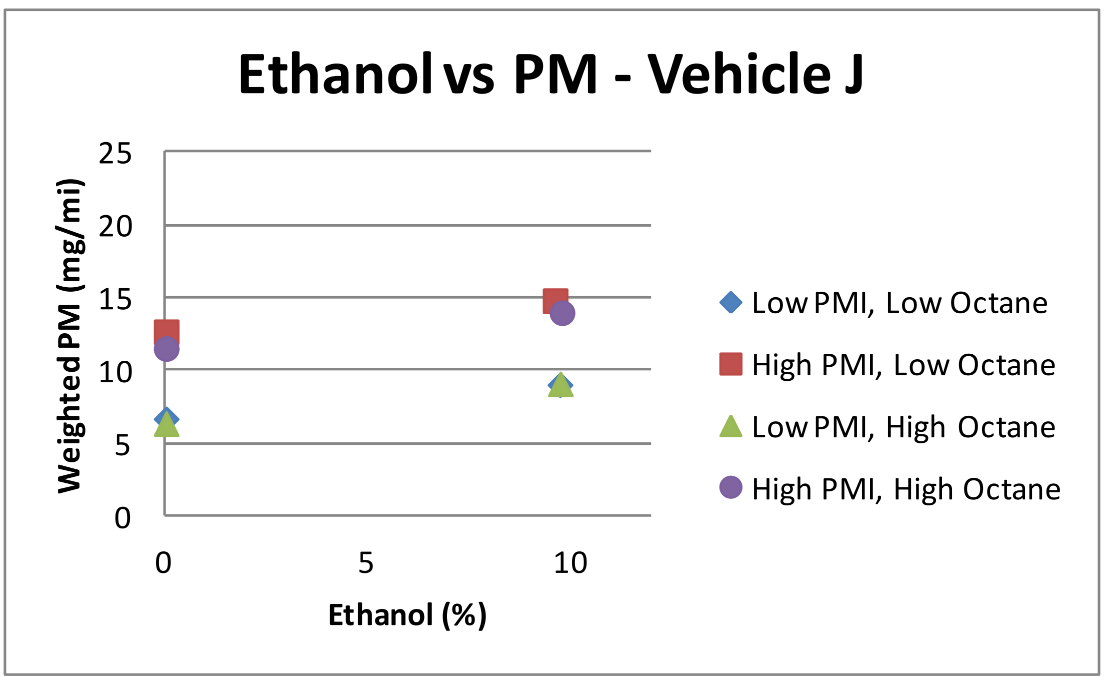


FIGURE F-34. VEHICLE J PM EMISSIONS VERSUS ETHANOL CONTENT

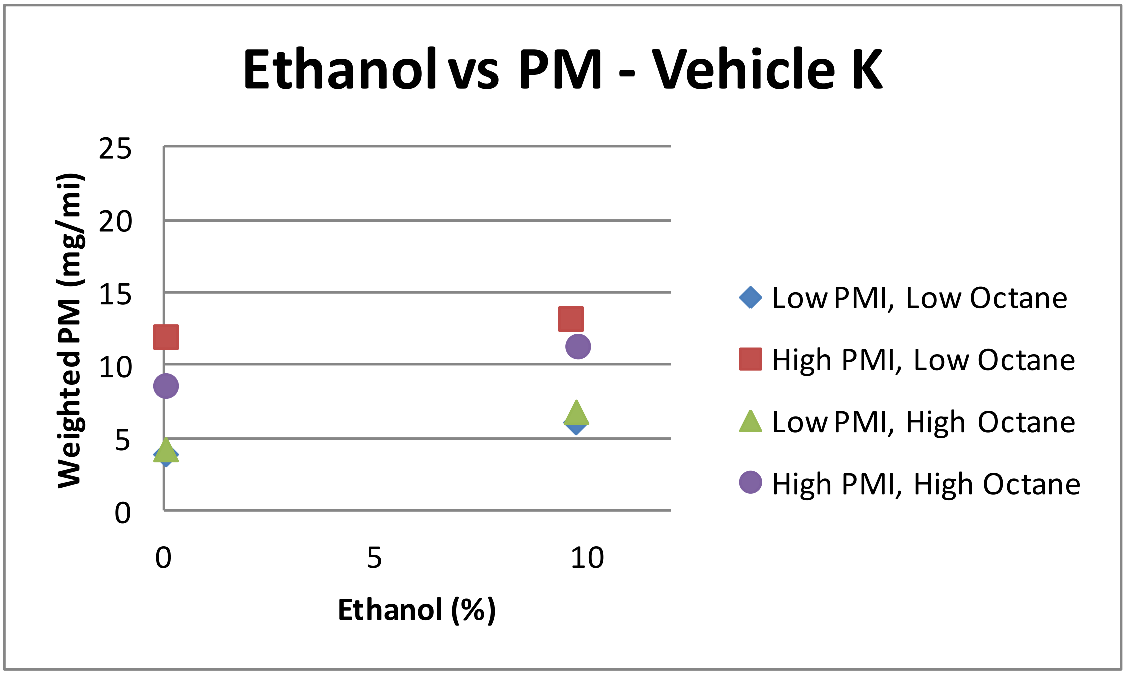


FIGURE F-35. VEHICLE K PM EMISSIONS VERSUS ETHANOL CONTENT

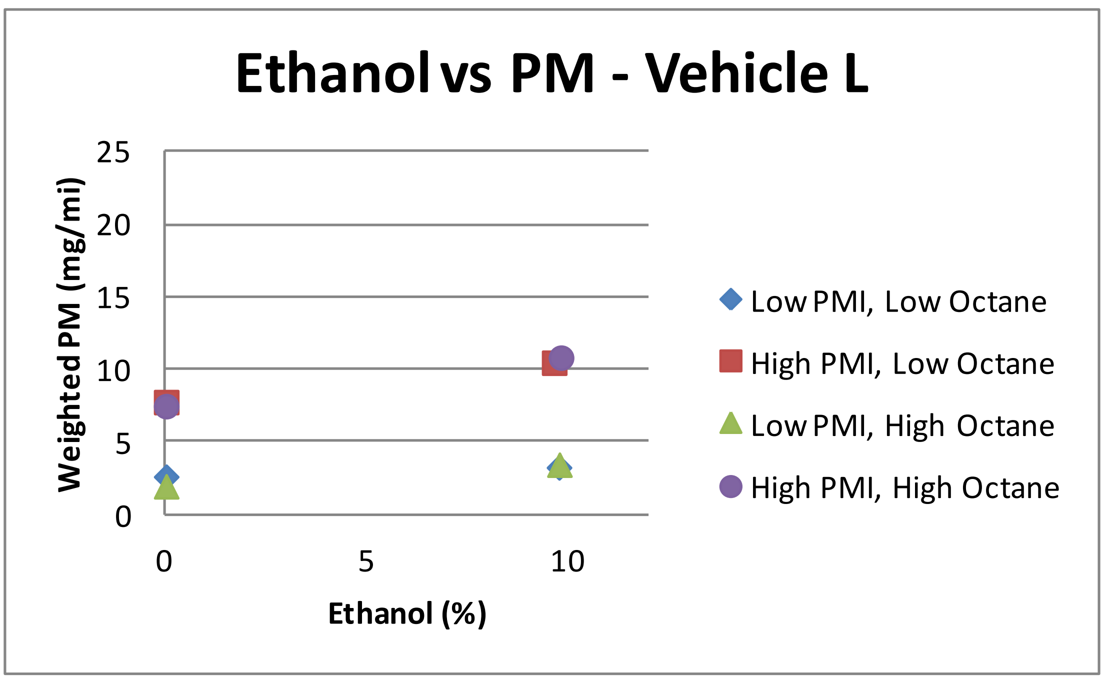


FIGURE F-36. VEHICLE L PM EMISSIONS VERSUS ETHANOL CONTENT

FIGURE G

PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION
REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS
REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS

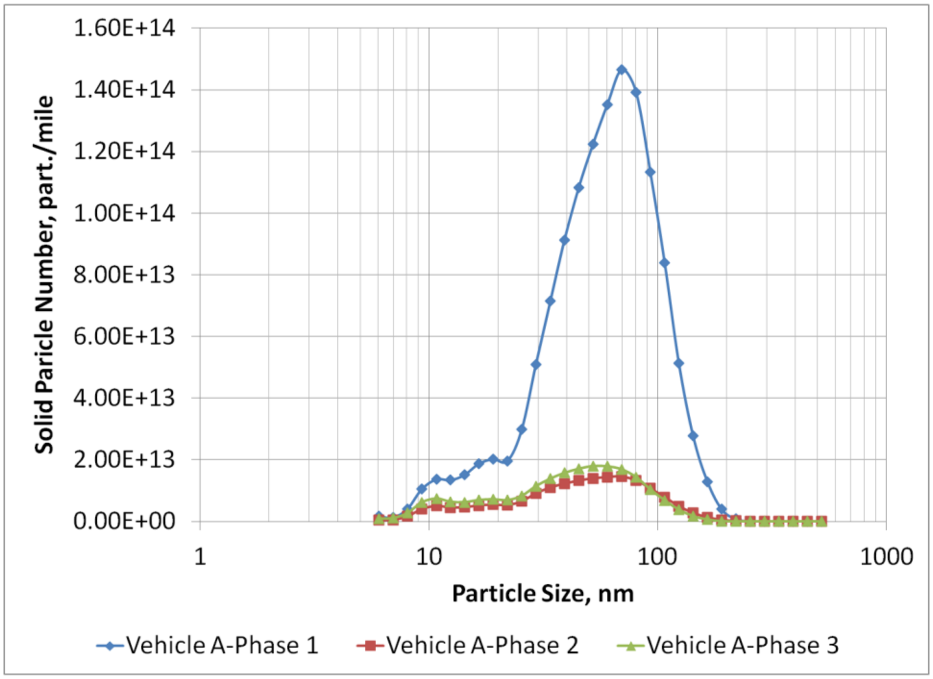


FIGURE G-1. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE A

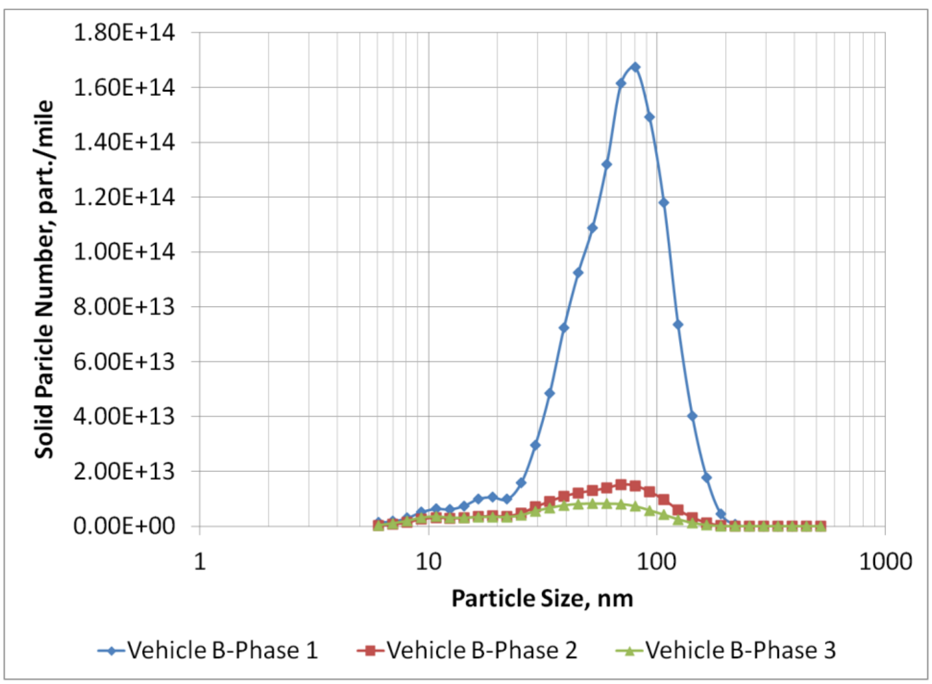


FIGURE G-2. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE B

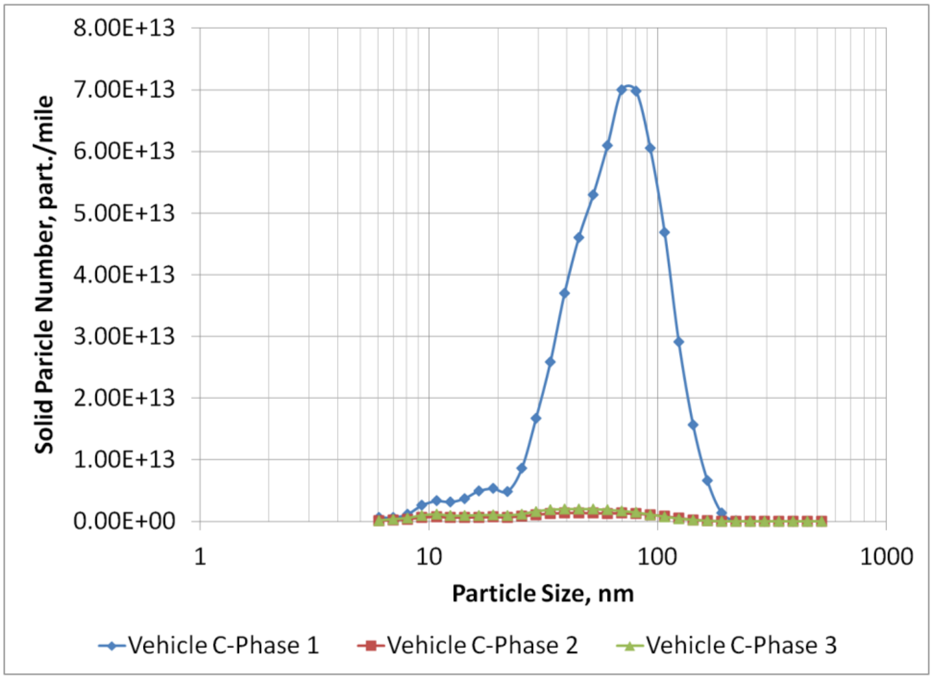


FIGURE G-3. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE C

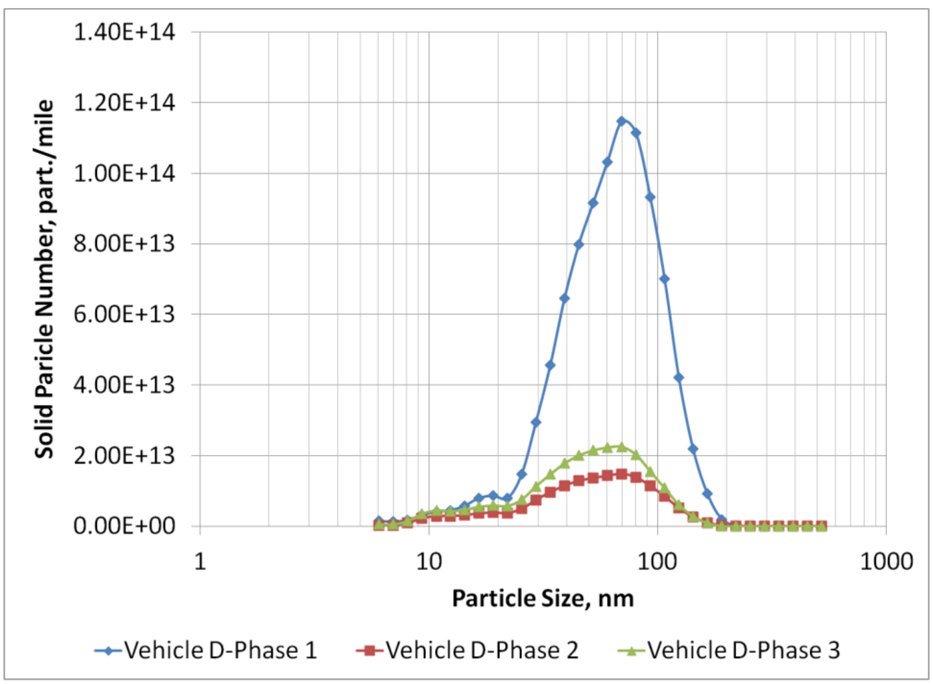


FIGURE G-4. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE D

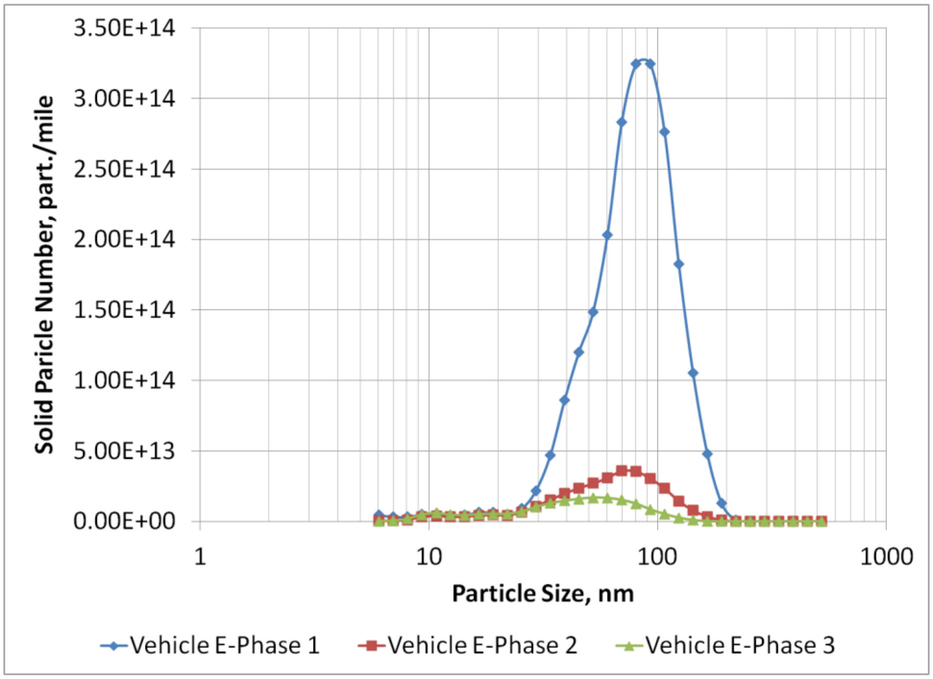


FIGURE G-5. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE E

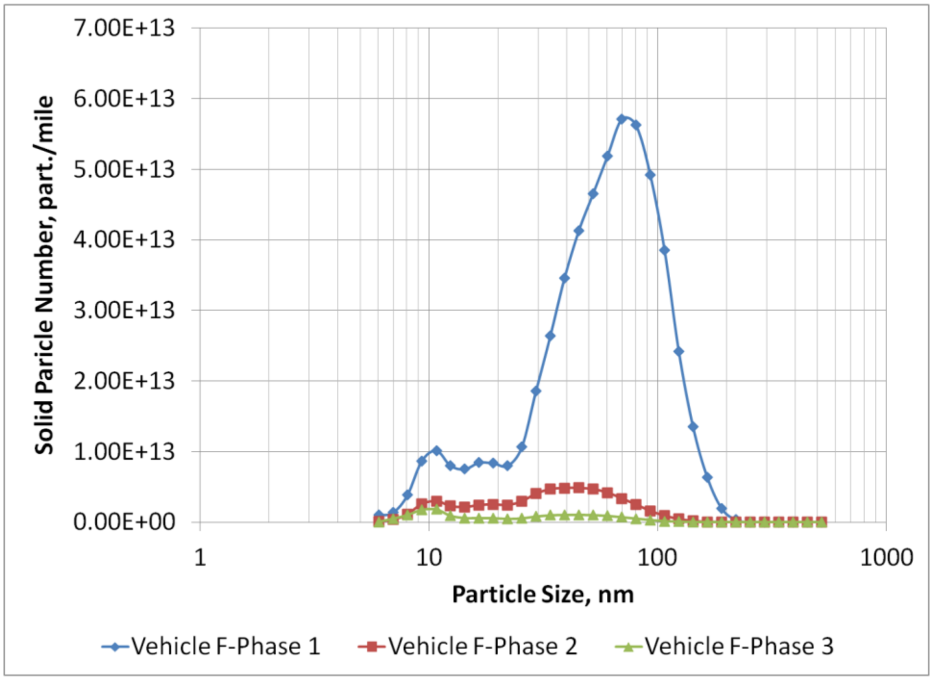


FIGURE G-6. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE F

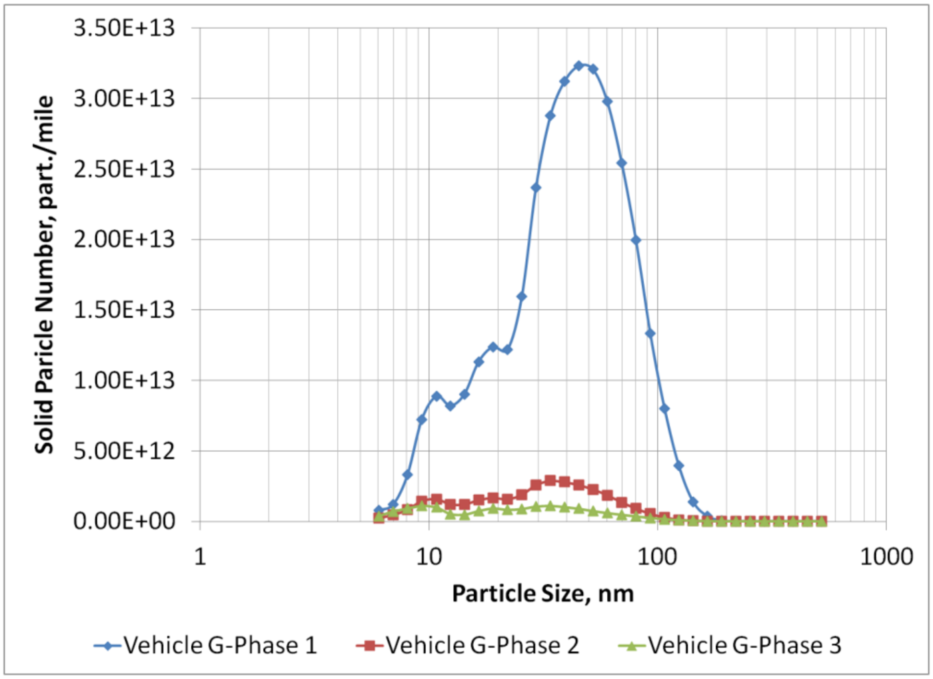


FIGURE G-7. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE G

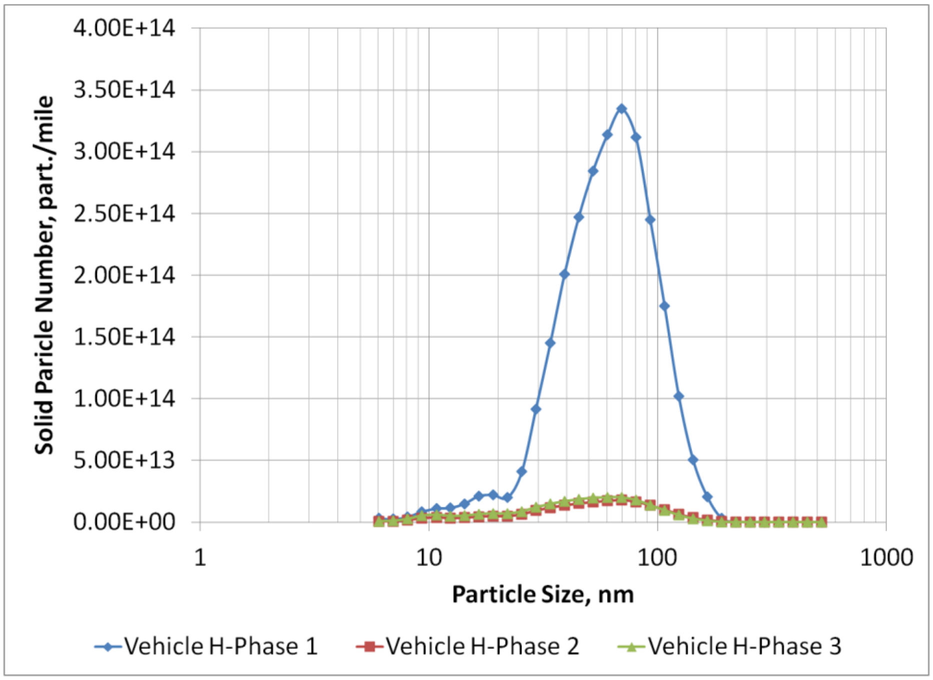


FIGURE G-8. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE H

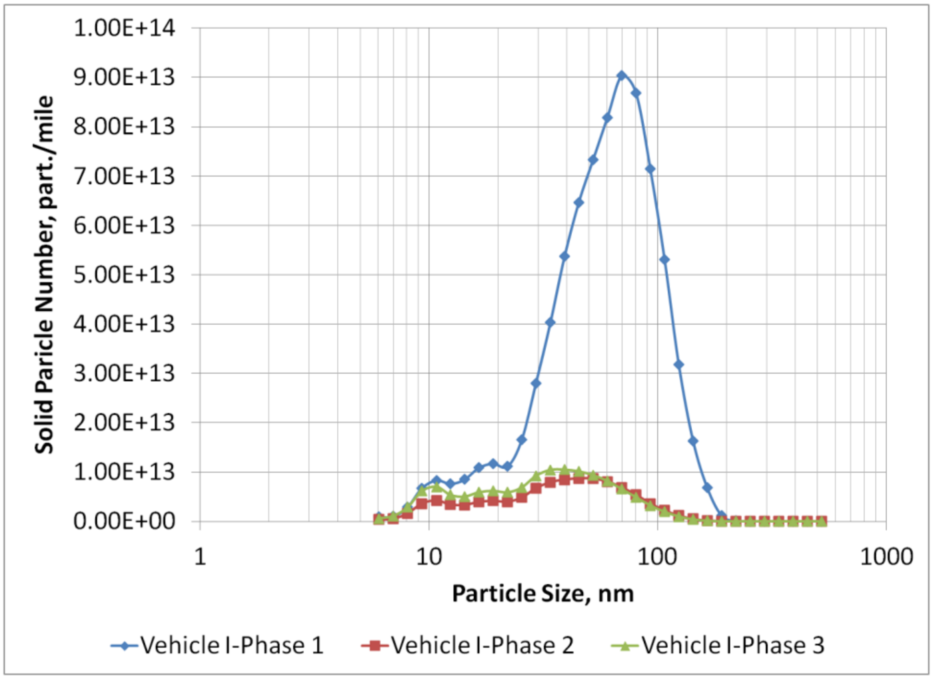


FIGURE G-9. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE I

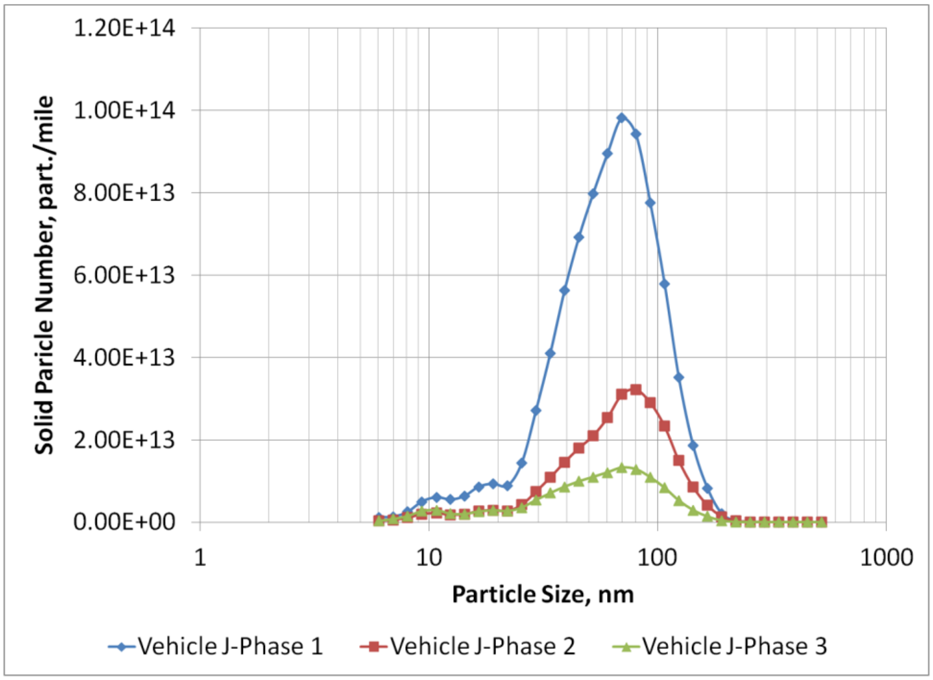


FIGURE G-10. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE J

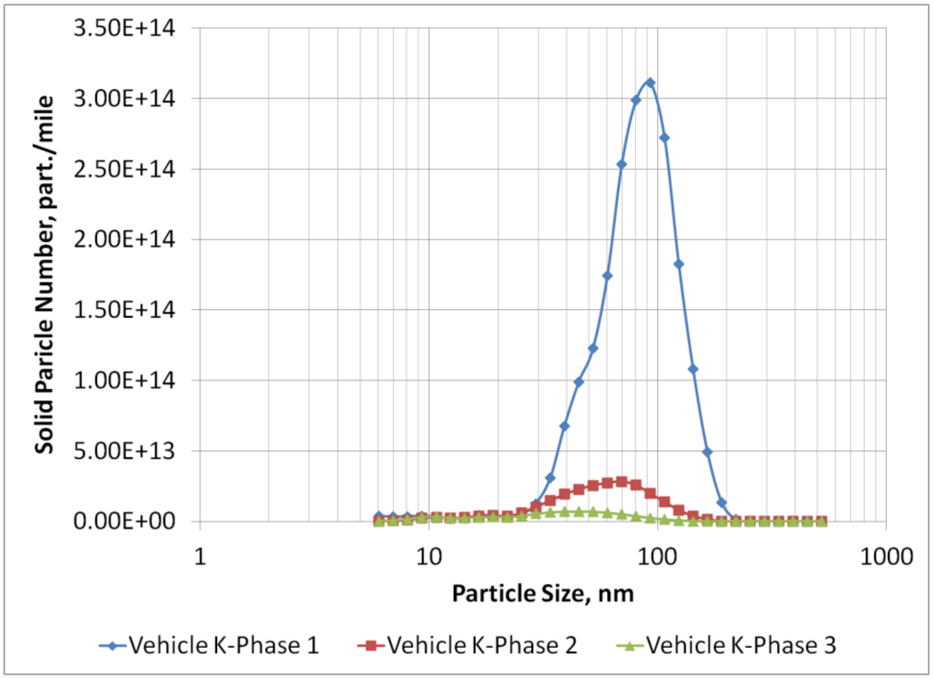


FIGURE G-11. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE K

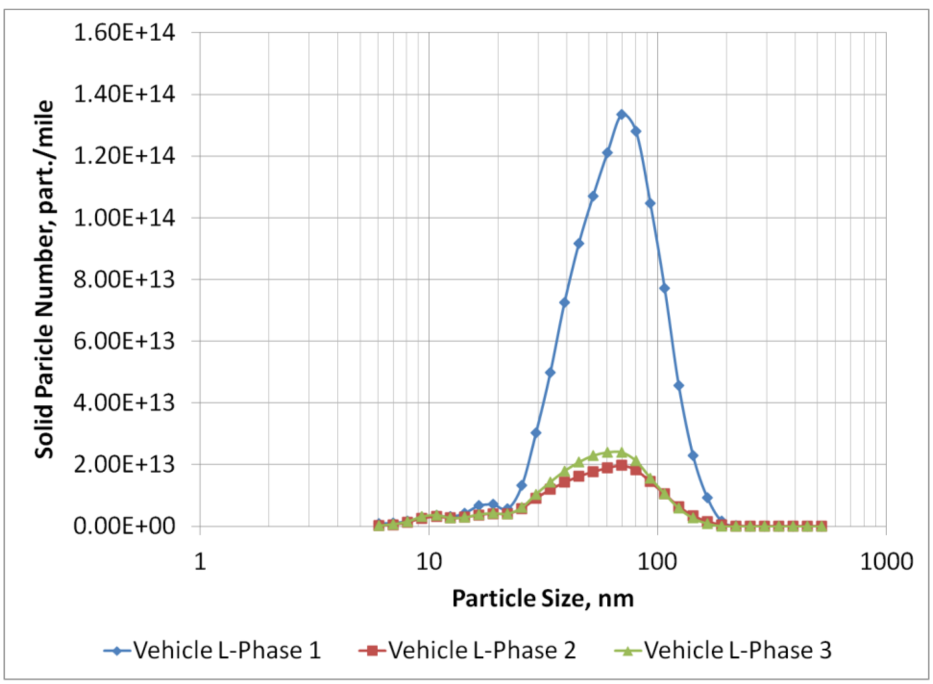


FIGURE G-12. PHASE-LEVEL PARTICLE NUMBER SIZE DISTRIBUTION FOR VEHICLE L

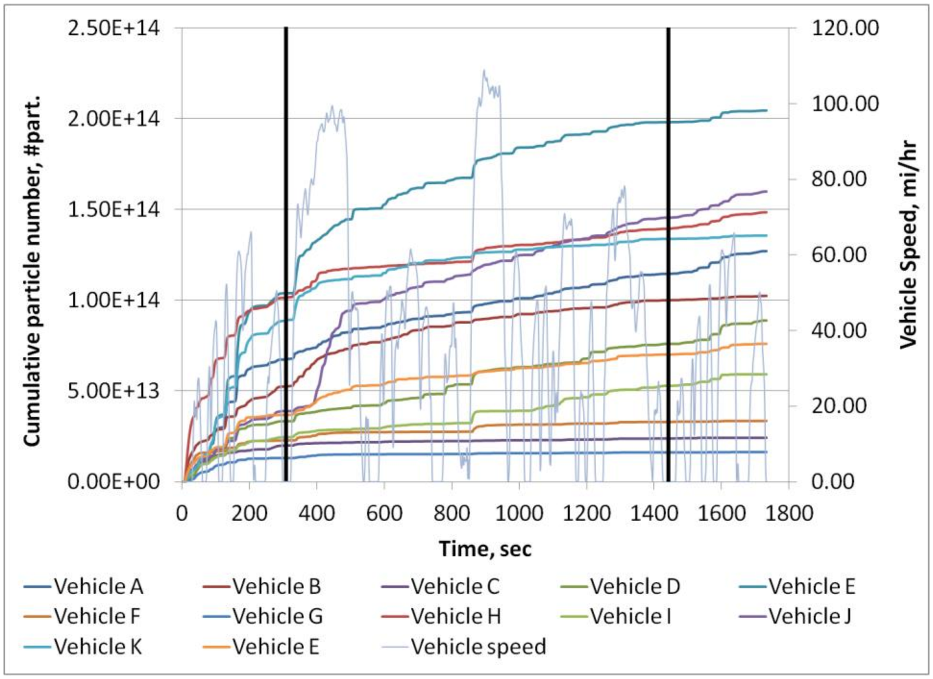


FIGURE G-13. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL A

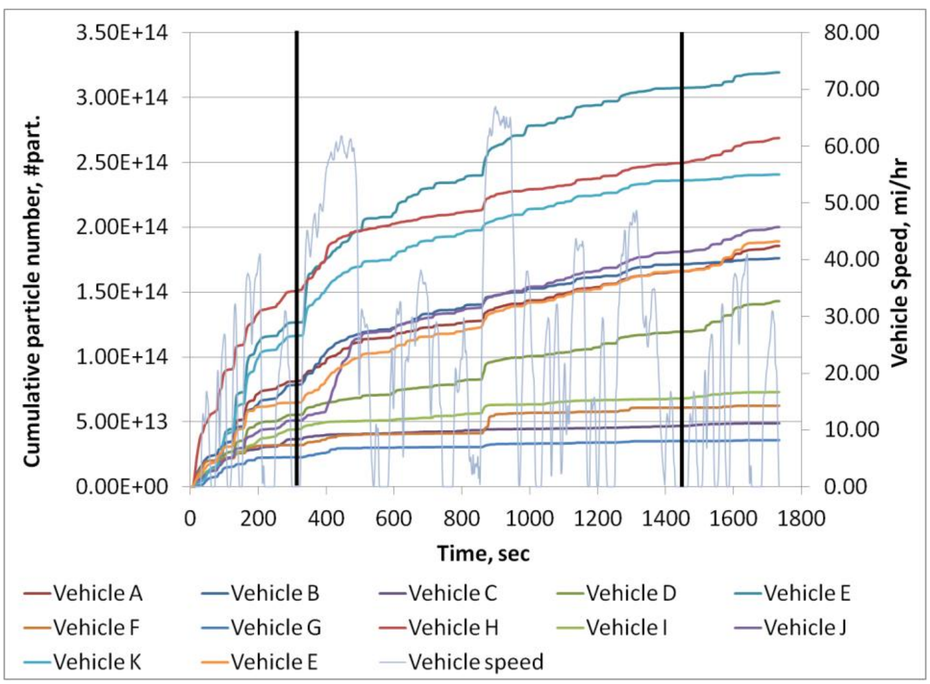


FIGURE G-14. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL B

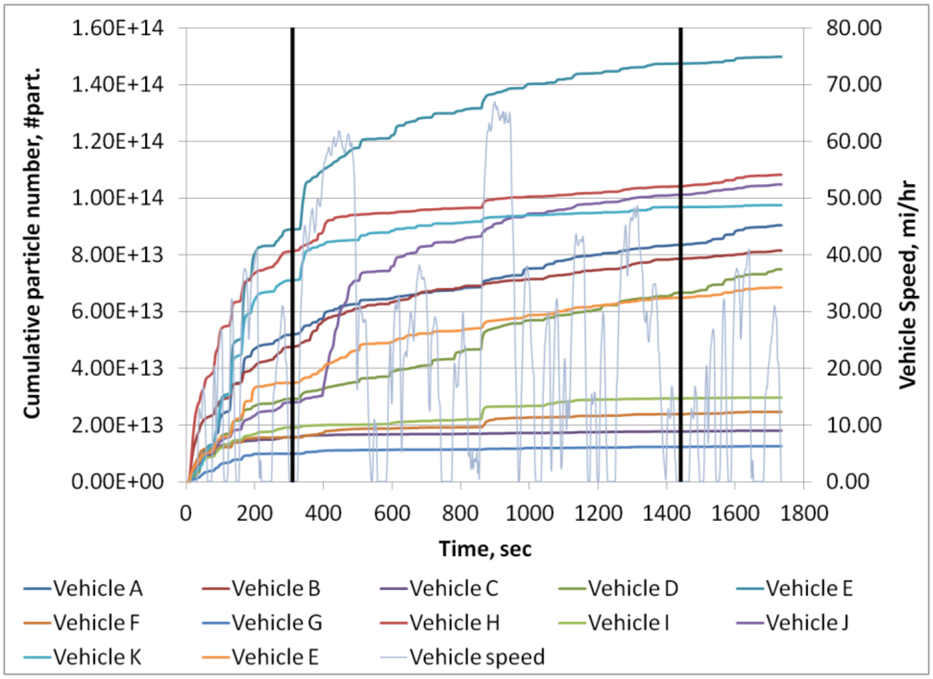


FIGURE G-15. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL C

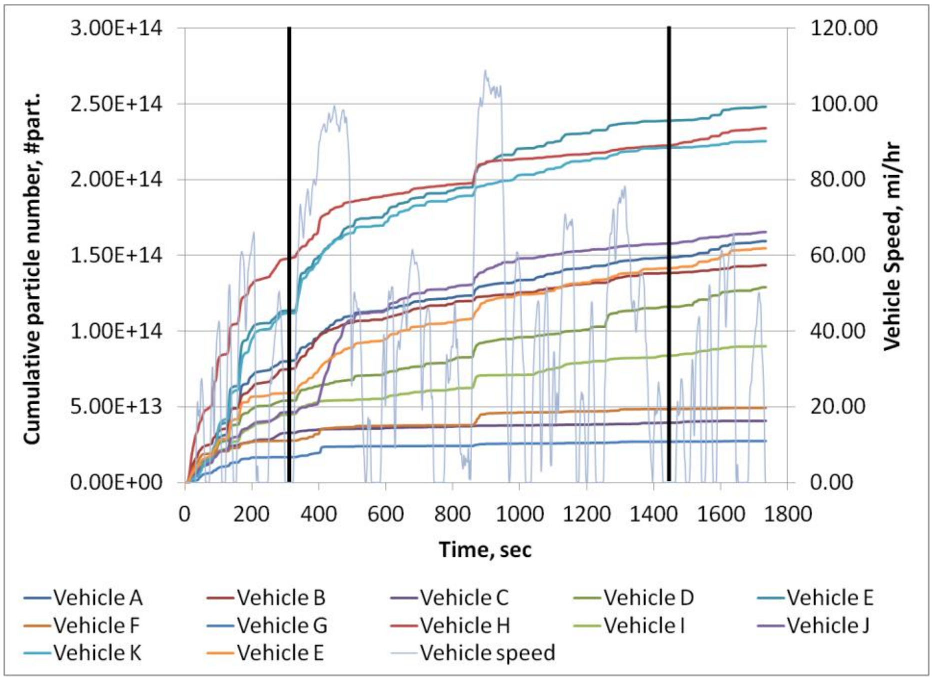


FIGURE G-16. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL D

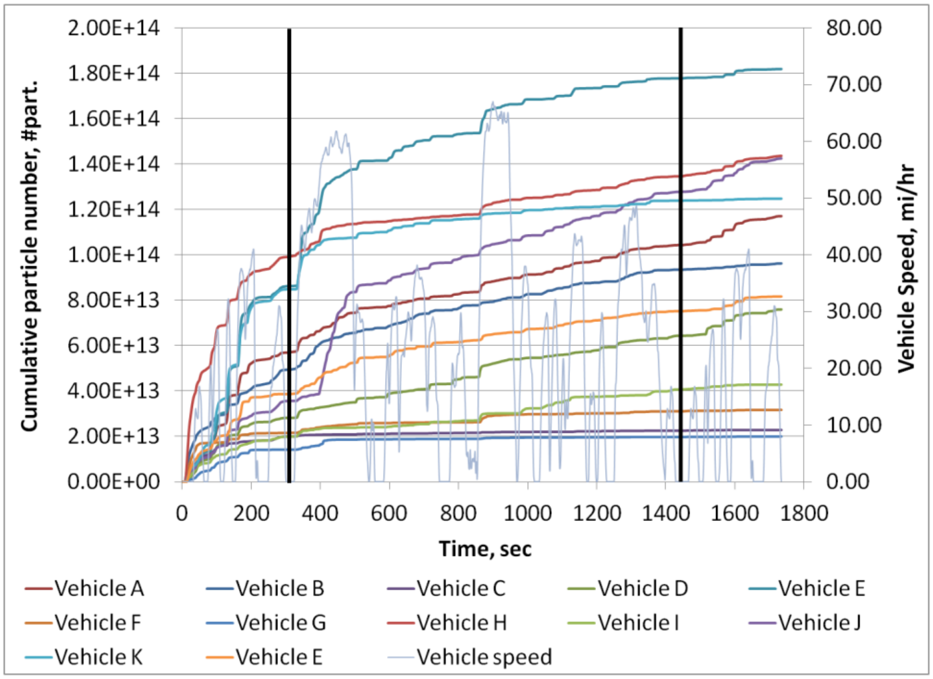


FIGURE G-17. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL E

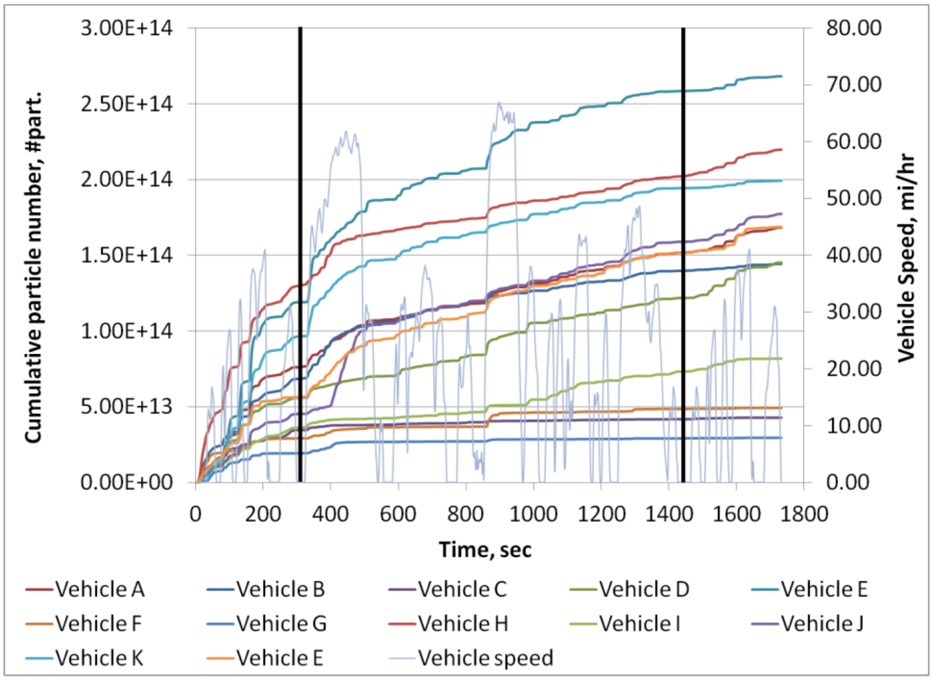


FIGURE G-18. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL F

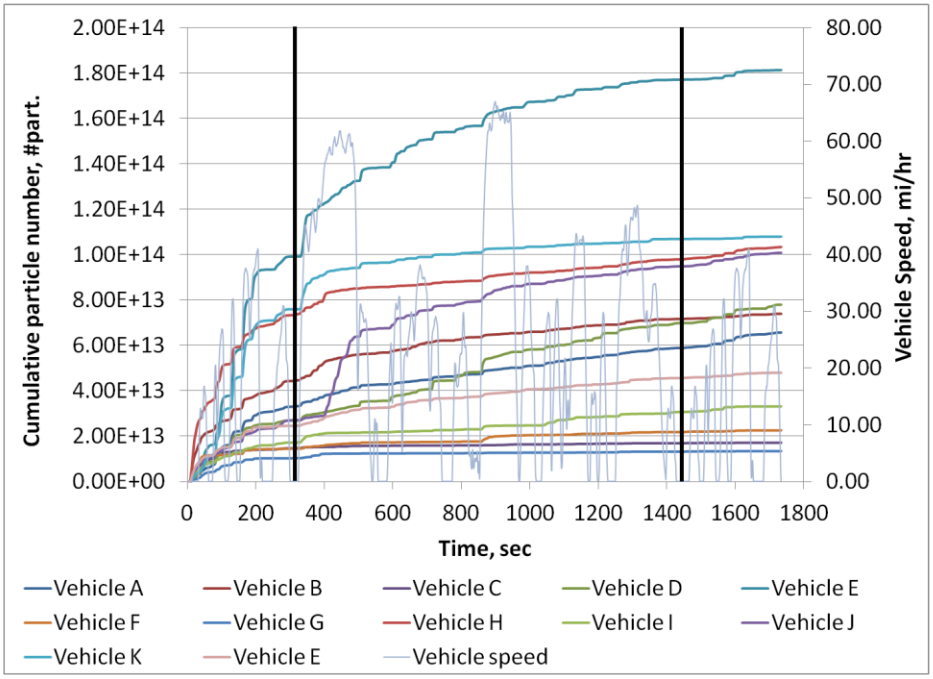


FIGURE G-19. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL G

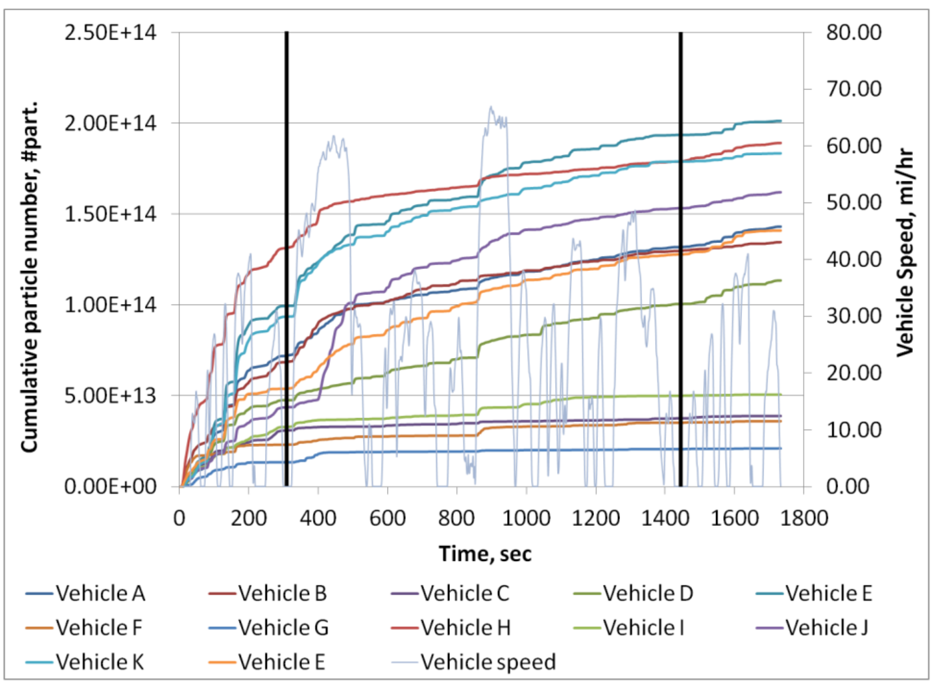


FIGURE G-20. REAL-TIME CUMULATIVE PARTICLE NUMBER EMISSIONS FOR ALL VEHICLES - FUEL H

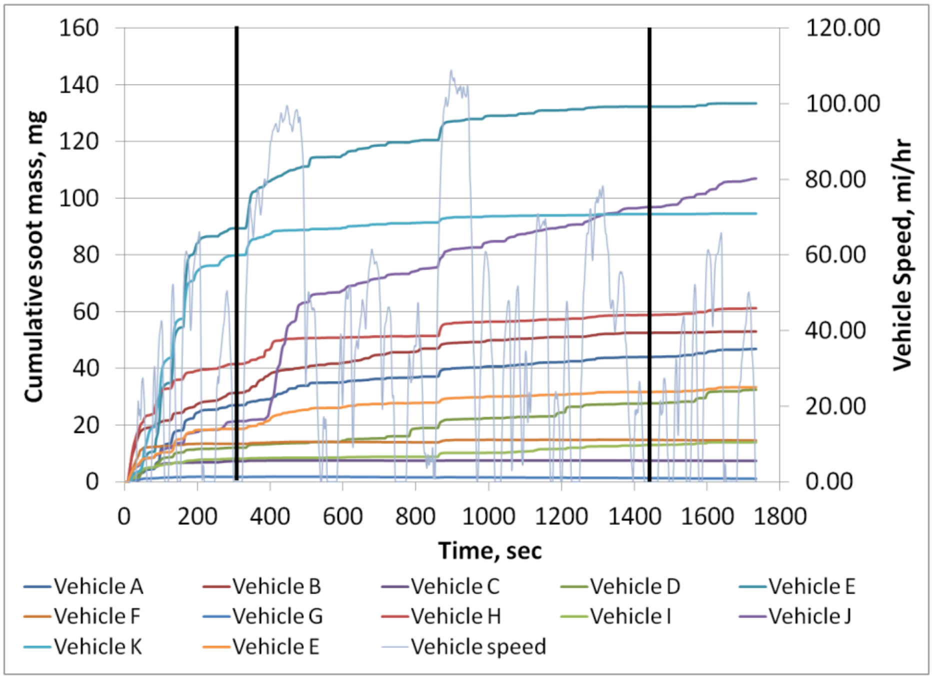


FIGURE G-21. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL A

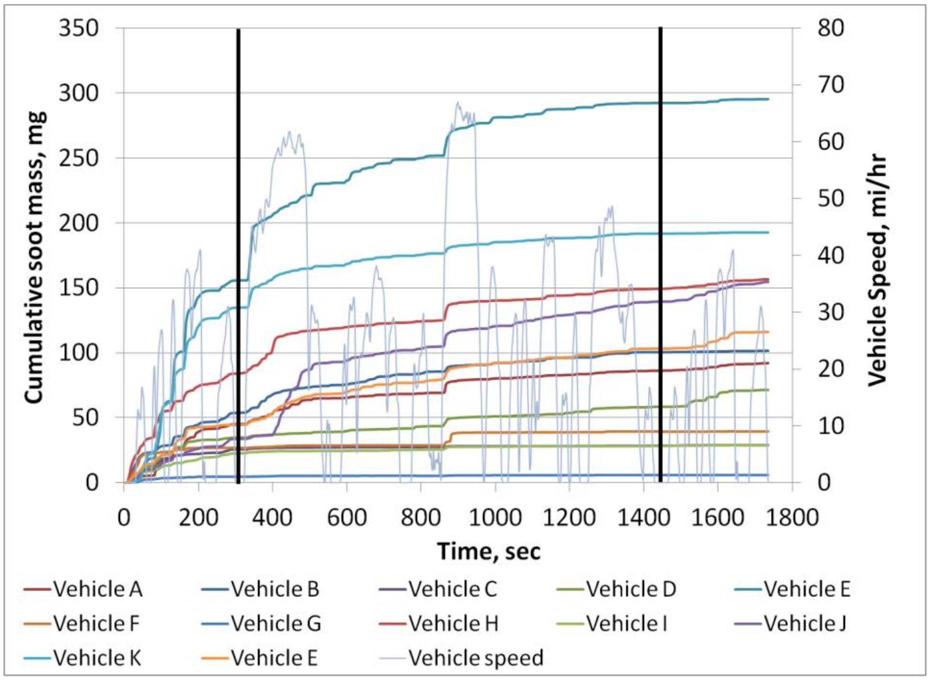


FIGURE G-22. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL B

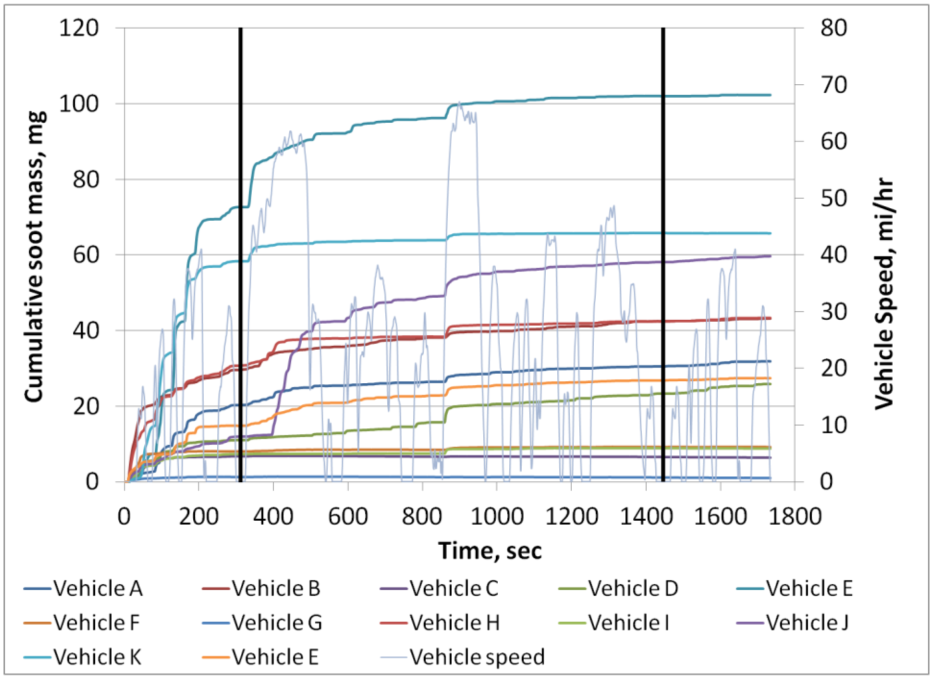


FIGURE G-23. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL C

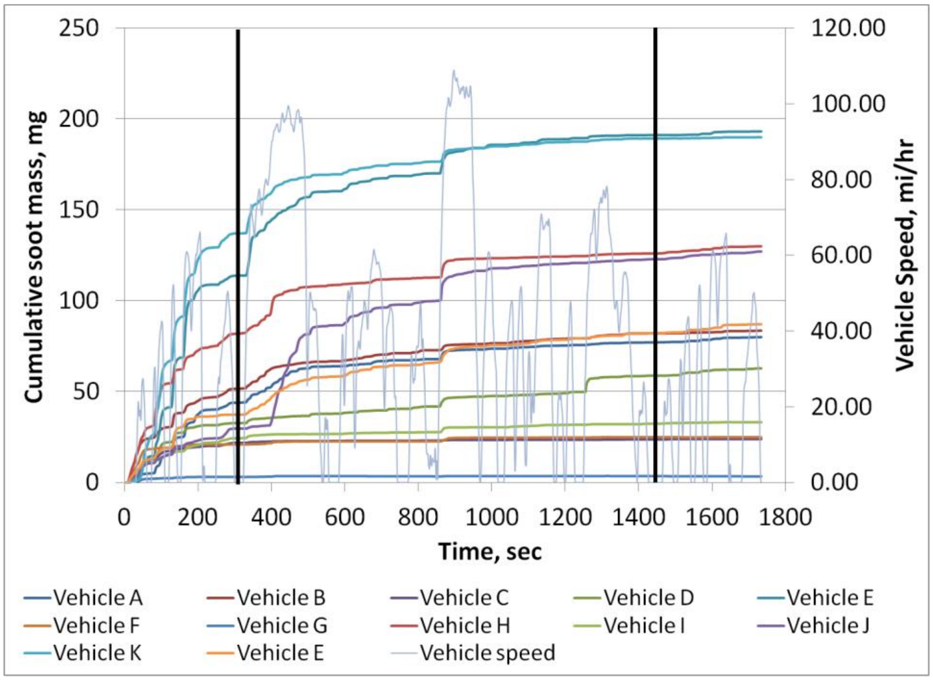


FIGURE G-24. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL D

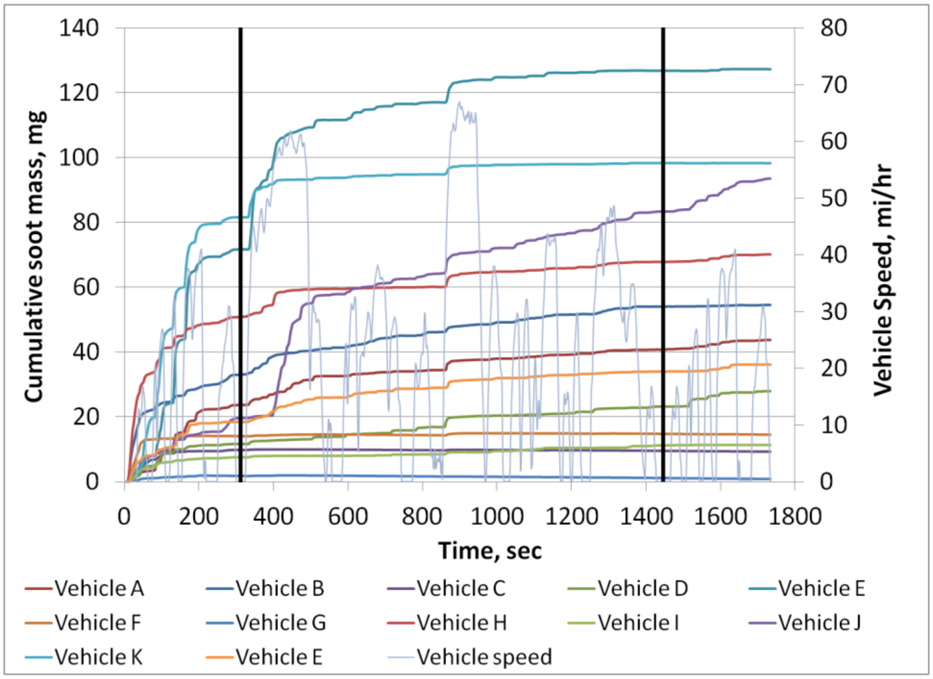


FIGURE G-25. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL E

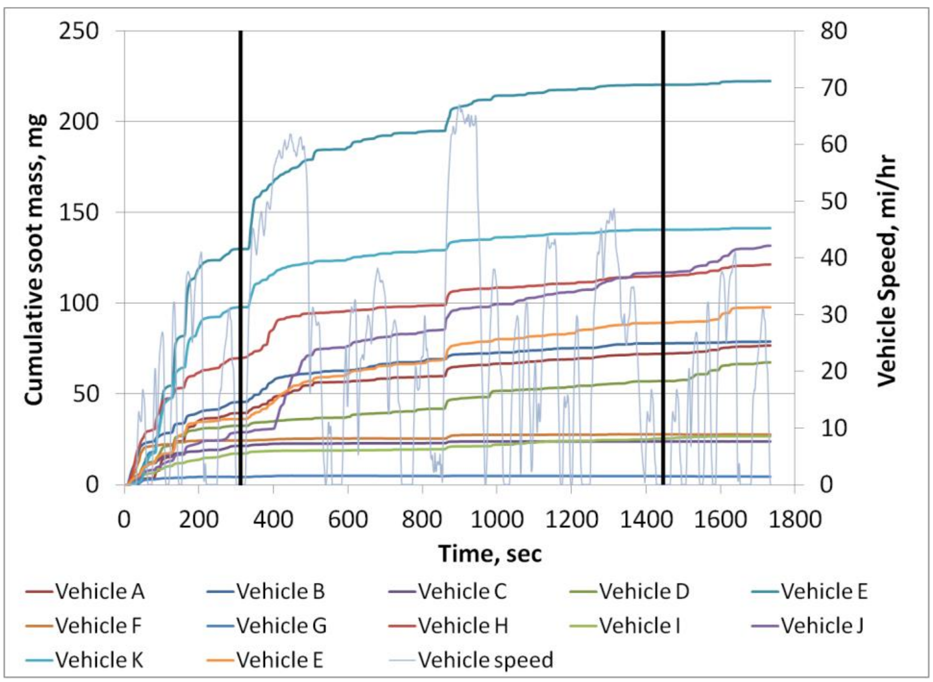


FIGURE G-26. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL F

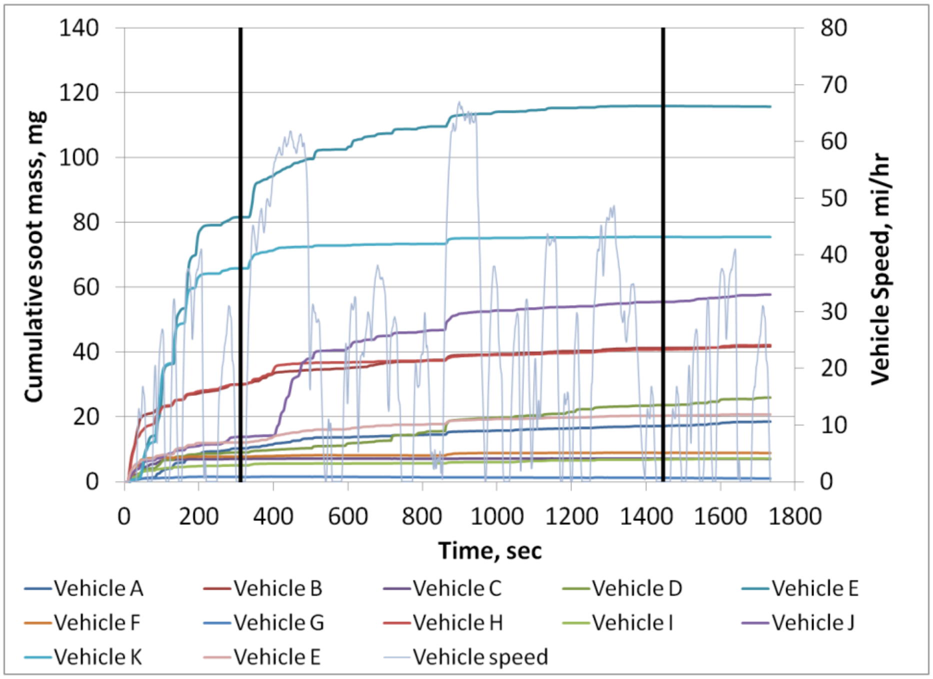


FIGURE G-27. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL G

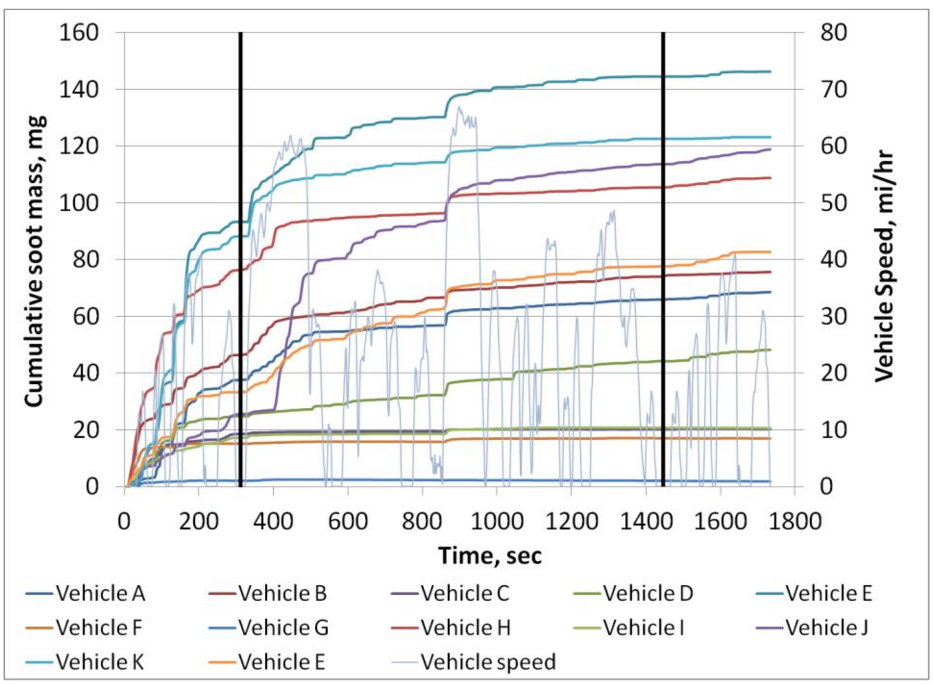


FIGURE G-28. REAL-TIME CUMULATIVE PARTICLE SOOT MASS EMISSIONS FOR ALL VEHICLES – FUEL H

APPENDIX H

SUPPORTING MATERIALS FOR STATISTICAL ANALYSIS

1.0 DETECTION AND REJECTION OF OUTLIERS

An initial step in the analysis was to screen the test run data for the presence of outliers. A statistical outlier is a data point that lies well away (either high or low) from most of the other values in a dataset such that it is an unlikely (but still possible) outcome of the experiment. Being an outlier in this sense does not automatically imply that the data point is invalid or should be excluded but, rather, that it requires additional scrutiny.

Two different statistical tests were applied to flag some test runs as candidate outliers:

- The Generalized ESD test[1] was used to compare the test runs overall using a method that determines how high or low (relative to the mean value) a data point is likely to fall merely by chance in a dataset of the given size.
- The Tukey test for outliers that underlies "box and whisker" plots[2] was applied to the residuals from a full-rank statistical model that related emissions to AKI, PMI and EtOH (see Eq. 1 in Section 5.2.5.1). This approach recognized that some vehicle/fuel combinations will have higher or lower emissions than others and may tend to fall in the tails of the statistical distribution.

The candidate outliers are reported in Tables H-1 and H-2. Test run 17344 for Vehicle J on Fuel A was evaluated by SwRI, which concluded that it accurately reflected the performance of the vehicle during the test. Also flagged by statistical tests, this test run is not considered an outlier.

For those test runs flagged as candidate outliers, t values were determined for the variation of the test runs around the average for the vehicle/fuel combination in the cases where N ≥ 3 test runs had been conducted. These are indicated in red font in the two tables.

TABLE H-1. CANDIDATE OUTLIERS (PARTICULATE EMISSIONS)

Vehicle	PM Group	Fuel (Test Run Number)			
		PN	PM	Bag 1 PM	EC
A					
D	Yes		A (15953)		
F	Yes		C (16561) C (16567)		D (16390)
J		A (17344)	A (17344)	A (17344)	A (17344)
G	Yes				F (16534)
I	Yes				
K					
L				E (17169) E (17155) E (17189) F (17014)	

[1] See http://www.itl.nist.gov/div898/handbook/eda/section3/eda35h3.htm for a description.
[2] See http://www.itl.nist.gov/div898/handbook/eda/section3/boxplot.htm for a description.

TABLE H-2. CANDIDATE OUTLIERS (GASEOUS EMISSIONS)

Vehicle	PM Group	Fuel (Test Run Number)			
		THC	CO	NOx	CO_2
A					
D	Yes			A (15948)	A (16146)
F	Yes			H (16709)	
J					
G	Yes			B (16430) B (16439)	
I	Yes				E (17166) F (16999)
K					
L		E (17169)	E (17169)		

Table H-3 summarized the result of this process and the number and identity of the test runs rejected for each pollutant. One test run (17169) was rejected for all dependent variables. The run showed an anomalous Bag 1 PM result that was inconsistent with the other measures of particulate emissions. It was also flagged as a candidate outlier for two of the four gaseous pollutants. In all other cases, a single test run for a given vehicle and fuel (out of 3 or 4 total test runs) was rejected for an individual dependent variable. From 1 to 4 test runs were rejected for each of the dependent variables.

TABLE H-3. DETECTION AND REJECTION OF OUTLYING TEST RUNS

	Candidate Outliers [a/] [b/]	Number Rejected	Vehicle (Fuel) Test Number
PN	1	1 + 0	
PM	4	1 + 1	D (A) 15953
Bag 1 PM	4	1	L (E) 17169 for all dependent variables
EC	3	1 + 1	F (D) 16390
THC	1	1 + 0	
CO	1	1 + 0	
NO_x	3	1 + 3	D (A) 15948; F (H) 16709; G (B) 16430
CO_2	3	1 + 2	D (A) 16146; I (F) 16999

[a/] Generalized ESD Test for Outliers applied to log(emissions) data. The assumption of a uniform standard deviation likely penalizes vehicles in the Low PM group due to their generally greater standard deviation in percent terms.

[b/] Tukey test for outliers (box/whisker plots) applied to residuals from a full-rank statistical model.

2.0 TEST CELL DRIFT

In a testing program that extends over several months, drift in the calibration of the instruments ("test cell drift") is a possibility. In this study, the first and best line of defense against test cell drift in this study was the attention that is given to instrument maintenance and calibration in the SwRI laboratory. Nevertheless, at the request of CRC Committee members, the data were examined for evidence of test cell drift as a precaution. As shown in this section, no such evidence was found.

To identify that drift has taken place, some method must be used to permit a comparison between the results actually observed in the test program over time and the results that *should* have been observed. Sometimes, a reference vehicle is tested periodically during the program with steps taken to assure that it remains in the same condition over time. Because drift at the SwRI laboratory is unlikely, reference vehicle testing was not done to conserve resources for the experiment.

Because of this, a statistical method was used here to allow the experimental data themselves to define the results that "should" have been observed in the test program over time. Because the experimental data involve known or expected differences in emissions by vehicle and fuel, these effects must first be removed. Once this is done, we expect to see no change in the average value of emissions over time under the hypothesis that test cell drift is absent. The method used for removing vehicle and fuel effects was to fit a full-rank model to the test run data for each of the eight pollutants examined in the study. The model form is that given in Eq. 1 in Section 5, but with the index notation extended to indicate that individual test runs are the data.

Use of the full-rank models accounts fully for whatever emission effects can be present in a 2 x 2 x 2 = 8 fuel experiment without imposing any assumptions or conclusions as to the emissions effects are actually present or how the model might correspondingly be simplified. The residuals from the full-rank model re-express the measured data in a form where the known or expected differences by vehicle and fuel have been removed, at least to the extent possible analytically. Individual test runs were used as the input data because this evaluation was conducted as part of a larger assessment of the test run data for outliers and other statistical characteristics. It is known that analysis of datasets with replicated test runs using the SAS GLM procedure produces flawed estimates of statistical significance. However, the coefficient estimates are correct and no use was made of the statistical significance estimated in the drift assessment.

Once the residuals were estimated, they were averaged by vehicle and fuel and then plotted against average test run number to produce the graphs seen below. The test runs were numbered sequentially during the program and the testing of each vehicle normally completed within a short period of time. Thus, the average test run number is a reliable indicator of when each vehicle/fuel combination was tested in relation to the others. A simple trend line was drawn through the scatter plot of residuals for each of the 8 dependent emissions variables with its coefficients and R^2 values indicated on the plots. In no case was the slope for average test number statistically significant, and in only one case, LA92 NO_X where two data points have high leverage on the slope, does the trend line deviate noticeably from horizontal. From this, we conclude that there is no evidence in the data suggesting the presence of test cell drift.

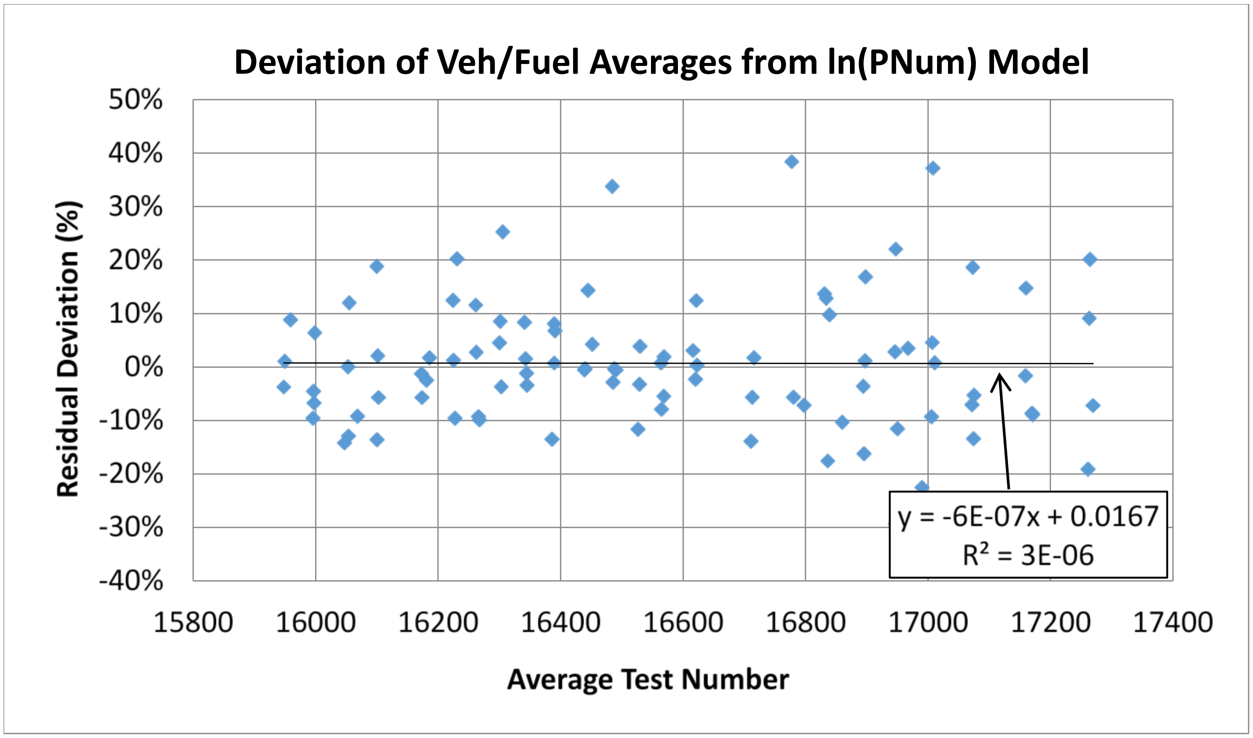


FIGURE H-1. EVALUATION OF TEST DRIFT FOR LA92 PN EMISSIONS

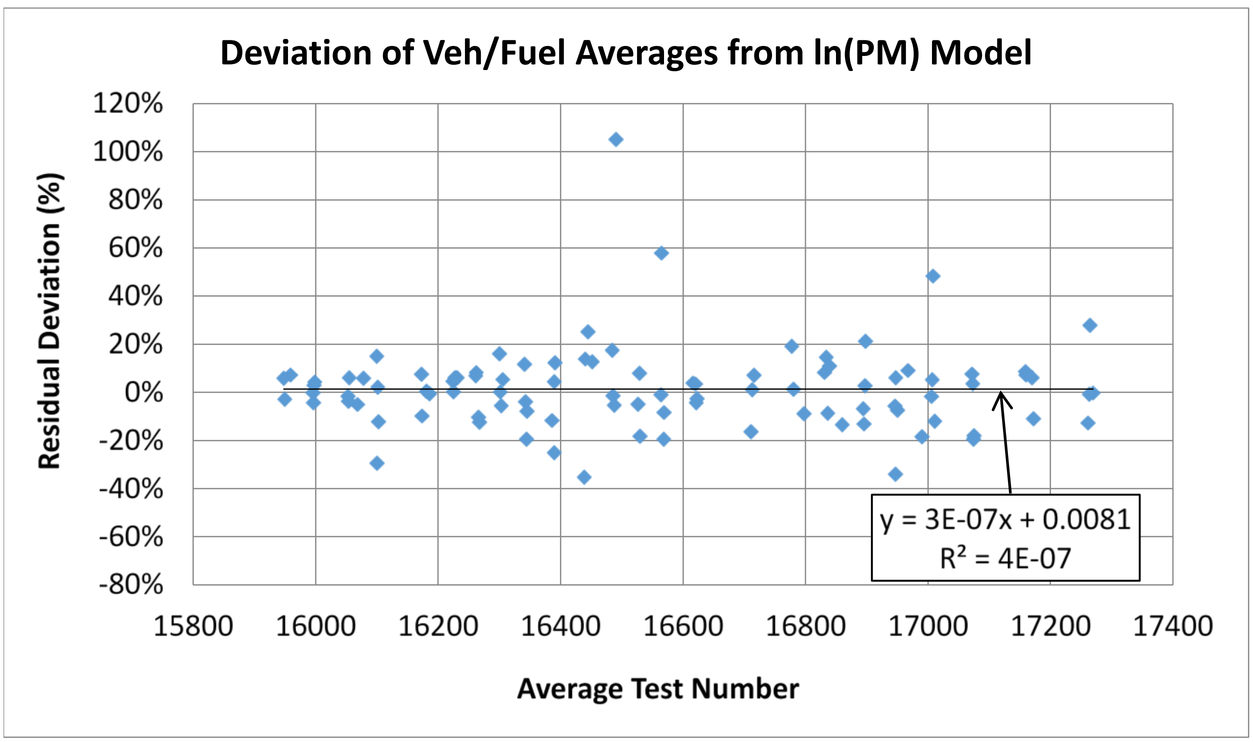


FIGURE H-2. EVALUATION OF TEST DRIFT FOR LA92 PM EMISSIONS

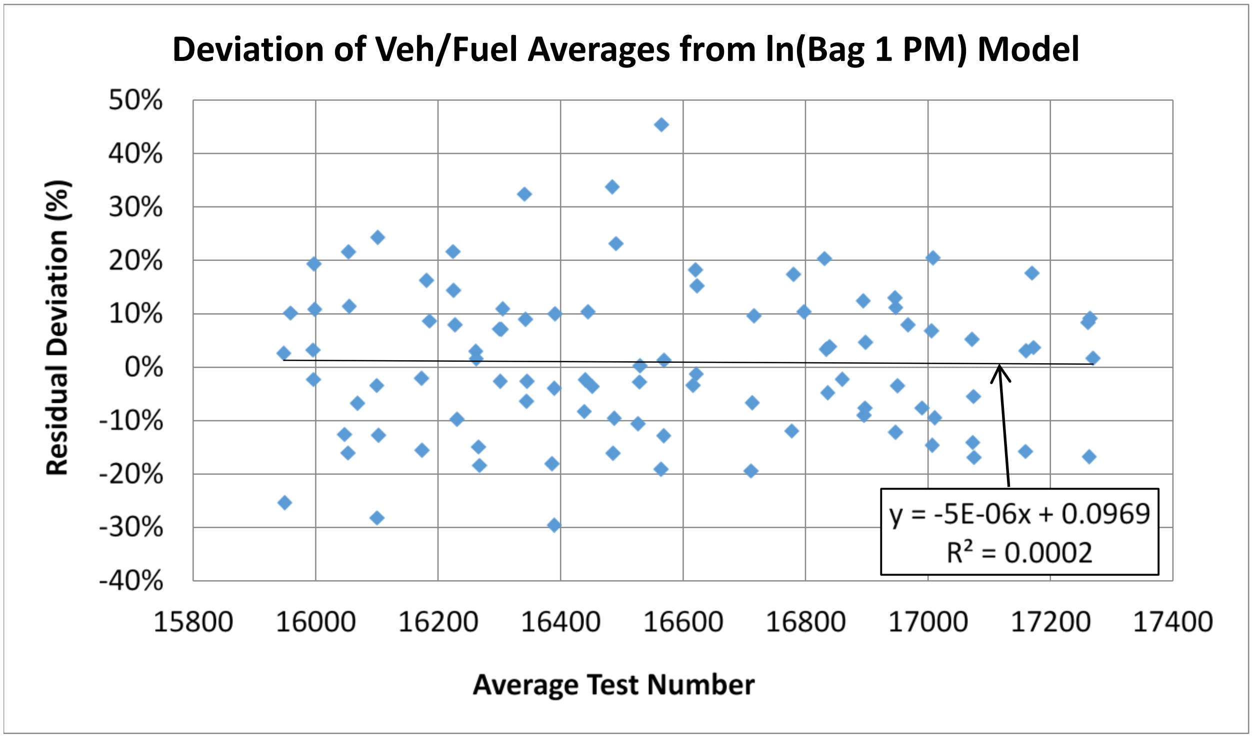


FIGURE H-3. EVALUATION OF TEST DRIFT FOR BAG 1 PM EMISSIONS

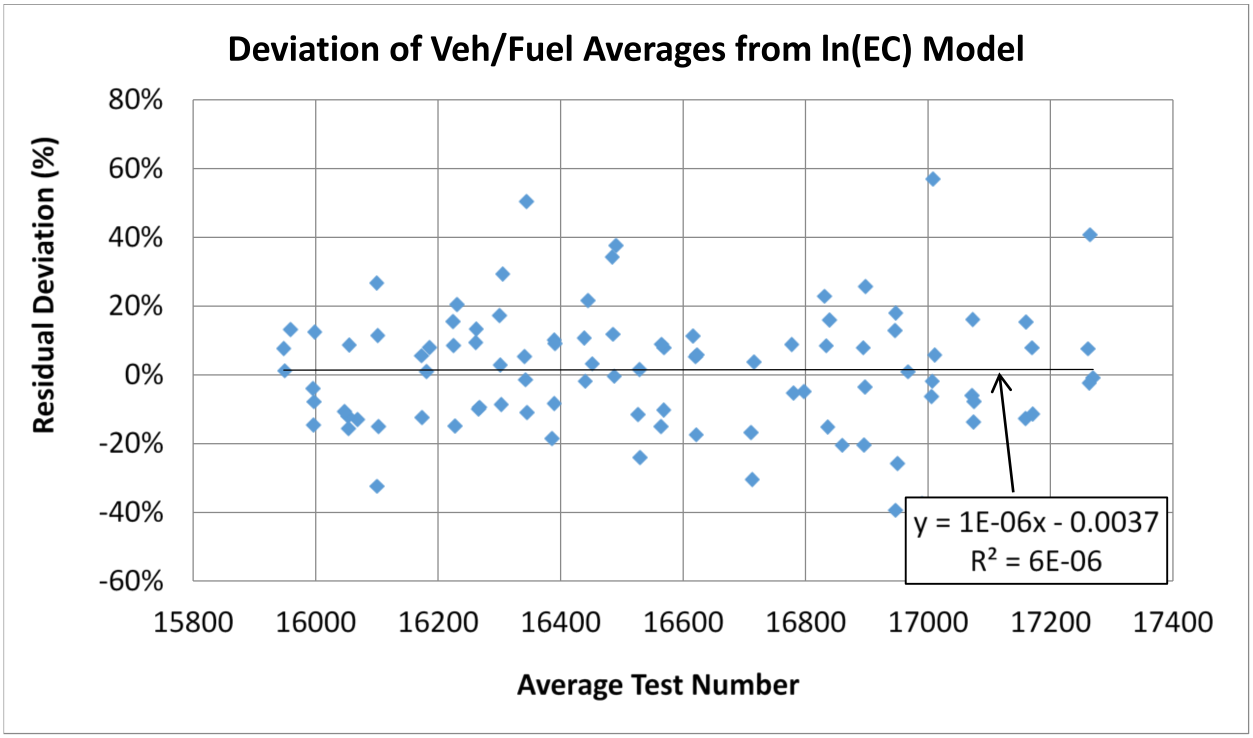


FIGURE H-4. EVALUATION OF TEST DRIFT FOR LA92 EC EMISSIONS

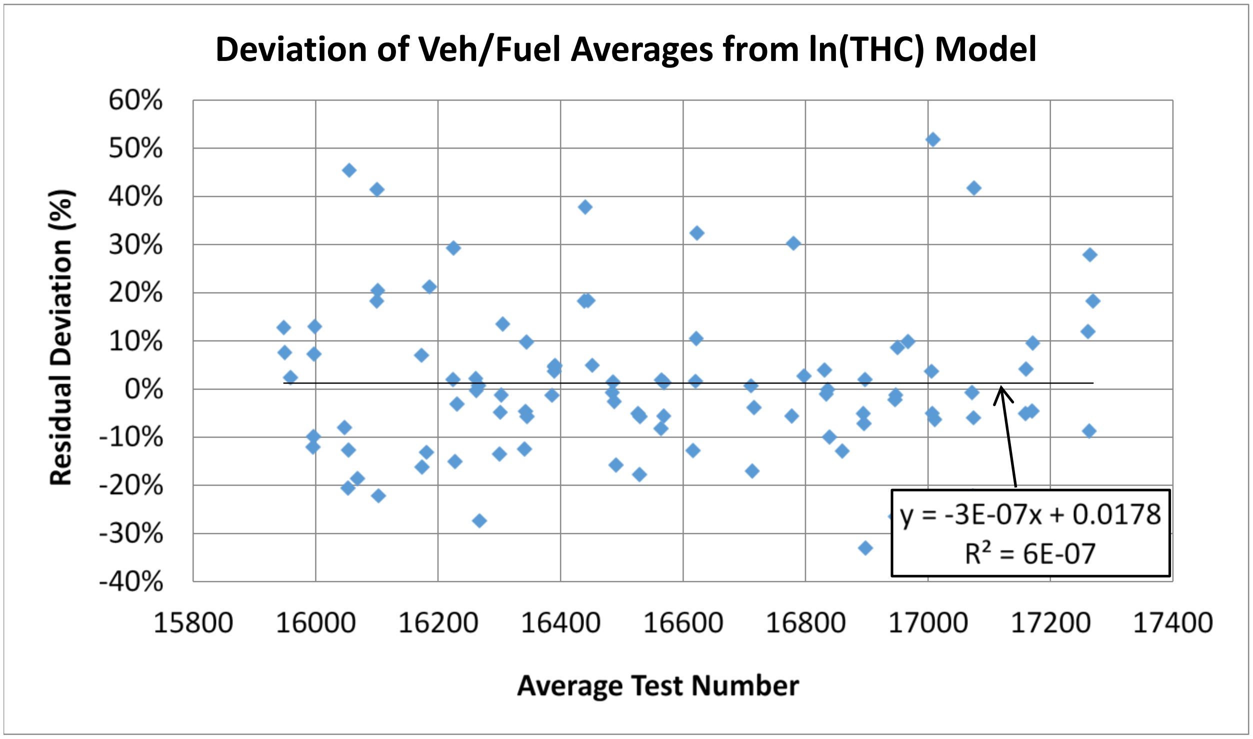


FIGURE H-5. EVALUATION OF TEST DRIFT FOR LA92 THC EMISSIONS

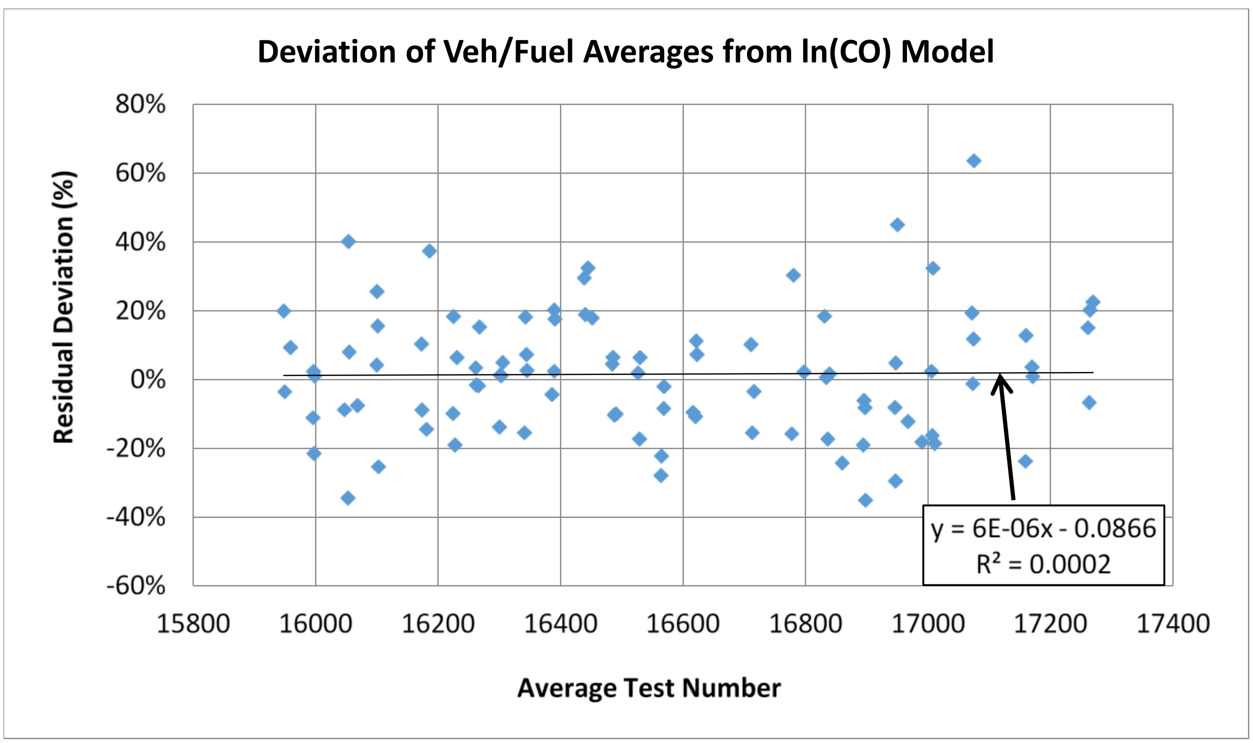


FIGURE H-6. EVALUATION OF TEST DRIFT FOR LA92 CO EMISSIONS

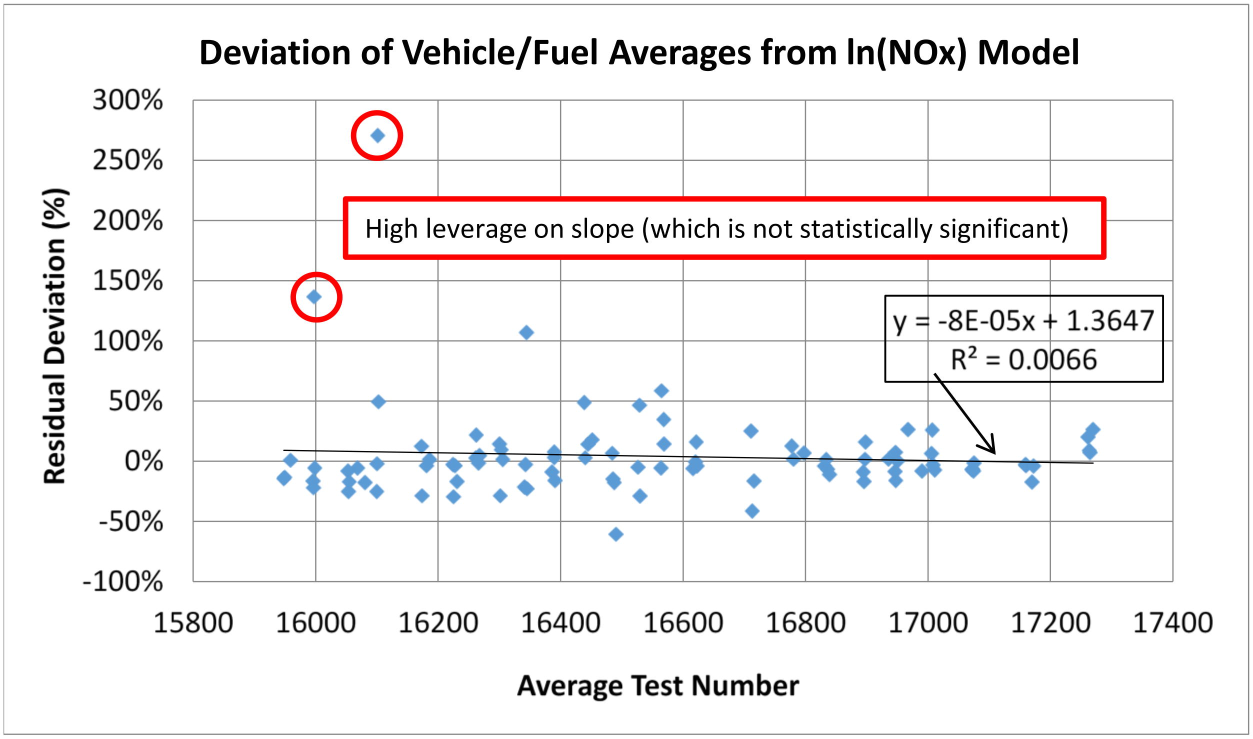


FIGURE H-7. EVALUATION OF TEST DRIFT FOR LA92 NO_X EMISSIONS

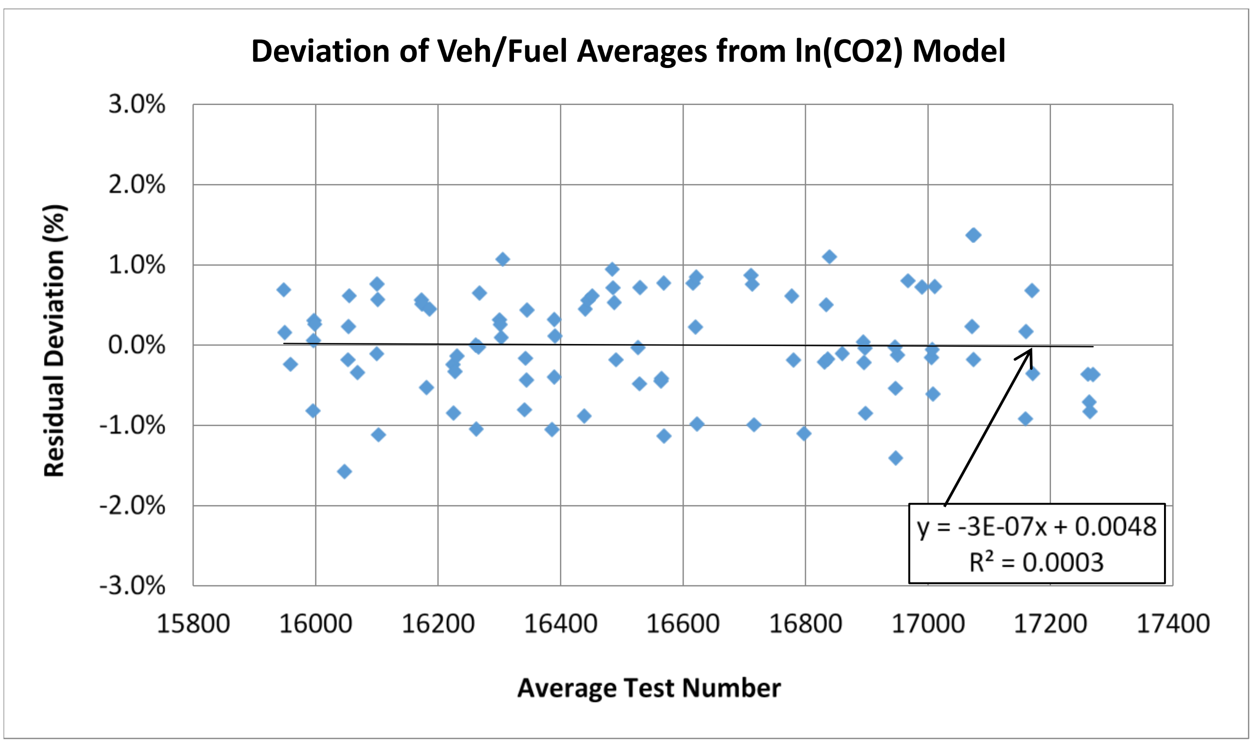


FIGURE H-8. EVALUATION OF TEST DRIFT FOR LA92 CO_2 EMISSIONS

3.0 LA92 PN EMISSIONS

TABLE H-4 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES MODEL 2: LN(PN) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	**Estimated Coefficient for Fuel Effect**				**Other Fuel Terms [a/]**
		Intercept	**AKI**	**PMI**	**EtOH**	
4-Cyl Nat Asp						
Vehicle B	0.936	2.62	0.0032	**0.371**	0.0024	none
Vehicle D	0.965	1.52	-0.0028	**0.703**	0.0075	none
Vehicle E	0.900	4.59	-0.0085	**0.308**	0.0239	none
Vehicle I	0.892	2.29	-0.0104	0.654	[0.0004]	RVP
Vehicle K	0.964	3.96	-0.0040	**0.375**	[0.0223]	none
4-Cyl Turbo						
Vehicle A	0.901	3.55	-0.0141	**0.534**	[0.0177]	none
Vehicle C	0.989	0.16	0.0134	**0.788**	0.0099	T60
Vehicle F	0.971	0.33	0.0123	**0.587**	0.0407	none
Vehicle J	0.988	0.07	0.0217	**0.507**	**0.0225**	none
Vehicle L	0.965	-0.86	0.0125	**0.828**	0.0297	none
V6 Engines						
Vehicle G	0.959	-0.12	0.0087	**0.327**	0.0104	RVP
Vehicle H	0.963	1.40	0.0154	**0.580**	0.0200	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

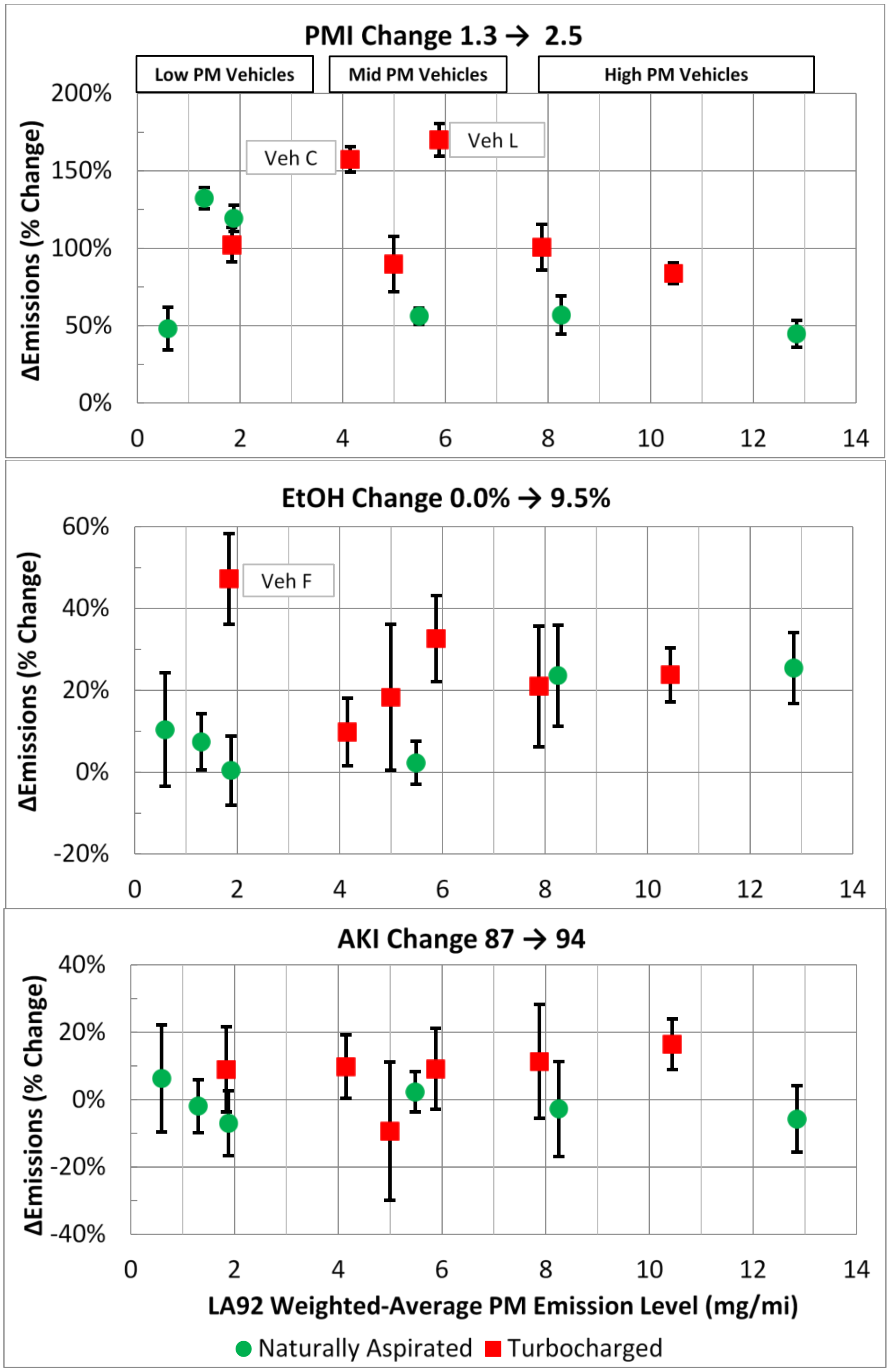


FIGURE H-9. RESPONSE OF LA92 PN EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-5 MODEL DOCUMENTATION FOR TEST FLEET MODEL 1: LN(PN) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients				Other Fuel Terms [a]
		Intercept	PMI	EtOH		
			All Fuels	Low PMI	High PMI	
Average Vehicle	0.982	0.460	0.600 ± 0.032 ($p < 0.0001$)	0.0334 ± 0.0038 ($p < 0.0001$)	0.0141 ± 0.0041 ($p = 0.001$)	None
Veh A		0.875				
Veh B		0.802				
Veh C		0.723				
Veh D		-0.839				
Veh E		1.447				
Veh F		-0.396				
Veh G		-1.078				
Veh H		1.063				
Veh I		-0.060				
Veh J		1.189				
Veh K		1.053				
Veh L		0.745				

[a] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-6. EFFECT OF FUELS ON LA92 PN EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 105% ± 4%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 37% ± 4%
	AKI 87 High PMI	+ 14% ± 4%
	AKI 94 Low PMI	+ 37% ± 4%
	AKI 94 High PMI	+ 14% ± 4%
AKI 87 → 94	All Fuels	—

TABLE H-7. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES
MODEL 1: LN(PN) EMISSIONS = F(V_K, AKI, PMI, ETOH)

<table>
<tr><th rowspan="3">Group</th><th rowspan="3">R^2</th><th colspan="5">Estimated Fuel Effects Coefficients</th><th rowspan="3">Other Fuel Terms[a/]</th></tr>
<tr><th rowspan="2">Intercept</th><th>PMI</th><th colspan="3">EtOH</th></tr>
<tr><th>All Fuels</th><th>AKI 87 All</th><th>AKI 94 Low PMI</th><th>AKI 94 High PMI</th></tr>
<tr><td>Average Vehicle</td><td rowspan="6">0.984</td><td>0.410</td><td rowspan="6">0.644
± 0.045
($p < 0.0001$)</td><td rowspan="6">0.0345
± 0.0060
($p = 0.0001$)</td><td rowspan="6">0.0137
± 0.0073
($p = 0.07$)</td><td rowspan="6">No Effect</td><td rowspan="6"></td></tr>
<tr><td>Veh B</td><td>0.731</td></tr>
<tr><td>Veh D</td><td>-0.910</td></tr>
<tr><td>Veh E</td><td>1.376</td></tr>
<tr><td>Veh I</td><td>-0.131</td></tr>
<tr><td>Veh K</td><td>0.982</td></tr>
<tr><td colspan="8">[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.</td></tr>
</table>

TABLE H-8. EFFECT OF FUELS ON LA92 PN EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 117% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 39% ± 6%
	AKI 87 High PMI	+ 14% ± 7%
	AKI 94 Low PMI	+ 39% ± 6%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-9. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(PN) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.956	0.759	0.533 ± 0.048 (p < 0.0001)	0.0224 ± 0.0063 (p = 0.001)	0.0311 ± 0.0086 (p = 0.001)	0.0178 ± 0.0087 (p = 0.05)	None
Veh A		1.007					
Veh C		0.855					
Veh F		-0.264					
Veh L		1.321					
Veh J		0.875					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-10. EFFECT OF FUELS ON LA92 PN EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 89% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 24% ± 6%
	AKI 87 High PMI	+ 24% ± 6%
	AKI 94 Low PMI	+ 38% ± 7%
	AKI 94 High PMI	+ 18% ± 9%
AKI 87 → 94	All Fuels	—

TABLE H-11. MODEL DOCUMENTATION FOR LOW PM VEHICLES MODEL 1: LN(PN) EMISSIONS = F(V_K, D87HIE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients				Other Fuel Terms[a/]
		Intercept	Fuel Terms: AKI 87 High PMI E0	PMI: All Fuels	EtOH: All Fuel	
Average Vehicle	0.992	-0.492	0.215 ± 0.081 (p = 0.013)	0.507 ± 0.041 (p < 0.0001)	0.0346 ± 0.0051 (p < 0.0001)	None
Veh D		-0.738				
Veh F		-0.295				
Veh G		-0.976				
Veh I		0.041				

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-12. EFFECT OF FUELS ON LA92 PN EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 84% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 39% ± 5%
	AKI 87 High PMI	+ 39% ± 5%
	AKI 94 Low PMI	+ 39% ± 5%
	AKI 94 High PMI	+ 39% ± 5%
AKI 87 → 94	All Fuels	—

TABLE H-13. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(PN) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients			Other Fuel Terms[a/]
		Intercept	PMI	EtOH	
			All Fuels	All Fuels	
Average Vehicle	0.880	0.894	0.564 ± 0.043 ($p < 0.0001$)	0.0228 ± 0.0055 ($p = 0.0003$)	None
Veh A		0.983			
Veh B		0.910			
Veh C		0.830			
Veh L		0.853			

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-14. EFFECT OF FUELS ON LA92 PN EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 93% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 24% ± 5%
	AKI 87 High PMI	+ 24% ± 5%
	AKI 94 Low PMI	+ 27% ± 5%
	AKI 94 High PMI	+ 24% ± 5%
AKI 87 → 94	All Fuels	–

TABLE H-15. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(PN) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients			Other Fuel Terms[a/]
		Intercept	PMI	EtOH	
			All Fuels	All Fuels	
Average Vehicle	0.906	1.475	0.456 ± 0.036 ($p < 0.0001$)	0.0218 ± 0.0045 ($p < 0.0001$)	None
Veh E		1.734			
Veh H		1.349			
Veh J		1.475			
Veh K		1.340			

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-16. EFFECT OF FUELS ON LA92 PN EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 PN
PMI 1.3 → 2.5	All Fuels	+ 73% ± 4%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 23% ± 4%
	AKI 87 High PMI	+ 23% ± 4%
	AKI 94 Low PMI	+ 23% ± 4%
	AKI 94 High PMI	+ 23% ± 4%
AKI 87 → 94	All Fuels	–

4.0 LA92 PM EMISSIONS

TABLE H-17 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES
MODEL 2: LN(PM) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				**Other Fuel Terms**[a/]
		Intercept	AKI	PMI	EtOH	
4-Cyl Nat Asp						
Vehicle B	**0.935**	0.79	~~-0.0019~~	**0.491**	[0.0225]	none
Vehicle D	0.980	-0.38	~~-0.0156~~	**0.623**	0.0184	none
Vehicle E	0.920	1.96	~~-0.0060~~	**0.472**	**0.0334**	none
Vehicle I	0.914	1.63	~~-0.0228~~	**0.458**	[0.0236]	RVP
Vehicle K	0.933	0.05	~~-0.0065~~	**0.648**	[0.0286]	RVP
4-Cyl Turbo						
Vehicle A	0.879	0.33	~~-0.0016~~	**0.624**	~~0.0287~~	none
Vehicle C	0.985	0.48	~~-0.0024~~	**0.543**	**0.0121**	none
Vehicle F	0.916	0.82	~~-0.0176~~	**0.579**	[0.0265]	none
Vehicle J	0.972	0.75	~~-0.0064~~	**0.455**	**0.0222**	none
Vehicle L	0.974	-2.23	~~-0.0206~~	**0.950**	0.0331	none
V6 Engines						
Vehicle G	0.657	-3.30	~~-0.0275~~	~~0.185~~	~~-0.0211~~	none
Vehicle H	0.960	-0.41	~~-0.0095~~	**0.720**	[0.0250]	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

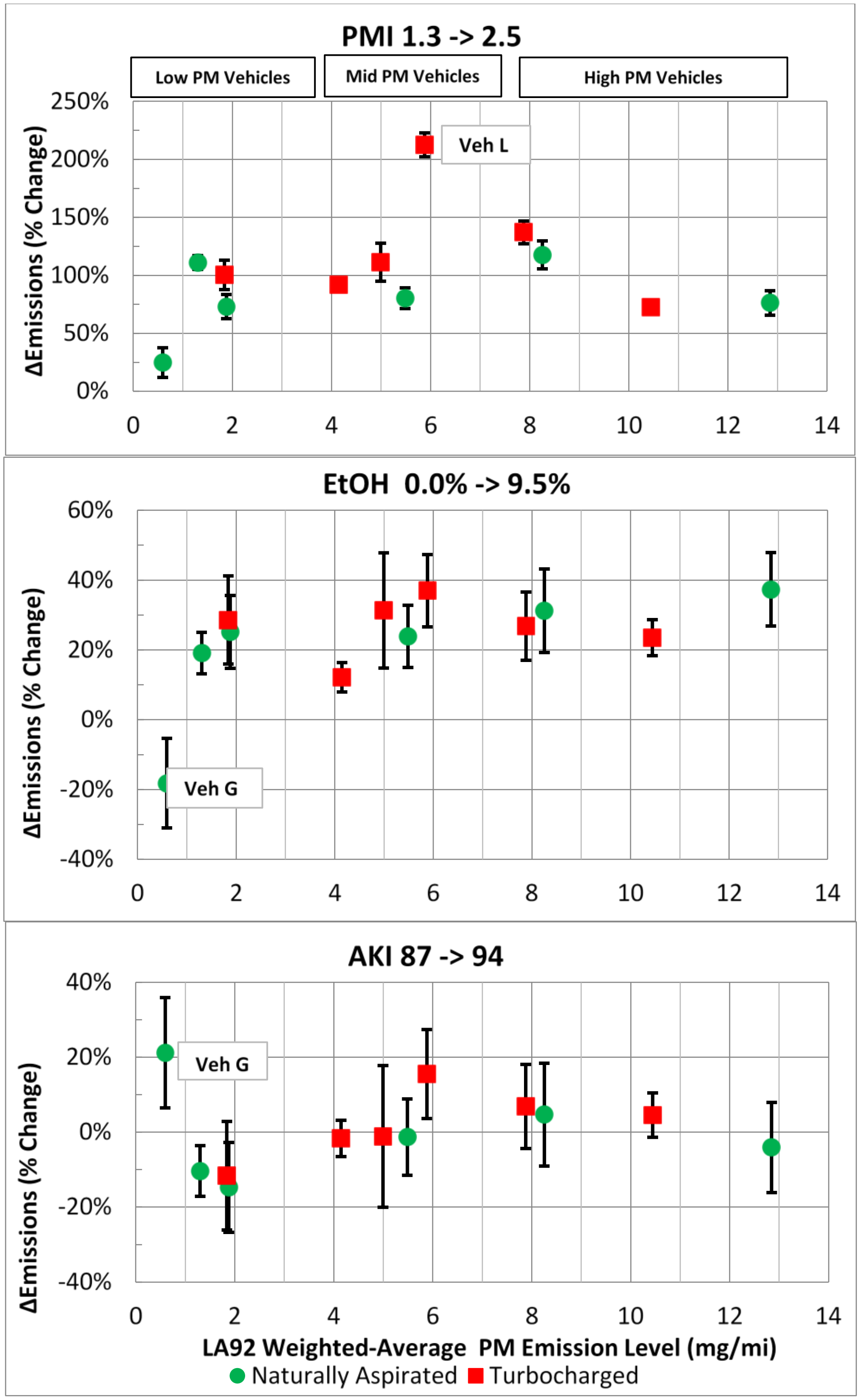


FIGURE H-10. RESPONSE OF LA92 PM EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE

TABLE H-18 MODEL DOCUMENTATION FOR TEST FLEET MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.973	-0.353	0.601 ± 0.028 (p < 0.0001)	0.0304 ± 0.0036 (p < 0.0001)	0.0304 ± 0.0036 (p < 0.0001)	No Effect	RVP
Veh A		-0.133					
Veh B		0.009					
Veh C		-0.299					
Veh D		-1.411					
Veh E		0.825					
Veh F		-1.195					
Veh G		-2.217					
Veh H		0.301					
Veh I		-1.101					
Veh J		0.646					
Veh K		0.367					
Veh L		-0.029					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-19. EFFECT OF FUELS ON LA92 PM EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 106% ± 3%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 33% ± 3%
	AKI 87 High PMI	+ 33% ± 3%
	AKI 94 Low PMI	+ 33% ± 3%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-20. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

<table>
<tr><th rowspan="3">Group</th><th rowspan="3">R^2</th><th colspan="5">Estimated Fuel Effects Coefficients</th><th rowspan="3">Other Fuel Terms[a/]</th></tr>
<tr><th rowspan="2">Intercept</th><th>PMI</th><th colspan="3">EtOH</th></tr>
<tr><th>All Fuels</th><th>AKI 87 All</th><th>AKI 94 Low PMI</th><th>AKI 94 High PMI</th></tr>
<tr><td>Average Vehicle</td><td rowspan="6">0.990</td><td>0.129</td><td rowspan="6">0.601
± 0.028

(p < 0.0001)</td><td rowspan="6">0.0304
± 0.0036

(p < 0.0001)</td><td rowspan="6">0.0304
± 0.0036

(p < 0.0001)</td><td rowspan="6">No Effect</td><td rowspan="6">RVP</td></tr>
<tr><td>Veh B</td><td>0.400</td></tr>
<tr><td>Veh D</td><td>-1.020</td></tr>
<tr><td>Veh E</td><td>1.216</td></tr>
<tr><td>Veh I</td><td>-0.710</td></tr>
<tr><td>Veh K</td><td>0.758</td></tr>
<tr><td colspan="8">[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.</td></tr>
</table>

TABLE H-21. EFFECT OF FUELS ON LA92 PM EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 136% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 20% ± 6%
	AKI 87 High PMI	+ 20% ± 7%
	AKI 94 Low PMI	+ 46% ± 6%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-22. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.962	-0.014	0.714 ± 0.046 (p < 0.0001)	0.0190 ± 0.0063 (p = 0.005)	0.0398 ± 0.0090 (p = 0.0001)	No Effect	None
Veh A		0.055					
Veh C		-0.111					
Veh F		-1.007					
Veh L		0.835					
Veh J		0.159					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-23. EFFECT OF FUELS ON LA92 PM EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 89% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 24% ± 6%
	AKI 87 High PMI	+ 24% ± 6%
	AKI 94 Low PMI	+ 38% ± 7%
	AKI 94 High PMI	+ 18% ± 9%
AKI 87 → 94	All Fuels	–

TABLE H-24. MODEL DOCUMENTATION FOR LOW PM VEHICLES MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients			Other Fuel Terms[a/]
		Intercept	PMI AKI 87 High PMI E0	EtOH All Fuels	
Average Vehicle	0.870	-0.731	0.472 ± 0.064 (p < 0.0001)	No Effect	None
Veh D		-0.660			
Veh F		-0.445			
Veh G		-1.467			
Veh I		-0.351			

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-25. EFFECT OF FUELS ON LA92 PM EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 76% ± 8%
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-26. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients			Other Fuel Terms[a/]
		Intercept	PMI	EtOH	
			All Fuels	All Fuels	
Average Vehicle	0.897	0.038	0.736 ± 0.053 (p < 0.0001)	0.0174 ± 0.0073 (p = 0.025)	0.0399 ± 0.0103 (p = 0.001)
Veh A		0.018			
Veh B		0.160			
Veh C		-0.149			
Veh L		0.121			

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-27. EFFECT OF FUELS ON LA92 PM EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 140% ± 7%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 18% ± 7%
	AKI 87 High PMI	+ 18% ± 7%
	AKI 94 Low PMI	+ 46% ± 10%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-28. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.957	0.926	0.620 ± 0.039 (p < 0.0001)	0.0206 ± 0.0049 (p = 0.0003)	0.0361 ± 0.0073 (p < 0.0001)	No Effect	None
Veh E		1.216					
Veh H		0.692					
Veh J		1.038					
Veh K		0.758					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-29. EFFECT OF FUELS ON LA92 PM EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 PM
PMI 1.3 → 2.5	All Fuels	+ 110% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 22% ± 5%
	AKI 87 High PMI	+ 22% ± 5%
	AKI 94 Low PMI	+ 41% ± 7%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

5.0 BAG 1 PM EMISSIONS

TABLE H-30 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES
MODEL 2: LN(BAG 1 PM) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	AKI	PMI	EtOH	
4-Cyl Nat Asp						
Vehicle B	0.980	2.62	~~-0.0032~~	**0.371**	~~0.0024~~	none
Vehicle D	0.977	1.52	~~-0.0028~~	**0.703**	~~0.0075~~	none
Vehicle E	0.886	4.59	~~-0.0085~~	0.308	[0.0239]	none
Vehicle I	0.961	2.29	~~-0.0104~~	**0.654**	~~0.0004~~	none
Vehicle K	0.832	3.96	~~-0.0040~~	0.375	[0.0223]	RVP
4-Cyl Turbo						
Vehicle A	0.818	3.55	~~-0.0141~~	0.534	~~0.0177~~	none
Vehicle C	0.973	0.16	~~-0.0134~~	**0.788**	~~0.0099~~	none
Vehicle F	0.939	0.33	~~-0.0123~~	**0.587**	0.0407	none
Vehicle J	0.964	0.07	[0.0217]	**0.507**	0.0225	none
Vehicle L	0.968	-0.38	0.0241	**0.682**	0.0270	none
V6 Engines						
Vehicle G	0.714	-0.12	~~-0.0087~~	0.327	0.0104	none
Vehicle H	0.876	1.40	~~-0.0154~~	**0.580**	0.0200	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the p ≤ 0.01 level (≥ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the p = 0.05 level (≥ 95% confidence).
Brackets indicate the estimate has marginal significance (p ≤ 0.10), but fails to reach full statistical significance (p ≤ 0.05)
Strikethrough indicates the estimate fails to reach marginal statistical significance (p = 0.10 or better).

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

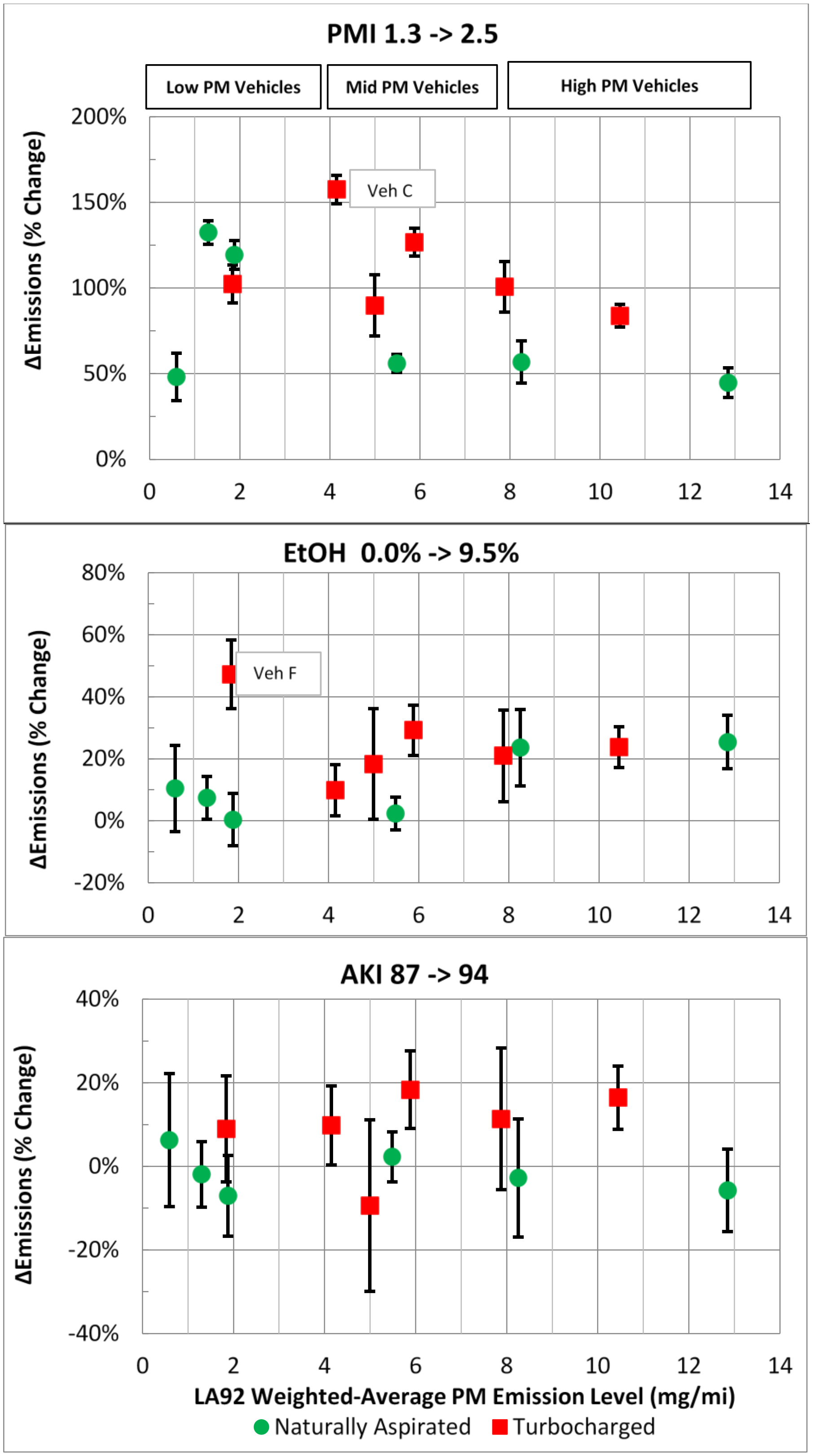


FIGURE H-11. RESPONSE OF BAG 1 PM EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-31 MODEL DOCUMENTATION FOR TEST FLEET MODEL 1: LN(BAG 1 PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.977	1.994	0.603 ± 0.028 (p < 0.0001)	0.0120 ± 0.0039 (p = 0.002)	0.0328 ± 0.0055 (p = 0.0001)	No Effect	None
Veh A		2.158					
Veh B		2.410					
Veh C		1.712					
Veh D		1.427					
Veh E		3.297					
Veh F		1.539					
Veh G		0.118					
Veh H		2.782					
Veh I		1.382					
Veh J		1.894					
Veh K		3.191					
Veh L		2.019					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-32. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ Bag 1 PM
PMI 1.3 → 2.5	All Fuels	+ 106% ± 3%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 12% ± 4%
	AKI 87 High PMI	+ 12% ± 4%
	AKI 94 Low PMI	+ 37% ± 5%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

Table H-33. Model Documentation for 4-Cylinder Naturally Aspirated Vehicles
Model 1: ln(Bag 1 PM) Emissions = f(v_k, AKI, PMI, EtOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.980	2.494	0.529 ± 0.041 (p < 0.0001)	0.0134 ± 0.0056 (p = 0.02)	0.0219 ± 0.0079 (p = 0.01)	No Effect	None
Veh B		2.562					
Veh D		1.579					
Veh E		3.449					
Veh I		1.535					
Veh K		3.343					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-34. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ Bag 1 PM
PMI 1.3 → 2.5	All Fuels	+ 89% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 14% ± 5%
	AKI 87 High PMI	+ 14% ± 5%
	AKI 94 Low PMI	+ 23% ± 8%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-35. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(BAG 1 PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	**R^2**	**Estimated Fuel Effects Coefficients**						**Other Fuel Terms**[a/]
		Intercept	**PMI**	**EtOH**				
			All Fuels	**AKI 87 Low PMI**	**AKI 87 High PMI**	**AKI 94 Low PMI**	**AKI 94 Hi PMI**	
Average Vehicle	0.936	1.539	0.763 ± 0.043 (p < 0.0001)	0.0219 ± 0.0074 (p = 0.006)	No Effect	0.0474 ± 0.0077 (p < 0.001)	No Effect	None
Veh A		1.833						
Veh C		1.387						
Veh F		1.213						
Veh L		1.569						
Veh J		1.694						

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-36. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	**Fuel**	**Δ BAG 1 PM**
PMI 1.3 → 2.5	All Fuels	+ 150% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 23% ± 7%
	AKI 87 High PMI	—
	AKI 94 Low PMI	+ 57% ± 8%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-37. MODEL DOCUMENTATION FOR LOW PM VEHICLES
MODEL 1: LN(BAG 1 PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.951	1.183	0.567 ± 0.050 (p < 0.0001)	0.0147 ± 0.0063 (p = 0.03)			None
Veh D		1.494					
Veh F		1.606					
Veh G		0.185					
Veh I		1.449					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-38. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ BAG 1 PM
PMI 1.3 → 2.5	All Fuels	+ 97% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 15% ± 6%
	AKI 87 High PMI	+ 15% ± 6%
	AKI 94 Low PMI	+ 15% ± 6%
	AKI 94 High PMI	+ 15% ± 6%
AKI 87 → 94	All Fuels	–

TABLE H-39. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(BAG 1 PM) EMISSIONS = F(V_K, AKI, PMI, ETOH)

<table>
<tr><th rowspan="3">Group</th><th rowspan="3">R^2</th><th colspan="5">Estimated Fuel Effects Coefficients</th><th rowspan="3">Other Fuel Terms[a/]</th></tr>
<tr><th rowspan="2">Intercept</th><th>PMI</th><th colspan="3">EtOH</th></tr>
<tr><th>All Fuels</th><th>AKI 87 All</th><th>AKI 94 Low PMI</th><th>AKI 94 High PMI</th></tr>
<tr><td>Average Vehicle</td><td rowspan="5">0.887</td><td>1.984</td><td rowspan="5">0.665
± 0.050
(p < 0.0001)</td><td rowspan="5">No Effect</td><td rowspan="5">0.0239
± 0.0064
(p = 0.001)</td><td rowspan="5">No Effect</td><td rowspan="5">None</td></tr>
<tr><td>Veh A</td><td>2.067</td></tr>
<tr><td>Veh B</td><td>2.319</td></tr>
<tr><td>Veh C</td><td>1.621</td></tr>
<tr><td>Veh L</td><td>1.928</td></tr>
<tr><td colspan="8">[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.</td></tr>
</table>

TABLE H-40. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ BAG 1 PM
PMI 1.3 → 2.5	All Fuels	+ 122% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	+ 35% ± 9%
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-41. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(BAG 1 PM) EMISSIONS = F(V_K, D87LOE0, AKI, PMI, ETOH)

<table>
<tr><th rowspan="3">Group</th><th rowspan="3">R^2</th><th colspan="6">Estimated Fuel Effects Coefficients</th><th rowspan="3">Other Fuel Terms[a/]</th></tr>
<tr><th rowspan="2">Intercept</th><th>Fuel Term</th><th>PMI</th><th colspan="3">EtOH</th></tr>
<tr><th>AKI 87 Low PMI E0</th><th>All Fuels</th><th>AKI 87 All</th><th>AKI 94 Low PMI</th><th>AKI 94 High PMI</th></tr>
<tr><td>Average Vehicle</td><td rowspan="5">0.969</td><td>3.192</td><td rowspan="5">-0.214
± 0.078

(p = 0.01)</td><td rowspan="5">0.402
± 0.039

(p < 0.0001)</td><td colspan="3" rowspan="5">0.0165
± 0.0051

(p = 0.003)</td><td rowspan="5">None</td></tr>
<tr><td>Veh E</td><td>3.700</td></tr>
<tr><td>Veh H</td><td>3.185</td></tr>
<tr><td>Veh J</td><td>2.297</td></tr>
<tr><td>Veh K</td><td>3.594</td></tr>
<tr><td colspan="9">[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.</td></tr>
</table>

TABLE H-42. EFFECT OF FUELS ON BAG 1 PM EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ BAG 1 PM
PMI 1.3 → 2.5	All Fuels	+ 62% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 17% ± 5%
	AKI 87 High PMI	+ 17% ± 5%
	AKI 94 Low PMI	+ 17% ± 7%
	AKI 94 High PMI	+ 17% ± 7%
AKI 87 → 94	All Fuels	—

6.0 LA92 EC EMISSIONS

TABLE H-43 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES
MODEL 2: LN(EC) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	**AKI**	**PMI**	**EtOH**	
4-Cyl Nat Asp						
Vehicle B	**0.942**	2.62	~~-0.0032~~	0.371	0.0024	none
Vehicle D	0.959	1.52	~~-0.0028~~	**0.703**	[0.0075]	none
Vehicle E	0.929	4.59	~~-0.0085~~	0.308	0.0239	none
Vehicle I	0.957	2.29	~~-0.0104~~	**0.654**	[0.0004]	none
Vehicle K	0.929	3.96	~~-0.0040~~	0.375	[0.0223]	RVP
4-Cyl Turbo						
Vehicle A	0.858	3.55	~~-0.0141~~	0.534	0.0177	none
Vehicle C	0.992	0.16	~~-0.0134~~	**0.788**	0.0099	none
Vehicle F	0.927	-1.02	~~-0.0049~~	0.663	0.0449	none
Vehicle J	0.970	0.07	~~-0.0217~~	**0.507**	0.0225	none
Vehicle L	0.953	-3.57	~~-0.0272~~	**1.182**	[0.0324]	none
V6 Engines						
Vehicle G	0.856	-0.12	~~0.0087~~	0.327	~~0.0104~~	none
Vehicle H	0.951	1.40	~~0.0154~~	**0.580**	[0.0200]	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

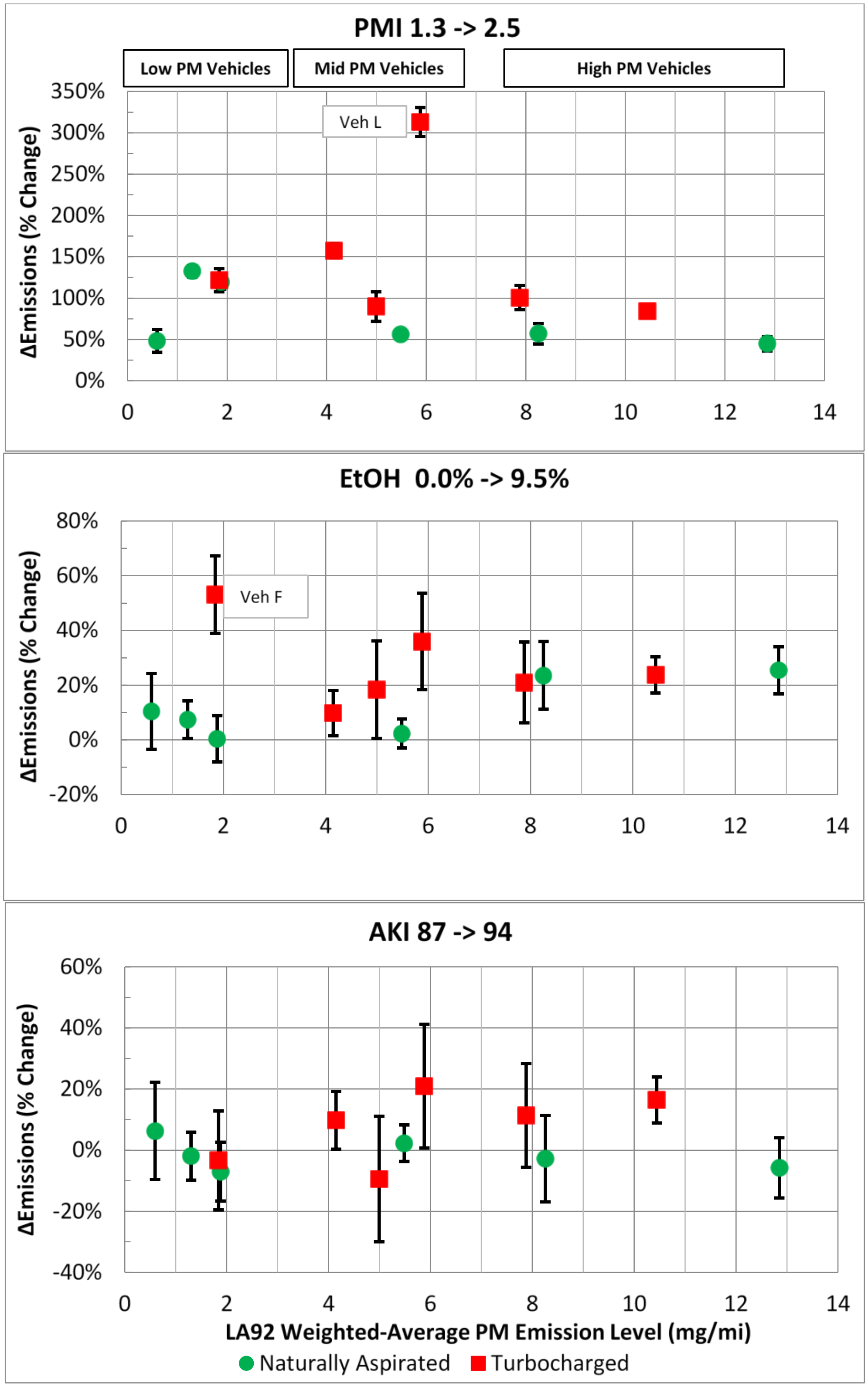


FIGURE H-12. RESPONSE OF LA92 EC EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-44 MODEL DOCUMENTATION FOR TEST FLEET
MODEL 1: LN(EC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.980	-0.776	0.819 ± 0.043 (p < 0.0001)	0.0402 ± 0.0057 (p < 0.0001)	0.0202 ± 0.0069 (p = 0.005)	**No Effect**	None
Veh A		-0.447					
Veh B		-0.252					
Veh C		-0.660					
Veh D		-2.004					
Veh E		0.629					
Veh F		-1.667					
Veh G		-3.460					
Veh H		0.040					
Veh I		-1.760					
Veh J		0.445					
Veh K		0.191					
Veh L		-0.369					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-45. EFFECT OF FUELS ON LA92 EC EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 167% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 47% ± 6%
	AKI 87 High PMI	+ 21% ± 7%
	AKI 94 Low PMI	+ 47% ± 6%
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-46. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES MODEL 1: LN(EC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

<table>
<tr><th rowspan="3">Group</th><th rowspan="3">R^2</th><th colspan="5">Estimated Fuel Effects Coefficients</th><th rowspan="3">Other Fuel Terms[a/]</th></tr>
<tr><th rowspan="2">Intercept</th><th>PMI</th><th colspan="3">EtOH</th></tr>
<tr><th>All Fuels</th><th>AKI 87 All</th><th>AKI 94 Low PMI</th><th>AKI 94 High PMI</th></tr>
<tr><td>Average Vehicle</td><td rowspan="6">0.986</td><td>-0.674</td><td rowspan="6">0.836 ± 0.052 (p < 0.0001)</td><td rowspan="6">0.0425 ± 0.0070 (p = 0.0001)</td><td rowspan="6">0.0186 ± 0.0085 (p = 0.04)</td><td rowspan="6">No Effect</td><td rowspan="6">None</td></tr>
<tr><td>Veh B</td><td>-0.287</td></tr>
<tr><td>Veh D</td><td>-2.039</td></tr>
<tr><td>Veh E</td><td>-0.594</td></tr>
<tr><td>Veh I</td><td>-1.795</td></tr>
<tr><td>Veh K</td><td>0.156</td></tr>
<tr><td colspan="8">[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.</td></tr>
</table>

TABLE H-47. EFFECT OF FUELS ON LA92 EC EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 173% ± 6%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 50% ± 7%
	AKI 87 High PMI	+ 19% ± 8%
	AKI 94 Low PMI	+ 50% ± 7%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-48. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(EC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.943	-0.533	0.822 ± 0.065 ($p < 0.0001$)	0.0218 ± 0.0088 ($p = 0.02$)	0.0463 ± 0.0126 ($p = 0.001$)	No Effect	None
Veh A		-0.440					
Veh C		-0.653					
Veh F		-1.660					
Veh J		0.452					
Veh L		-0.362					

[a] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-49. EFFECT OF FUELS ON LA92 EC EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 168% ± 8%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 23% ± 9%
	AKI 87 High PMI	+ 23% ± 9%
	AKI 94 Low PMI	+ 55% ± 13%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-50. MODEL DOCUMENTATION FOR LOW PM VEHICLES
MODEL 1: LN(EC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.928	2.236	0.809 ± 0.085 (p < 0.0001)	No Effect	0.026 ± 0.016 (p = 0.12)	No Effect	T40
Veh D		-1.002					
Veh F		-0.680					
Veh G		-0.950					
Veh I		-0.760					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-51. EFFECT OF FUELS ON LA92 EC EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 165% ± 7%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 47% ± 7%
	AKI 87 High PMI	+ 47% ± 7%
	AKI 94 Low PMI	+ 47% ± 7%
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-52. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(EC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	PMI	EtOH			
			All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.849	0.299	0.745 ± 0.069 ($p < 0.0001$)	0.0276 ± 0.0087 ($p = 0.004$)	0.0276 ± 0.0087 ($p = 0.004$)	0.0276 ± 0.0087 ($p = 0.004$)	None
Veh A		-0.314					
Veh B		-0.119					
Veh C		-0.527					
Veh L		-0.236					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-53. EFFECT OF FUELS ON LA92 EC EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 144% ± 9%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 30% ± 9%
	AKI 87 High PMI	+ 30% ± 9%
	AKI 94 Low PMI	+ 30% ± 9%
	AKI 94 High PMI	+ 30% ± 9%
AKI 87 → 94	All Fuels	—

TABLE H-55. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(EC) EMISSIONS = F(V_K, D87LOE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients						Other Fuel Terms[a/]
			Fuel Term	PMI	EtOH			
		Intercept	AKI 87 Low PMI E0	All Fuels	AKI 87 All	AKI 94 Low PMI	AKI 94 High PMI	
Average Vehicle	0.956	0.720	-0.168 ± 0.072 (p = 0.03)	0.0632 ± 0.042 (p < 0.0001)	0.0176 ± 0.0050 (p = 0.002)	0.0389 ± 0.0078 (p < 0.0001)	0.0176 ± 0.0050 (p = 0.002)	None
Veh E		1.023						
Veh H		0.434						
Veh J		0.838						
Veh K		0.585						

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-56. EFFECT OF FUELS ON LA92 EC EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 EC
PMI 1.3 → 2.5	All Fuels	+ 114% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	+ 18% ± 5%
	AKI 87 High PMI	+ 18% ± 5%
	AKI 94 Low PMI	+ 45% ± 8%
	AKI 94 High PMI	+ 18% ± 5%
AKI 87 → 94	All Fuels	—

7.0 LA92 THC EMISSIONS

TABLE H-57 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES MODEL 2: LN(THC) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	**AKI**	**PMI**	**EtOH**	
4-Cyl Nat Asp						
Vehicle B	**0.870**	-1.84	[-0.0214]	-0.177	~~-0.0109~~	none
Vehicle D	0.960	-2.65	[-0.0230]	**0.399**	~~-0.0082~~	RVP
Vehicle E	0.685	-1.72	~~-0.0252~~	[0.169]	~~-0.0013~~	none
Vehicle I	0.869	-3.32	~~-0.0051~~	0.069	-0.0085	none
Vehicle K	0.772	-1.86	-0.0303	~~0.001~~	~~-0.0120~~	none
4-Cyl Turbo						
Vehicle A	0.372	-4.16	~~-0.0072~~	~~-0.107~~	~~-0.0007~~	none
Vehicle C	0.426	-2.72	~~-0.0122~~	~~-0.034~~	~~-0.0065~~	none
Vehicle F	0.783	-2.46	~~-0.0171~~	[0.107]	~~-0.0109~~	none
Vehicle J	0.409	-4.36	~~-0.0087~~	~~0.101~~	~~-0.0090~~	none
Vehicle L	0.144	-6.72	~~-0.0406~~	~~0.057~~	~~-0.0046~~	none
V6 Engines						
Vehicle G	0.850	-0.81	-0.0372	~~0.044~~	[0.0174]	Benzene
Vehicle H	0.146	-2.22	~~-0.0113~~	~~-0.004~~	~~0.0075~~	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

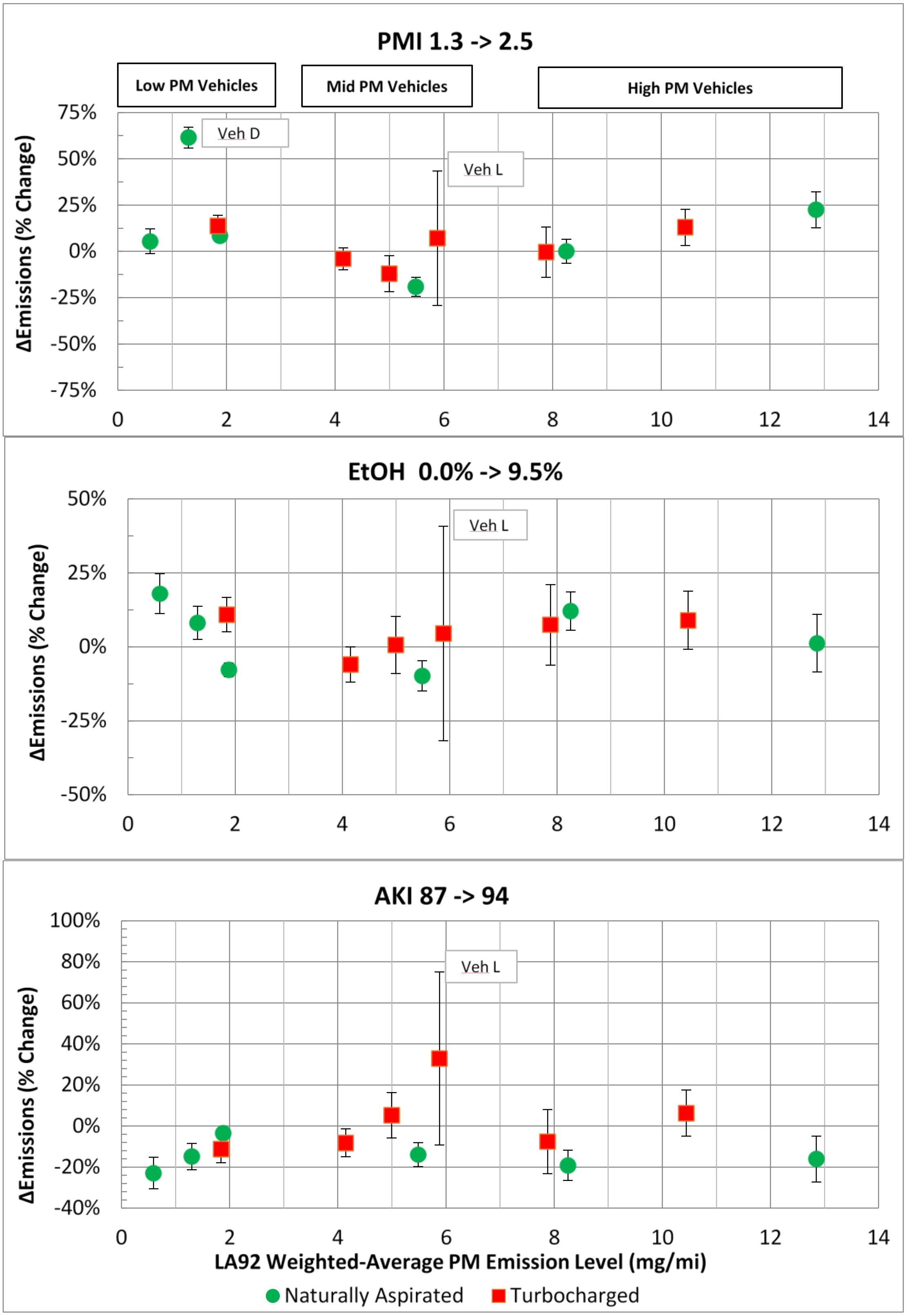


FIGURE H-13. RESPONSE OF LA92 THC EMISSIONS TO PMI, ETOH

TABLE H-58 MODEL DOCUMENTATION FOR TEST FLEET
MODEL 1: LN(THC) EMISSIONS = F(V_K, D94LOE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Terms AKI 94 Low PMI E0	PMI All Fuels	EtOH All Fuels	AKI All Fuels	
Average Vehicle	0.874	-3.720	0.161 ± 0.054 (p = 0.004)	No Effect	No Effect	No Effect	None
Veh A		-3.692					
Veh B		-4.157					
Veh C		-3.907					
Veh D		-3.909					
Veh E		-3.656					
Veh F		-3.731					
Veh G		-3.999					
Veh H		-3.197					
Veh I		-3.676					
Veh J		-3.308					
Veh K		-4.536					
Veh L		-2.879					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-59. EFFECT OF FUELS ON LA92 THC EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-60. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES
MODEL 1: LN(THC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.832	-1.889	None	No Effect	No Effect	-0.0233 ± 0.0084 (p = 0.01)	FBP
Veh B		-2.059					
Veh D		-1.811					
Veh E		-1.558					
Veh I		-1.578					
Veh K		-2.438					

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-61. EFFECT OF FUELS ON LA92 THC EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	- 15% ± 6%

TABLE H-62. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(THC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.810	-3.524	None	No Effect	No Effect	No Effect	None
Veh A		-3.712					
Veh C		-3.927					
Veh F		-3.751					
Veh J		-3.328					
Veh L		-2.899					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-63. EFFECT OF FUELS ON LA92 THC EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	–
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-64. MODEL DOCUMENTATION FOR LOW PM VEHICLES
MODEL 1: LN(THC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.683	-3.88	None	0.158 ± 0.040 (p < 0.001)	No Effect	-0.0216 ± 0.0078 (p = 0.01)	None
Veh D		-2.275					
Veh F		-2.097					
Veh G		-2.365					
Veh I		-2.042					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-65. EFFECT OF FUELS ON LA92 THC EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	+ 21% ± 5%
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	- 14% ± 6%

TABLE H-66. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(THC) EMISSIONS = F(V_K, D87HIE10, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Terms	PMI	EtOH	AKI	
			AKI 87 High PMI E10 Fuel	All Fuels	All Fuels	All Fuels	
Average Vehicle	0.878	-3.65	-0.210 ± 0.105 (p = 0.06)	No Effect	No Effect	No Effect	None
Veh A		-3.69					
Veh B		-4.15					
Veh C		-3.90					
Veh L		-2.87					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-67. EFFECT OF FUELS ON LA92 THC EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-68. MODEL DOCUMENTATION FOR HIGH PM VEHICLES
MODEL 1: LN(THC) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.949	-2.12	None	No Effect	No Effect	- 0.00168 ± 0.00060 (p = 0.01)	None
Veh E		-2.11					
Veh H		-1.65					
Veh J		-1.76					
Veh K		-2.99					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-69. EFFECT OF FUELS ON LA92 THC EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 THC
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	- 11% ± 6%

Synopsis of Findings with respect to LA92 THC

AKI and (in one case) PMI are observed to influence LA92 THC emissions in the subgroups. The analysis estimates that increased AKI decreases THC emissions by -15% in 4-cylinder NA vehicles, by -14% in low PM vehicles and by -11% in high PM vehicles. This is the only instance in which AKI is found to affect vehicle emissions in the study. As Figure H-13 suggests, the observed AKI effect may be generally present in naturally aspirated vehicles and in subgroups containing NA vehicles.

With respect to PMI, the analysis estimates that increased PMI increases THC emissions by +21% in low PM vehicles. However, the effect can be traced to the individual performance of Vehicle D in the Low PM group. EtOH has no effect on THC emissions.

In low PM vehicles, the AKI effect is present but at ~1σ of measurement variability is not detectable in back-to-back test runs. The PMI effect can be detected at ~2σ.

8.0 LA92 CO EMISSIONS

TABLE H-70 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES
MODEL 2: LN(CO) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	AKI	PMI	EtOH	
4-Cyl Nat Asp						
Vehicle B	**0.612**	-0.60	~~-0.003~~	~~-0.211~~	~~-0.024~~	T60
Vehicle D	0.686	-4.46	~~-0.021~~	[0.179]	~~-0.016~~	None
Vehicle E	0.526	-0.46	~~-0.004~~	~~-0.091~~	~~-0.012~~	RVP, T05, DI
Vehicle I	0.937	-1.47	~~-0.002~~	~~-0.051~~	**-0.052**	None
Vehicle K	0.638	2.23	~~-0.030~~	~~-0.149~~	~~-0.006~~	None
4-Cyl Turbo						
Vehicle A	0.406	2.11	~~-0.023~~	~~-0.117~~	~~0.015~~	None
Vehicle C	0.116	1.45	~~-0.016~~	~~-0.080~~	~~0.010~~	RVP, T50, T60
Vehicle F	0.418	1.10	~~-0.012~~	~~-0.061~~	~~0.008~~	none
Vehicle J	0.598	0.98	~~-0.011~~	~~-0.054~~	~~0.007~~	none
Vehicle L	0.112	1.41	~~-0.015~~	~~-0.078~~	~~0.010~~	none
V6 Engines						
Vehicle G	0.895	1.40	~~-0.015~~	[0.078]	**0.010**	none
Vehicle H	0.546	2.11	~~-0.023~~	~~-0.117~~	~~0.015~~	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the p ≤ 0.01 level (≥ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the p = 0.05 level (≥ 95% confidence).
Brackets indicate the estimate has marginal significance (p ≤ 0.10), but fails to reach full statistical significance (p ≤ 0.05)
Strikethrough indicates the estimate fails to reach marginal statistical significance (p = 0.10 or better).

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

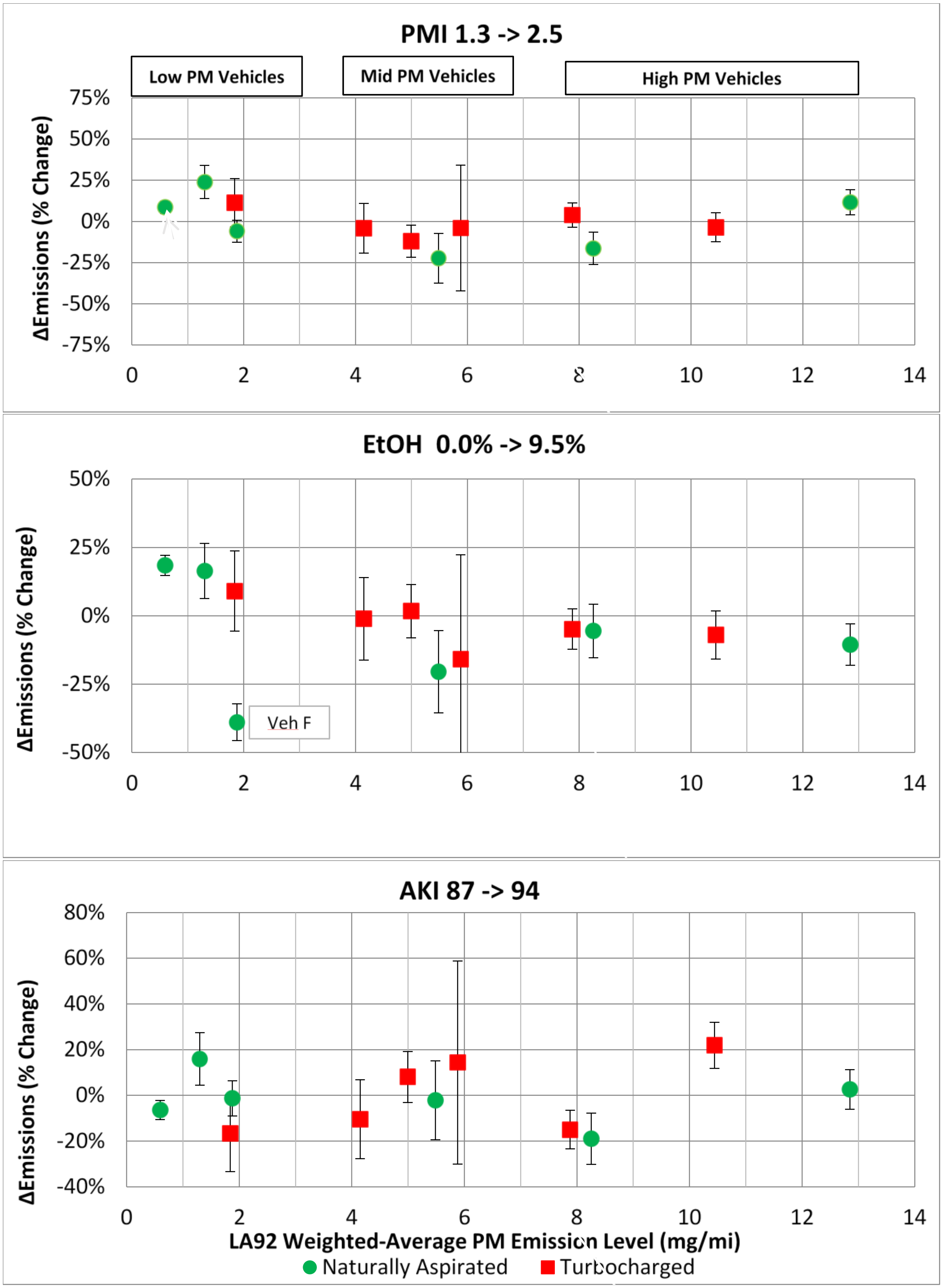


FIGURE H-14. RESPONSE OF LA92 CO EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-71 MODEL DOCUMENTATION FOR TEST FLEET MODEL 1: LN(CO) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	**R^2**	**Estimated Fuel Effects Coefficients**					**Other Fuel Terms**[a/]
		Intercept	**Fuel Differences**	**PMI**	**EtOH**	**AKI**	
				All Fuels	**All Fuels**	**All Fuels**	
Average Vehicle	0.920	-1.156	None	No Effect	No Effect	No Effect	T20
Veh A		-1.642					
Veh B		-1.401					
Veh C		-1.150					
Veh D		-2.119					
Veh E		0.001					
Veh F		-1.684					
Veh G		-0.979					
Veh H		-0.301					
Veh I		-1.983					
Veh J		-1.197					
Veh K		-0.808					
Veh L		-0.615					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-72. EFFECT OF FUELS ON LA92 CO EMISSIONS OF TEST FLEET

Fuel Change	**Fuel**	**Δ LA92 CO**
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-73. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES MODEL 1: LN(CO) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.953	-1.187	None	No Effect	-0.0156 ± 0.0063 (p = 0.02)	No Effect	T60
Veh B		-1.326					
Veh D		-2.044					
Veh E		0.075					
Veh I		-1.908					
Veh K		-0.733					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-74. EFFECT OF FUELS ON LA92 CO EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 CO
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	- 14% ± 6%
	AKI 87 High PMI	- 14% ± 6%
	AKI 94 Low PMI	- 14% ± 6%
	AKI 94 High PMI	- 14% ± 6%
AKI 87 → 94	All Fuels	—

TABLE H-75. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(CO) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.789	-1.258	None	No Effect	No Effect	No Effect	None
Veh A		-1.642					
Veh C		-1.150					
Veh F		-1.684					
Veh J		-1.197					
Veh L		-0.615					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-76. EFFECT OF FUELS ON LA92 CO EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 CO
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-77. MODEL DOCUMENTATION FOR LOW PM VEHICLES MODEL 1: LN(CO) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.847	-1.69	No Effect	No Effect	No Effect	No Effect	None
Veh D		-2.12					
Veh F		-1.68					
Veh G		-0.98					
Veh I		-1.98					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-78. EFFECT OF FUELS ON LA92 CO EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-79. MODEL DOCUMENTATION FOR MID PM VEHICLES
MODEL 1: LN(CO) EMISSIONS = F(V_K, D87LOE0, D94HIE10, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Terms	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.815	-1.202	AKI 87 Low PMI E0 -0.24 ± 0.11 (p = 0.044) AKI 87 High PMI E10 -0.240 ± 0.11 (p = 0.045)	No Effect	No Effect	No Effect	None
Veh A		-1.642					
Veh B		-1.401					
Veh C		-1.150					
Veh L		-0.616					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-80. EFFECT OF FUELS ON LA92 CO EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-81. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(CO) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.949	-0.576	None	No Effect	No Effect	No Effect	None
Veh E		0.001					
Veh H		-0.301					
Veh J		-1.197					
Veh K		-0.808					

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-82. EFFECT OF FUELS ON LA92 CO EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO
PMI 1.3 → 2.5	All Fuels	–
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

Synopsis of Findings with respect to LA92 CO

There is no evidence in the data that PMI or AKI influences CO emissions. EtOH is observed to decrease CO emissions by -14% for the group of 4-cylinder NA vehicles, but no corresponding effect can be seen in the 4-cylinder turbocharged vehicles.

No fuel effects are detected when vehicles are grouped by PM level. Therefore, no fuel effects are detectable or measureable in low PM vehicles.

9.0 LA92 NOX EMISSIONS

TABLE H-83 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES
MODEL 2: LN(NOX) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	AKI	PMI	EtOH	
4-Cyl Nat Asp						
Vehicle B	0.325	-6.21	~~-0.032~~	~~-0.458~~	~~-0.007~~	none
Vehicle D	0.443	-6.46	~~-0.016~~	~~-0.136~~	~~-0.008~~	none
Vehicle E	0.207	-5.17	~~-0.005~~	~~-0.012~~	~~-0.011~~	T60, T70
Vehicle I	0.370	-2.66	~~-0.013~~	~~-0.071~~	~~-0.002~~	none
Vehicle K	0.846	-4.02	~~-0.012~~	0.096	[0.009]	T60, T70
4-Cyl Turbo						
Vehicle A	0.858	-4.11	~~-0.001~~	[-0.051]	**0.012**	none
Vehicle C	0.278	-2.51	~~-0.028~~	~~-0.221~~	~~-0.022~~	RVP, FBP
Vehicle F	0.741	-2.82	[-0.023]	~~-0.053~~	~~-0.014~~	none
Vehicle J	0.255	-3.28	~~-0.012~~	~~-0.045~~	~~-0.010~~	none
Vehicle L	0.224	-3.95	~~-0.015~~	~~-0.025~~	~~-0.005~~	none
V6 Engines						
Vehicle G	0.880	10.56	**-0.156**	~~-0.216~~	[0.047]	none
Vehicle H	0.221	-3.01	~~-0.019~~	~~-0.046~~	~~-0.018~~	none

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

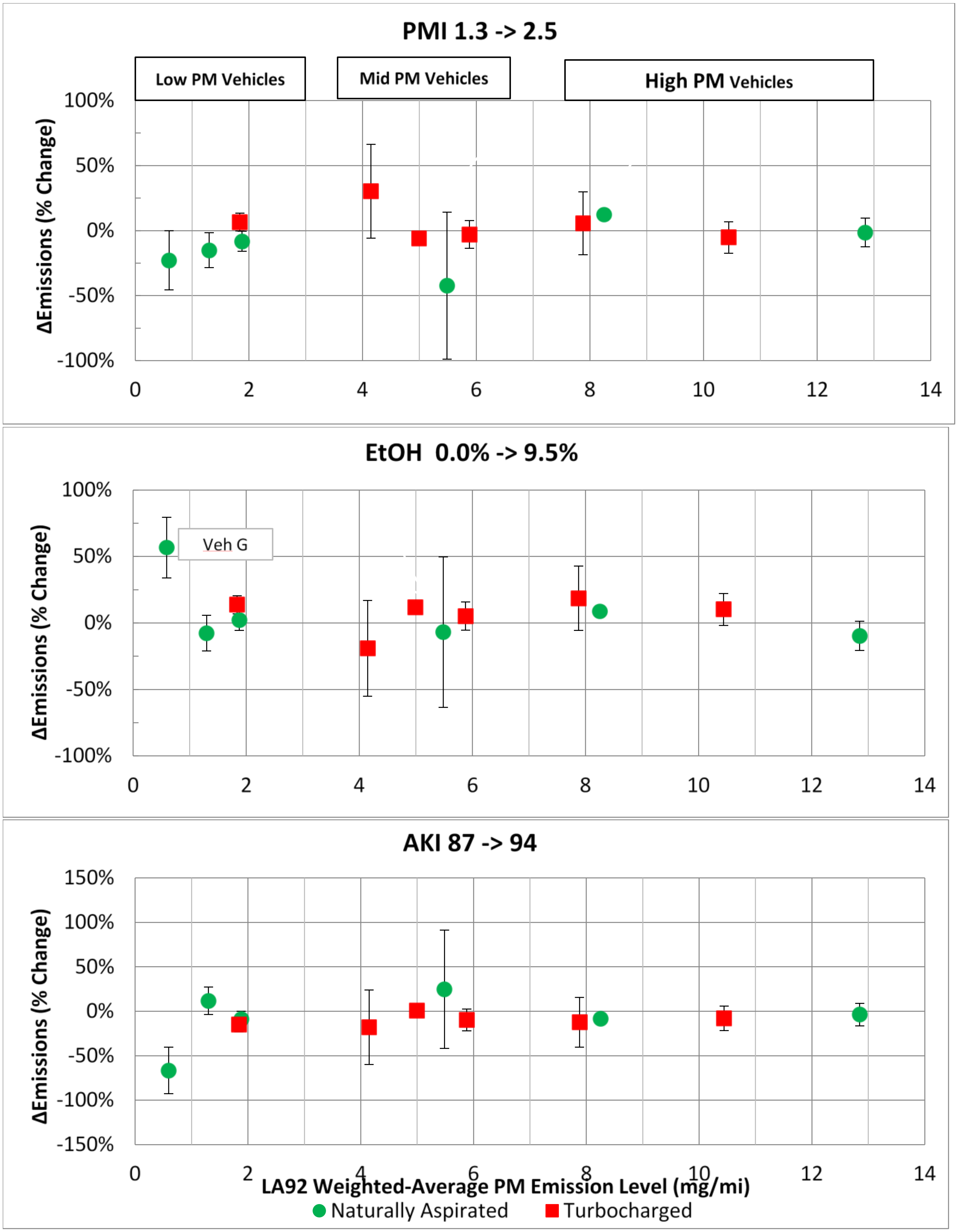


FIGURE H-15. RESPONSE OF LA92 NOX EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-84 MODEL DOCUMENTATION FOR TEST FLEET
MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.812	-4.650	None	No Effect	No Effect	No Effect	None
Veh A		-4.042					
Veh B		-4.264					
Veh C		-4.757					
Veh D		-5.317					
Veh E		-5.739					
Veh F		-4.763					
Veh G		-3.812					
Veh H		-4.546					
Veh I		-3.984					
Veh J		-4.381					
Veh K		-4.906					
Veh L		-5.292					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-85. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-86. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.856	-4.842	None	No Effect	No Effect	No Effect	FBP
Veh B		-4.264					
Veh D		-5.317					
Veh E		-5.739					
Veh I		-3.984					
Veh K		-4.906					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-87. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-88. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.829	-4.647	None	No Effect	No Effect	No Effect	RVP
Veh A		-4.042					
Veh C		-4.757					
Veh F		-4.763					
Veh J		-4.381					
Veh L		-5.292					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-89. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-80. MODEL DOCUMENTATION FOR LOW PM VEHICLES MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.826	-0.476	None	No Effect	No Effect	-0.044 ± 0.018 (p = 0.02)	None
Veh D		-1.324					
Veh F		-0.769					
Veh G		0.182					
Veh I		0.009					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-91. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	–
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	- 27% ± 13%

TABLE H-92. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.677	-4.893	None	No Effect	No Effect	No Effect	None
Veh A		-5.739					
Veh B		-4.546					
Veh C		-4.381					
Veh L		-4.906					

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-93. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	—
	AKI 87 High PMI	—
	AKI 94 Low PMI	—
	AKI 94 High PMI	—
AKI 87 → 94	All Fuels	—

TABLE H-94. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(NOX) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.977	-4.589	None	No Effect	No Effect	No Effect	None
Veh E		-4.042					
Veh H		-4.264					
Veh J		-4.757					
Veh K		-5.292					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-95. EFFECT OF FUELS ON LA92 NOX EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 NOX
PMI 1.3 → 2.5	All Fuels	–
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

<u>Synopsis of Findings with respect to LA92 NOX</u>

There is no evidence in the data that PMI or EtOH influence NOx emissions. AKI is observed to influence NOx emissions in one subgroup, Low PM vehicles, where it decreases NOx emissions by -27%. However, the effect can be traced to the individual performance of Vehicle G.

The AKI effect is present in low PM vehicles, but at ~1σ is not detectable in back-to-back test runs.

10.0 LA92 CO_2 EMISSIONS

TABLE H-96 MODEL DOCUMENTATION FOR INDIVIDUAL VEHICLES MODEL 2: LN(CO_2) EMISSIONS = F(AKI, PMI, ETOH)

	R^2	Estimated Coefficient for Fuel Effect				Other Fuel Terms[a/]
		Intercept	**AKI**	**PMI**	**EtOH**	
4-Cyl Nat Asp						
Vehicle B	**0.443**	5.89	~~-0.0000~~	~~0.0052~~	~~0.00069~~	None
Vehicle D	0.632	5.57	~~-0.0005~~	[0.0107]	~~0.00094~~	None
Vehicle E	0.725	5.78	[0.0017]	~~0.0030~~	[0.00103]	C10Arom, T05, T60
Vehicle I	0.812	5.80	-0.0014	~~0.0008~~	~~0.00057~~	None
Vehicle K	0.563	5.90	~~-0.0004~~	~~0.0016~~	~~0.00093~~	RVP
4-Cyl Turbo						
Vehicle A	0.777	5.80	[0.0010]	~~0.0013~~	0.00079	None
Vehicle C	0.813	5.89	[-0.0008]	~~0.0029~~	[0.00059]	None
Vehicle F	0.388	5.93	~~-0.0006~~	~~0.0011~~	~~0.00045~~	None
Vehicle J	0.493	5.89	~~-0.0018~~	~~-0.0013~~	~~0.00096~~	None
Vehicle L	0.527	6.08	[-0.0022]	~~-0.0020~~	~~0.00005~~	None
V6 Engines						
Vehicle G	0.646	5.86	~~-0.0015~~	~~0.0030~~	~~0.00095~~	None
Vehicle H	0.806	6.46	-0.0020	~~-0.0001~~	~~0.00041~~	None

Notes:

Bold font indicates the estimate reaches strong statistical significance at the $p \leq 0.01$ level ($\geq$ 99% confidence).
Regular font indicates the estimate reaches statistical significance at the $p = 0.05$ level ($\geq$ 95% confidence).
Brackets indicate the estimate has marginal significance ($p \leq 0.10$), but fails to reach full statistical significance ($p \leq 0.05$)
Strikethrough indicates the estimate fails to reach marginal statistical significance ($p = 0.10$ or better).

[a/] Statistical significance judged at $p = 0.05$ level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

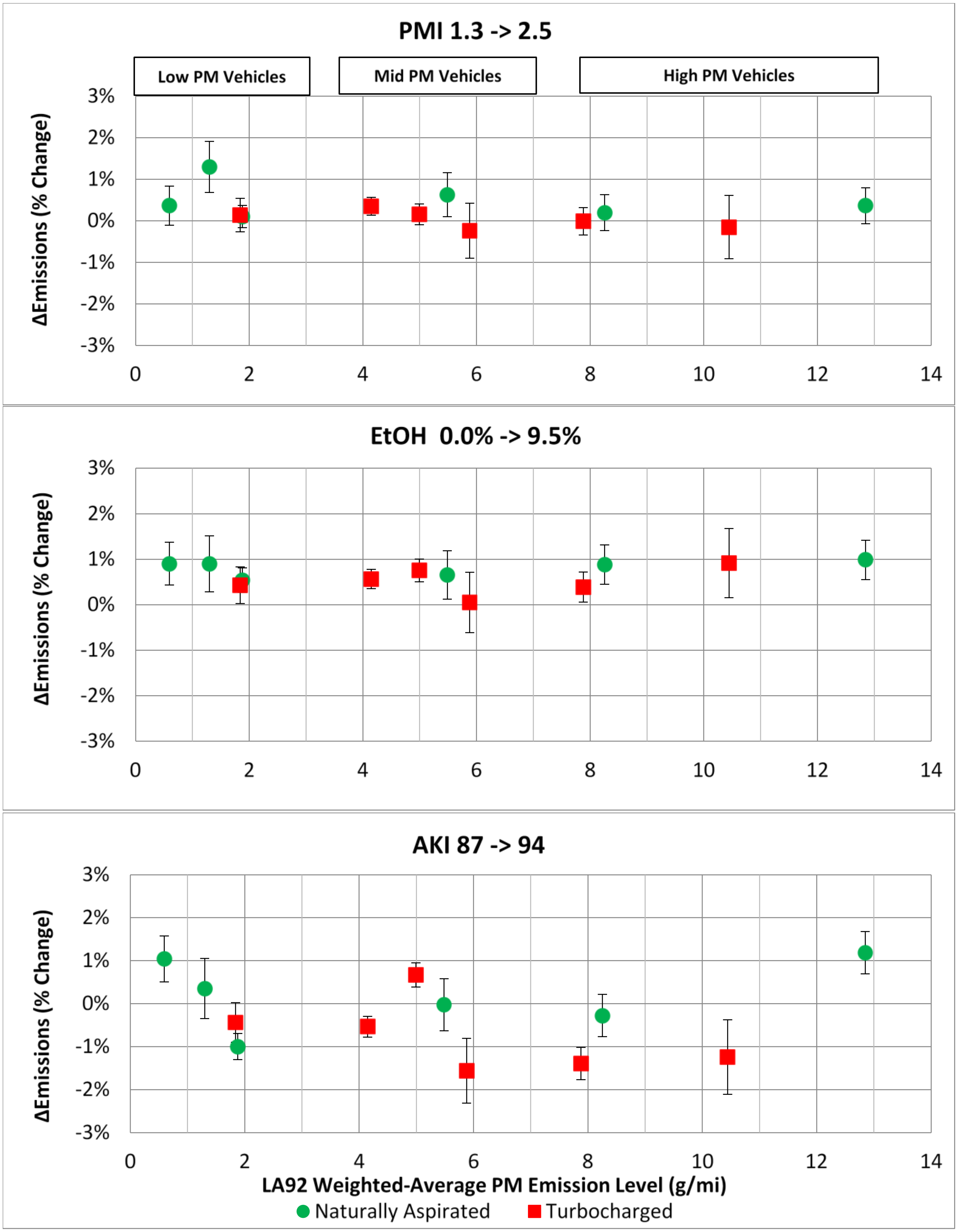


FIGURE H-16. RESPONSE OF LA92 CO_2 EMISSIONS TO PMI, ETOH AND AKI BY VEHICLE. ERROR BARS SHOW 1σ RANGE.

TABLE H-97. MODEL DOCUMENTATION FOR TEST FLEET MODEL 1: $LN(CO_2)$ EMISSIONS = $F(V_K$, D94LOWE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Term: AKI 94 Low PMI E0	PMI: All Fuels	EtOH: All Fuels	AKI: All Fuels	
Average Vehicle	0.998	5.875	-0.0078 ± 0.0023 (p = 0.001)	No Effect	0.00054 ± 0.00016 (p = 0.001)	No Effect	None
Veh A		5.894					
Veh B		5.899					
Veh C		5.822					
Veh D		5.643					
Veh E		5.940					
Veh F		5.872					
Veh G		5.998					
Veh H		6.281					
Veh I		5.676					
Veh J		5.730					
Veh K		5.872					
Veh L		5.876					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-98. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF TEST FLEET

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	0.51% ± 0.15%
	AKI 87 High PMI	0.51% ± 0.15%
	AKI 94 Low PMI	0.51% ± 0.15%
	AKI 94 High PMI	0.51% ± 0.15%
AKI 87 → 94	All Fuels	—

TABLE H-99. MODEL DOCUMENTATION FOR 4-CYLINDER NATURALLY ASPIRATED VEHICLES MODEL 1: LN(CO_2) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.997	5.803	None	No Effect	0.00086 ± 0.00023 (p < 0.001)	No Effect	C10Arom
Veh B		5.897					
Veh D		5.640					
Veh E		5.937					
Veh I		5.673					
Veh K		5.870					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-100. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF 4-CYLINDER NATURALLY ASPIRATED VEHICLES

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	0.82% ± 0.22%
	AKI 87 High PMI	0.82% ± 0.22%
	AKI 94 Low PMI	0.82% ± 0.22%
	AKI 94 High PMI	0.82% ± 0.22%
AKI 87 → 94	All Fuels	—

TABLE H-101. MODEL DOCUMENTATION FOR 4-CYLINDER TURBOCHARGED VEHICLES
MODEL 1: LN(CO_2) EMISSIONS = F(V_K, D94LOWE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
			Fuel Terms	PMI	EtOH	AKI	
		Intercept	AKI 94 Low PMI E0	AKI 94 E0	All Fuels	All Fuels	
Average Vehicle	0.990	5.843	-0.0092 ± 0.0033 (p = 0.009)	-0.0031 ± 0.0014 (p = 0.03)	No Effect	No Effect	None
Veh A		5.898					
Veh C		5.827					
Veh F		5.877					
Veh J		5.734					
Veh L		5.880					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-102. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF 4-CYLINDER TURBOCHARGED VEHICLES

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	AKI 94 E0 (Only)	-0.82% ± 0.22%
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-103. MODEL DOCUMENTATION FOR LOW PM VEHICLES MODEL 1: LN(CO_2) EMISSIONS = F(V_K, D94LOWE0, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Terms: AKI 94 Low PMI E0	PMI: All Fuels	EtOH: All Fuels	AKI: All Fuels	
Average Vehicle	0.998	5.800	-0.0126 ± 0.0036 (p = 0.002)	No Effect	No Effect	No Effect	T10
Veh D		5.646					
Veh F		5.876					
Veh G		6.001					
Veh I		5.679					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-104. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF LOW PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	All Fuels	–
EtOH 0% → 9.5%	AKI 87 Low PMI	–
	AKI 87 High PMI	–
	AKI 94 Low PMI	–
	AKI 94 High PMI	–
AKI 87 → 94	All Fuels	–

TABLE H-105. MODEL DOCUMENTATION FOR MID PM VEHICLES MODEL 1: LN(CO_2) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.958	5.872	None	No Effect	0.00058 ± 0.00026 (p = 0.03)	No Effect	None
Veh A		5.893					
Veh B		5.898					
Veh C		5.821					
Veh L		5.875					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-106. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF MID PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	0.55% ± 0.24%
	AKI 87 High PMI	0.55% ± 0.24%
	AKI 94 Low PMI	0.55% ± 0.24%
	AKI 94 High PMI	0.55% ± 0.24%
AKI 87 → 94	All Fuels	—

TABLE H-107. MODEL DOCUMENTATION FOR HIGH PM VEHICLES MODEL 1: LN(CO_2) EMISSIONS = F(V_K, AKI, PMI, ETOH)

Group	R^2	Estimated Fuel Effects Coefficients					Other Fuel Terms[a/]
		Intercept	Fuel Differences	PMI	EtOH	AKI	
				All Fuels	All Fuels	All Fuels	
Average Vehicle	0.998	5.593	None	No Effect	0.00088 ± 0.00029 (p = 0.005)	No Effect	None
Veh E		5.937					
Veh H		6.279					
Veh J		5.728					
Veh K		5.869					

[a/] Statistical significance judged at p = 0.05 level. A higher level of statistical confidence is needed to conclude such terms are meaningful because multiple comparisons are being made.

TABLE H-108. EFFECT OF FUELS ON LA92 CO_2 EMISSIONS OF HIGH PM VEHICLES

Fuel Change	Fuel	Δ LA92 CO_2
PMI 1.3 → 2.5	All Fuels	—
EtOH 0% → 9.5%	AKI 87 Low PMI	0.84% ± 0.28%
	AKI 87 High PMI	0.84% ± 0.28%
	AKI 94 Low PMI	0.84% ± 0.28%
	AKI 94 High PMI	0.84% ± 0.28%
AKI 87 → 94	All Fuels	—

<u>Synopsis of Findings with respect to LA92 CO_2</u>

The analysis indicates that PMI or AKI do not influence CO_2 emissions. The one instance (4-cylinder turbocharged vehicles) in which a PMI effect is detected should probably be discounted as a false positive because it is not seen in other subgroups or for the individual test vehicles.

The analysis indicates that EtOH influences CO_2 emissions in many vehicle subgroups. It increases CO_2 by amounts ranging from 0.5% to 0.8% in the 4-cylinder NA vehicles and in subgroups containing them. No EtOH effect is seen in the 4-cylinder turbocharged vehicles.

No fuel effects can be detected in Low PM vehicles.